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GAIT TERMINATION IN THE YOUNG, THE HEALTHY ELDERLY, AND THE ELDERLY WITH TYPE 2 DIABETES AFFECTED BY PERIPHERAL NEUROPATHY

BY

MARGRIT-REGULA MEIER

THESIS PRESENTED TO THE FACULTY OF MEDICINE WITH REGARD TO OBTAINING THE DEGREE OF PHILOSOPIAHE DOCTOR (PH.D.) IN CLINICAL SCIENCES NOVEMBER 1999

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To
My mother, my brother and my two sisters
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GLOSSARY OF GAIT TERMINATION SPECIFIC TERMS

A/P  Anterior/posterior: back-and-forward movements in the walking direction.

Approach Phase

The step considered before the Stopping Phase. It lasts from HC1 to HC2.

A/P COM velocity<0.05 m/s

The point where, by definition, visually and biomechanically a full stop is reached. COM motions below 0.05 m/s are considered as movements, which occur during standing still.

COM  Centre of mass. Applied to biomechanics, it represents the mass centre of a person (Figure 1, page 16).

COP  Centre of pressure. It represents the point of application of the resultant of all ground reaction forces acting upon the foot (Figure 1, page 16).

HC  Heel Contact: The event in a gait cycle where the heel touches the ground. In normal gait HC is considered as the beginning of a gait cycle.

HC1  Heel Contact 1: The start of the Approach Phase and the beginning of the fist step considered for the analyses. It is carried out by the ipsilateral limb.
HC2  Heel Contact 2: The end of the Approach Phase, the end of the first step and simultaneously the start of the Stopping Phase and the start of the second step. It is carried out by the contra-lateral limb.

HC3  Heel Contact 3: The end of the second step and the event where walking appears to stop. It is carried out by the ipsilateral limb.

M/L  Medio/lateral: side-to-side movements.

TO   Toe-Off: The event at the end of the stance phase at which the toes no longer contact the ground.

Stopping Phase

The last step during which the person stops visually and biomechanically. It lasts from HC2 to A/P COM velocity <0.05 m/s.
RÉSUMÉ

Introduction: L'arrêt de la marche requiert des exigences spéciales en raison d'une transition d'une situation dynamique à une situation quasi-statique. Lors de l'arrêt de la marche, des personnes âgées en santé peuvent présenter des difficultés causées par le déclin physiologique relié au vieillissement normal. Il est possible que ces difficultés soient accentuées chez des personnes âgées ayant une sensibilité réduite au niveau des pieds comme les personnes diabétiques, mais ceci n'est pas connu. Le but de l'étude consiste à analyser des caractéristiques biomécaniques reliées à l'arrêt de la marche chez des personnes jeunes (Jeunes) et âgées en santé (Âgées) et chez des personnes âgées diabétiques de type 2 (Diabétiques) affectées par une neuropathie périphérique.

Méthodologie: Trois groupes de personnes ont participé à l'étude. Chaque groupe est composé de 15 participants âgés entre 20 et 40 ans (Jeunes) et entre 60 et 75 ans (Âgées et Diabétiques). Les Âgées sont appariés selon l'âge, le genre, et l'indice de masse corporelle avec le groupe des Diabétiques. L'expérimentation a consisté à au moins huit essais durant lesquels les participants devaient marcher à une vitesse normale le long du parcours indiqué et s'arrêter devant une ligne marquée au sol. Les variables analysées reliées à l'arrêt de la marche sont le seuil de sensibilité vibratoire, la vitesse du centre de masse (COM) en direction antéro/postérieure (A/P), les overshoots du centre de pression (COP) et du COM en direction A/P et médio/latérale (M/L) et des variables reliées à la force (entre autres: Forces maximales, temps relatif nécessaire pour développer les forces maximales, impulsions). Les deux derniers
pas avant que l'arrêt final a été accompli ont été analysées. Ces deux pas ont été divisés dans une phase d'approche et une phase d'arrêt.

**Résultats:** Les différences du seuil de sensibilité vibratoire sont significatives entre les trois groupes. La différence entre les Âgées et les Jeunes est la plus petite tandis que les différences entre les Âgées et les Diabétiques et les Jeunes et les Diabétiques sont les mêmes.

La vitesse du COM en direction A/P est significativement différente entre les trois groupes au touche-talon 1 (HC1) et HC2 mais non significative entre les Âgées et les Diabétiques au HC3.

Il n'existe pas de différence entre les Âgées et les Diabétiques dans les *overshoots* du COP et du COM en toutes directions. Cependant, les *overshoots* de COP et du COM sont significativement différents dans toutes les directions, sauf une, entre les Jeunes et les Âgées et les Jeunes et les Diabétiques. L'exemption est une différence non-significative du COP l' *overshoots* en direction A/P entre les Âgées et les Jeunes.

Le temps relatif utilisé pour freiner pendant la phase d'approche est similaire entre les Jeunes et les Âgées, mais est significativement plus court chez les Diabétiques. Ces derniers prennent plus de temps relatif pour développer leur force de freinage maximale comparativement aux Âgées et aux Jeunes. Le temps relatif nécessaire pour développer la force de propulsion maximale est similaire dans les trois groupes. Les forces de propulsion maximale et les impulsions correspondantes sont également comparables entre les trois groupes.

Pendant la phase de l'arrêt, le temps relatif utilisé pour développer la force maximale est dépendant de l'âge seulement. Les impulsions sont
significativement différentes entre les Jeunes et les Diabétiques, mais non entre les Jeunes et les Âgées, ni entre les Âgées et les Diabétiques. Par contre, la force maximale de freinage pendant l'appui simple de la phase de l'arrêt est significativement différente entre les groupes, les Diabétiques développant la force la plus faible.

**Discussion:** L'effet de l'âge sur les variables biomécaniques est bien démontré car les personnes âgées ont des *overshoots* jusqu'à deux fois plus longs que les participants jeunes. Par contre, les résultats non significatifs sur les *overshoots* entre les Âgées et les Diabétiques sont inattendus, car en posture il est bien démontré que les trajectoires du COP et du COM sont plus larges chez les personnes âgées diabétiques que chez les personnes âgées en santé. Le seuil de sensibilité vibratoire ne semble pas avoir un effet sur les *overshoots* du COP et du COM. Pourtant, les Diabétiques ont marché à une vitesse significativement plus lente que les Âgées indiquant que la neuropathie périphérique a un impact.

**Conclusions et recommandations:** Les résultats démontrent que, sous les conditions testées, les Âgées et les Diabétiques ne sont pas différents au niveau des *overshoots* du COP et du COM. Par contre, au niveau des forces maximales, les Diabétiques ont développé la force la plus faible. De plus, les Diabétiques ont pris le temps relatif le plus long pour développer ces forces maximales comparativement au personnes Jeunes et Âgées. Ce résultat confirme indirectement le temps de réaction élevé chez les personnes âgées diabétiques affectées par une neuropathie périphérique. Durant la phase d'approche, les
Diabétiques ont développé l'impulsion de propulsion la plus élevée et durant la phase d'arrêt par contre l'impulsion de freinage la plus faible.

Suite à ces résultats, des études supplémentaires contrôlant pour la vitesse du COM avant que l'arrêt soit initié et/ou avec des tâches plus spécifiques sont requises pour confirmer les résultats obtenus.
ABSTRACT

Introduction: Terminating gait puts special demands on the body as a transition occurs from a dynamic to a quasi-static situation. Elderly people can have difficulties in stopping due to age related physiological decline. It is unknown if these difficulties worsen for elderly people with impaired foot sensitivity such as those with diabetes. The study analysed biomechanical characteristics of gait termination in healthy young (Young), healthy elderly (Elderly) persons, and elderly people with type 2 diabetes (Diabetics) affected by peripheral neuropathy.

Methods: Three groups participated in the study. Each group was composed of 15 participants between 20 and 40 years of age (Young) and between 60 and 75 years of age (Elderly and Diabetics). In addition, the Elderly were matched with the Diabetics according to age, gender and body mass index. The experiment consisted of at least eight trials in which the participants were simply asked to walk at a normal pace along the indicated walkway and to stop in front of the marked stop-line. The measured variables related to gait termination are the vibration sensitivity threshold, the A/P (anterior/posterior) COM (Centre of mass) velocities at specific events, the COP (Centre of pressure) and COM overshoots in the A/P and M/L (medio/lateral) directions and force related variables (among others: maximal forces, relative time needed to develop these forces, and impulses). The variables have been analysed for the last two steps before full stop was reached. These last two steps were divided into an Approach and a Stopping Phase.
**Results:** Statistical differences in the vibration sensitivity threshold were found between all three groups. The difference between the Young and the Elderly is smallest, whereas the differences between the Elderly and the Diabetics and between the Diabetics and the Young are the same.

The A/P COM velocity is significantly different at heel contact 1 (HC1) and HC2 between all three groups. However, at HC3 it is non-significant only between the Elderly and the Diabetics.

No differences in the analysed COP and COM overshoots in either direction were found between the Elderly and the Diabetics. Only between the Young and the Elderly and the Young and the Diabetics are the COP and the COM overshoots significantly different in all directions, except one. This exception is a non-significant difference in the A/P COP overshoots between the Elderly and the Young.

The relative braking time during the Approach Phase is similar between the Young and the Elderly, but significantly shorter in the Diabetics. The Diabetics take significantly longer to develop their maximal braking force when compared with the Elderly and the Young. The relative time needed to develop maximal propulsion force is similar in all three groups and so are the maximal propelling forces and the corresponding impulses.

During the Stopping Phase, the relative time taken to develop maximal stopping force is dependent on age only. The impulses are significantly different only between the Young and the Diabetics, but not between the Young and the Elderly or the Elderly and the Diabetics. Nevertheless, the maximal stopping force
during single support of the Stopping Phase is significantly different in all three groups, with the Diabetics having the weakest stopping force.

**Discussion:** The age effect on the COP and COM overshoots is clearly demonstrated, with the elderly persons having overshoots up to twice as long than in the young. However, the non-significant results of the overshoots obtained between the Elderly and the Diabetics is unexpected, as larger postural COP and COM trajectories in persons with diabetes have been reported. The vibration sensitivity threshold seems not to have an effect on the COP and COM overshoots. Yet, the Diabetics walked with a significantly lower velocity than the Elderly indicating that peripheral neuropathy does have an impact.

**Conclusions and recommendations:** The results demonstrate that under the tested conditions, the COP and COM overshoots do not differ between the Elderly and the Diabetics. However, the Diabetics always exhibited the weakest maximal forces of the three groups. In addition, the Diabetics took the longest relative time to develop these forces compared with the Young and the Elderly. These results indirectly confirm the increased reaction time present in elderly people affected with diabetes and peripheral neuropathy. During the Approach Phase, the Diabetics developed the highest propulsion impulse. During the Stopping Phase, however, their braking impulses were the weakest.

To confirm these results, further studies controlling the COM velocities prior to gait termination and/or demanding more specific tasks will have to be performed.
1. INTRODUCTION AND RATIONALE

The thesis is introduced with the rationale followed by the literature review chapter. Next, the objectives and the hypothesis of the study are explained before the chapters of the methodology and the results are presented. The results are discussed in chapter six and the thesis terminates with the conclusions and recommendations for future studies.

Gait is a major feature of humans and is a topic in which researchers have been interested for a long time. Its characteristics are well documented and include gait changes due to normal ageing (e.g. Winter et al., 1990). However, most of the published documents have one characteristic in common. The participants have been analysed during walking at normal cadence. Only a handful of studies have examined gait termination. Terminating gait, as a specific part of the walking process, makes special demands as a transition occurs from a dynamic situation (walking) to a quasi-static situation (standing). Elderly people seem to have difficulties in stopping, as the results of Cao et al. (1997 and 1998) have demonstrated. It is unknown, however, if these difficulties worsen for elderly people with impaired foot sensitivity such as elderly persons with diabetes.

It is well documented that industrialised western countries have a rapidly increasing elderly population. In 2031, the elderly Canadian population will number over eight million, representing more than 20% of the total population. In Québec it will be over two million, more than 2.5 times that of 1991 (Gauthier and Duchesne, 1991).
Pathologies are much more likely to occur with increasing age. Many pathologies such as rheumatism, other types of arthritis and diabetes can cause gait disorders (Horak et al., 1989; Alexander, 1996a). It is therefore reasonable to expect that they also influence gait termination. Diabetes mellitus type 2 (referred to simply as ‘diabetes’ in the following text) is one of the top six chronic diseases in Canada (Statistics Canada, 1996) in terms of incidence. It is about eight to ten times more common than type 1 diabetes (see review by Gaster and Hirsch, 1998). Eleven per cent of elderly Canadians aged 65 to 74 (say 210 000 persons) are affected by diabetes. This proportion is nearly twice that of the 55 to 64 age group (Statistics Canada, 1996). After the age of 75, only a slight increase in prevalence is noted, compared to the 65 to 74 age group. Again, men are more affected than women, but the increase in both genders is approximately the same (Statistics Canada, 1996).

On a long-term basis, diabetes affects all bodily systems, with neuropathy, nephropathy, retinopathy (all considered micro-vascular changes) and angiopathy (considered a macro-vascular change) as main consequences (WHO, 1985; Sherwin, 1996; Seaquist 1998). Sixty to seventy per cent of people with diabetes face neurological deficits, particularly peripheral neuropathy (CDC, 1995). Peripheral neuropathy affects lower limbs first and exhibits the following symptoms: a) sensitivity reduction due to demyelisation and degeneration of axons, b) muscle atrophy and c) perturbation of the skin metabolism. In severe cases, sensitivity is totally lost. On the basis of this lack of sensory stimulus, people with diabetes are more dependent on vision than their age-matched counterparts (Courtemanche et al., 1996). Unfortunately, vision is also strongly
affected by diabetic retinopathy. Damaged and leaky capillaries cause the retina to bleed and swell, resulting in blurred vision. Diabetes is the leading cause of blindness in adults (CDC, 1995). Hence, peripheral neuropathy and retinopathy caused by diabetes has a significant affect on gait and posture security (Cavanagh et al., 1992; Boucher et al., 1995).

Stopping one's gait is a very important task and can lead to serious problems if not executed properly. Situations in daily life require the capability to stop in front of unexpected obstacles, for example at the pavement curb or when approaching descending stairs. Little is known about gait termination in elderly people or its characteristics. Gait termination data of elderly people with diabetes are lacking in the literature. The present study provides information on gait termination not only in elderly persons with type 2 diabetes and impaired foot sensitivity but also in healthy young and elderly people not affected by diabetes. The study aims further to identify factors that influence gait termination.
2. LITERATURE REVIEW

In this section, the development and characteristics of gait are discussed, followed by the age-related changes of the bodily systems considered to influence gait the most. In the third part, gait termination and related studies are presented. Finally, diabetes mellitus, related pathologies and the resulting impacts on gait are described.

2.1. GAIT

For most of us, walking is so natural that we do not need to think about it. But walking is not an inborn reflex (Inman et al., 1981); it has to be learned and developed until the characteristic human gait pattern is achieved. But once learnt, leg muscle activation and movement control occur at a sub-conscious level, and walking becomes almost automatic (see review by Dietz, 1992; Horak and Nashner, 1986; Winter, 1991). The learning process starts from birth and involves the whole body (Woollacott et al., 1996). First, muscle strength has to develop to enable segmental movements, and later on when upright posture and stance is achieved, to support the body against gravity. The nervous system learns, during maturation, how to co-ordinate the different muscles and segments in order to achieve successful balance and locomotion (Berger et al., 1985; Sutherland et al., 1980; Woollacott et al., 1996). Within the balance and movement control, the information the central nervous system obtains from the afferent nerves, plays an important role. Inputs of afferent nerves are, among others, responsible for the
shaping and the stability of the basic locomotor rhythm and the control of limb movements (Martini and Timmons, 1995; Patla, 1996). Together with the efferent pathways, they maintain balance of the moving body and adapt the locomotor pattern to the environment and overall behavioural goals (Gordon, 1991).

The variation in the rate of change of the centre of gravity position in each child might be a factor in determining when a child begins independent locomotion (Burnett and Johnson, 1971a). The same authors go on to mention that this factor might also play a role in how rapidly gait develops. The change from an infant to an adult gait pattern typically occurs around 5 to 7 years of age (Berger et al., 1985; see review by Dietz, 1992; Inman et al., 1981). Nevertheless, refinement of locomotor balance control continues until at least 10 years of age (Woollacott et al., 1996). However, Sutherland et al. (1980) report that a mature gait pattern is well established by the age of three, when determined by the following criteria: duration of single limb stance, walking velocity, cadence, step length and the pelvic span/ankle spread ratio. This contrasts with the studies cited above. The definition of 'mature' might cause this confusing situation. Burnett and Johnson (1971b) define 'mature' only in so far as the adult-like walking movement is already present in young children. However, their child participants were between two and four years of age at the end of their study and further tests on these children were not documented.

In general, normal adult gait is marked by a smooth, alternating movement, characterised by reciprocal leg muscle activation and the typical braking/propulsion pattern during stance phase (Berger et al., 1985; Perry, 1992; Woollacott et al., 1996). Preferred walking speed requires minimal energy
expenditure and is highly efficient (Hreljac and Martin, 1993; Inman et al., 1981; Leonard and Robertson, 1995; Waters et al., 1988).

The short overview given above demonstrates that walking is a complex task, involving not only the muscle-skeletal system but also the nervous and cardiovascular system. In the following sections, biomechanical features and other characteristics of gait are presented.

2.1.1. Gait Characteristics

Gait characteristics can be described qualitatively or quantitatively. The former may be of more use in everyday clinical environment, whereas quantitative measurements are more common in research. Quantitative measurements include biomechanical analyses and their variability, two features which will be presented in the following sections. As these two measurements are not only influenced by a person's everyday behaviour but also by gender, results of studies analysing gender differences will also be presented.

Biomechanical Aspects of Gait

Gait is a cyclic event and is highly repetitive (Sekiya and Nagasaki, 1998; Winter, 1991). A cycle or stride in healthy individuals is usually defined as being from one heel contact to the next of the same limb. It can be described in two different ways: according to its phases or according to its events. Analysed according to its phases, a stride consists of one stance and one swing phases. These phases are generally measured against the whole cycle and last roughly 60% and 40% for stance and swing phase respectively in normal gait (Inman et
The stance and swing phases can also be further subdivided (for details please refer to Perry, 1992). The second way to describe a stride is to subdivide it according to its events: heel contact (HC), foot flat (FF), heel off (HO), toe off (TO) and mid-swing (MS) (Winter, 1991).

The phases and events described above are related to a single limb. Analysing both limbs at once shows another very important phase: double limb support. In this phase, which occurs twice during a stride, both limbs are in contact with the ground. During double limb support, the weight is transferred from the propelling leg to the new stance leg (Inman et al., 1981; Murray, 1967; Perry, 1992; Winter, 1980). Double limb support distinguishes walking from running, as this phase does not exist in running (Marey, 1873). If gait is symmetrical, the two double limb support phases, each 8-11% of a stride, will be equal in duration (Inman et al., 1981; Winter, 1991).

The trunk and upper extremities are not considered to actively contribute to walking, but help to smooth the trajectory of the body's total centre of mass and are, therefore, essential for an energy efficient gait (Inman et al., 1981; Perry, 1992). Inman et al. (1981) further stated that the rotation of the trunk and shoulder are 180° out of phase with the pelvis. However, the interaction of trunk and pelvis is far more complex. The results of the study of Stokes et al. (1989) showed that these segments are not simply rotating opposite to each other. Rotation about the vertical axis is in phase during double limb support. Rotation around the anterior-posterior axis is in phase during most of the gait cycle. However, during double limb support and at the beginning of single limb support, the shoulder and pelvis are out of phase.
To simplify the complexity of gait analyses, the person under study is often reduced to a stick figure (Winter, 1990). With kinematic, kinetic and anthropometric data, calculations of net forces and muscle moments acting upon and inside the body are possible using an inverse dynamic approach (Bresler and Frankel, 1950). Hence, an analyses of the cause of the observed moment can be performed (Winter, 1990). The kinematic and anthropometric data allow the calculation of the total centre of mass (COM), a key factor in gait analyses (Benda et al., 1994; Iida and Yamamuro, 1987). The COM is the sum of the centre of mass contributions from each body segment. In an upright person, it is located about two thirds of the total body height measured from the ground (Winter, 1995) (Figure 1, page 16). Therefore, the human body is not a very stable system. Hence, the COM represents a passive variable, which has to be controlled by the positions of the centre of pressure (COP) (Winter, 1995). The COP is a single point representing the resultant of all ground reaction vectors acting upon the foot (Winter, 1995) (Figure 1, page 16). Although the COM and the COP are related to each other, they have different trajectories when the COM is projected on the horizontal plane (Maki and McIlroy, 1996; Murray et al., 1967; Winter et al., 1996). During normal walking, the COP starts its path on the lateral part of the heel, traverses the foot in an approximate diagonal, and ends (toe off) medially at the first toe (Perry, 1992). Viewed over several steps from above, the assembly of the two individual COP trajectories under each foot form a sinusoidal curve (Winter, 1995). The COM also describes a sinusoidal curve, with its maximal values alternating to the right and left according to the weight bearing limb (Inman et al., 1981). However, in the medio-lateral plane, the COM moves along the medial
border of the foot indicating that its amplitude is somewhat smaller than that for the COP (Winter, 1995).

The COM and the COP trajectories cross each other during double limb support, the only event during walking when the COM lies within the base of support (Winter, 1995). During the rest of the cycle, the COM always passes outside of the supporting base. Hence, only by a safe foot placement of the swinging leg can a fall be avoided (Winter, 1995). Therefore, the ability to regulate the relationship between the COM and COP is essential to prevent the
body from falling. Thus, the interaction between the COM and the COP is of importance as the analyses of the two trajectories give an indication of the body's co-ordination abilities.

The anterior-posterior movement of the COP during walking is responsible for the typical braking/propulsion pattern of the COM trajectory (Jian et al., 1993; Winter, 1991; Winter, 1995). When analysing force vector patterns in the sagital plane, the same effect can be demonstrated (Perry, 1992; Simonsen et al., 1997).

The typical braking/propulsion pattern of the COM trajectory described previously, is similar to the A/P velocity pattern. The A/P COM velocity alternates during walking as illustrated in Figure 1a: A on the following page. For an easier understanding, the right limb serves as a reference in the explanation given throughout the following paragraphs. Due to the repetitive nature of human locomotion, the same explanations also apply for the left limb. Shortly after the right heel strikes the floor (RHC; Figure 1a: A, page 18), the A/P COM velocity reaches its first peak. Thereafter, during the weight-bearing phase until mid-stance, the velocity is gradually reduced due to the braking effect of the right limb. After mid-stance, the right limb starts to propel the body forward. This results in an A/P COM velocity increase. Before right toe-off (RTO; Figure 1a: A, page 18), the heel of the left limb (LHC) hits the ground, braking the A/P COM velocity yet again. This pattern is now repeated by the left limb. The two peaks of the A/P COM velocity curve shown in Figure 1a: A are therefore typical features of a single stride.
Figure 1a. COM Forward Velocity and Corresponding A/P Forces (Illustrations according to Winter, 1991)
In Figure 1a: B, the corresponding curve of the A/P ground reaction forces is shown. At comfortable walking speed, the stance phase makes up roughly 60% of a single stride. By definition, the stance phase covers the time a limb spends in contact with the floor. Throughout the remaining 40% of a stride, the limb is swinging. As no contact occurs with the floor, there are no ground reaction forces.

In Figure 1a: B, the stance phase of the right limb is illustrated. The stance phase lasts from right heel contact (RHC; Figure 1a: B, page 18) to right toe-off (RTO). Analysing the A/P ground reaction forces reveals that a stance phase is composed of a braking and a propelling phase. All negative forces of the A/P ground reaction forces are considered to be braking forces; all positive forces are considered as propelling forces.

Ground reaction force analyses are stated as early as 1873 by Marey. This author described the 'pressure' executed by the foot on the ground and documented it. However, accurate measurements of the ground reaction forces become possible with the development of force plate forms. Since then, they have been well documented (Boccardi et al., 1977; Bresler and Frankel, 1950; review by Winter et al., 1995) and are a fixed component of biomechanical analyses when force plates for gait examination are used today. In addition, ground reaction force analyses form the base for more detailed movement investigations such as moment and power analyses.

The area underneath a force-time curve is the total momentum (Hannah and Hilier, 1988). Linear momentum \( p \) is defined as mass \( m \) times velocity \( v \) \( (p=m\cdot v) \). The change of momentum is called the impulse. In biomechanics, masses are
normally not changing. Therefore impulses are an indicator of how much the velocity has changed over a given time.

**Gait Measurement Variability**

Gait related measurements have a low intra-subject variability (Arsenault et al., 1986; Winter, 1984). According to Arsenault et al. (1986), only one stride is needed to achieve reliable results when analysing EMG profiles. Although one stride is also sufficient to depict individual differences, Arsenault et al. recommend a minimal number of three strides to free the results from step to step adaptation effects. Winter (1984) analysed ground reaction forces, joint angle patterns and moment patterns regarding intra- and inter-subject variability. In all three categories, not only was intra-subject variability low but the inter-subject differences were also small. The largest inter-and intra-subject variability was found in knee and hip moment patterns. These differences had no effect on joint angle patterns, indicating that different moment patterns can result in nearly identical joint angle patterns during stance phase. Winter (1984) also stated that the variability of the moment patterns at the knee and hip decreases with increasing speed. Bohannon (1997), who confirmed that intra-subject variability of gait speed decreases with increased speed, supports these results. The correlation coefficients between trials on individuals were 0.90 for comfortable walking speed and 0.91 for maximum walking speed. Recent results confirm the findings of previous studies. Stolze et al. (1998) measured test-retest reliability of spatio-temporal gait parameters in children and adults. The mean adult correlation coefficient of all the tested variables was high (0.88). Only the
correlation coefficients for velocity (0.77) and swing phase (0.65) were lower. Sekiya and Nagasaki (1998) analyzed the test-retest reliability by means of the walk ratio (step-length/step-rate). The walk ratio was invariant for males at all speed levels but differed for females at slow speed. The interclass correlation coefficients between the different tests were nevertheless good and ranged between 0.60 to 0.80.

However, all the studies mentioned above based their results on sagital plane analyses alone. Kadaba et al. (1989) analysed intra-subject variability in adult gait in all three planes and combined EMG, kinematic and kinetic data. Furthermore, they analysed the diurnal and daily variability. Again, very good intra-subject repeatability was found in the sagital plane for kinematic data within a day (coefficient of multiple correlation CMC: 0.89) and good results between days (CMC: 0.87). Excellent results were achieved in the frontal and transverse plane for diurnal variability (CMC: 0.94, respectively 0.91), but were weaker for daily variability (CMC: 0.88, respectively 0.86). They stated that the weaker result was partly due to the variability in the alignment of the markers. Vertical reaction (CMC: 0.99) and braking and propulsion forces (CMC: 0.99) were more repeatable than were the medio-lateral forces (CMC: 0.95). But the diurnal and the daily repeatability were very high (CMC range from 0.94 to 0.99). Joint moments in the sagital plane were less variable than the moments in the frontal and transverse plan and the diurnal variability was slightly higher than the daily variability. The coefficient of multiple correlation ranged within the same day from 0.90 to 0.99 and between days from 0.81 to 0.98. The repeatability of the EMG-data follows this trend with a slightly lower intra-subject diurnal variability than
daily variability. The CMCs stated above represent means of the different
kinematic and kinetic variables Kadaba et al. (1989) have measured. Dujardin et
al. (1997) have related the inter-individual variation of hip motion to anatomical
characteristics. The inter-subject variability was significantly correlated with
height, step length and cadence.

The results presented in the preceding paragraph indicate that gait
measurements are highly repeatable.

*Gender Differences*

Gender differences, walking velocity and anthropometric features have been
the topics of many studies (e.g. Bohannon, 1997; Grieve and Gear, 1966; Waters
et al., 1981). Slow and fast velocities as well as stride length differed significantly
between male and female adults (Waters et al., 1988). In the same study,
females showed a significantly higher cadence under normal and fast conditions,
but not under slow conditions. These results support the findings found earlier by
Grieve and Gear (1966). However, not all authors have taken stature into account
(Waters et al, 1988), and only a few relate leg length as well as step length to
total body height (Bohannon, 1997; Yamasaki et al, 1991)

If step length is normalized to body height, the differences between gender
diminish, and become only significant at maximal walking speed (Yamasaki et al.,
1991). These results have been confirmed partly by Bohannon (1997). These
results showed that for the ratio of height-normalized, comfortable walking speed,
there was a negligible gender difference: 0.82 for men in their 30s and 40s,
compared with 0.86 and 0.85 for females in their 30s and 40s respectively. At
maximum walking speed, the differences between the height-normalized ratio in men and women in their 30s decreased further whereas the same ratio increased slightly by 0.09 between genders in their 40s. This disagreement with the results of Yamasaki et al. (1991) might be due to ethnic differences.

The possible influence of leg length on walking speed has been analysed by, among others, Hoffmann (1971) and Webb (1996). Their results showed a clear relationship between maximal running speed and leg length, but not between comfortable walking speed and leg length (Webb). Steudel (1996) supported these results. This last author hypothesised that the increased locomotor efficiency with longer limbs might be balanced by the decreased efficiency of the increased moment of inertia.

Gender differences were also found when analysing the trajectory of the COM during natural walking (Iida and Yamamuro, 1987). These differences were most obvious in the frontal plane. Women exhibited a nearly perfect U-shaped curve, whereas men showed a squeezed figure of eight.

Crowe et al. (1996) summarised the factors that influence individual gait characteristics as follows: circumstantial factors such as footwear, terrain and the size or distribution of a carried load influence gait. Another important factor is mood: people walk differently when exhilarated or mentally depressed (Buchner et al., 1996; Inman et al., 1981). Furthermore, genetically determined factors such as gender, race and stature have an influence on gait as well as acquired factors like histories of previous injuries, training and professional characteristics and age. This latter factor will be discussed in the following chapter.
2.2. AGE-RELATED CHANGES IN GAIT

Adult gait and its characteristics remain nearly unchanged until the age of 60. Thereafter, walking performance starts to decline (see review by Alexander, 1996b; Bohannon, 1997; see review by Sudarsky, 1990). The ageing process affects all bodily systems and results in their functional decline. In the following text, only those systems considered to influence gait the most, will be discussed further: the nervous, muscle-skeletal, cardiovascular and visual systems. Finally, this section will terminate with the ageing gait, summarizing the influence of the age-related decline on gait.

2.2.1. The Ageing Nervous System

Age-related changes of the central nervous system (CNS) start after the age of 20 (Strehler, 1976) or 30 years (Martini and Timmons, 1995) and declines gradually thereafter. The most common changes are a reduction in brain size and weight, a reduction in the number of neurones and their synaptic organisation, as well as intra- and intercellular habits, and a decrease in cranial blood flow (Martini and Timmons, 1995). Brain atrophy during normal ageing ranges from 10-15% up to 30% in severely demented patients (Wiśniewski and Terry, 1976). The results of Strehler (1976) are in the same range with a 10-20% brain weight loss between the ages of 20 and 90 years. The atrophy is mainly due to individual cell atrophy and cell loss (Martini and Timmons, 1995; Rubino, 1993; Strehler, 1976).

Another feature is the reduction of dendrite branches and synaptic interconnections, causing a decline in neurotransmitter production (Delwaide,
1986; Martini and Timmons, 1995). Furthermore, neurones start to accumulate intra-cellular deposits resulting in plaques and neurofibrillary tangles. Plaques are mainly an accumulation of the fibrillar protein amyloid, surrounded by abnormal dendrites and axons, whereas neurofibrillary tangles are dense mats of neurofibrils (Martini and Timmons, 1995; Wiśniewski and Terry, 1976). However, Morrison and Hof (1997) demonstrated that during normal ageing, i.e. non-neuro-pathological changes, neuronal losses are not likely to be the cause of functional decline.

The peripheral nervous system also undergoes age-related changes. Histologic peripheral nerve changes include axonal degeneration, a decrease in the number and density of nerve fibres with a disproportionate loss of large fibres, and an increase of connective tissues (Dorfman and Besley, 1979). These authors demonstrated that, in general, the conduction velocity (CV) of the peripheral median nerve slows at an approximate rate of 0.15 m/s per year for motor fibres, and 0.16 m/s per year for sensory fibres. Welford (1984) supports these results. However, spinal sensory CV is relatively stable from the age of 18 to 60 years, but declines thereafter at a rate of 0.78 m/s per year (Dorfman and Besley, 1979). General nerve conduction velocities in the lower limbs range from 40 to 60 m/s (Harrison, 1994). Therefore, the age-related changes in peripheral nerves documented by Dorfman and Besley represent a nerve conduction decrease of 0.26 to 0.4 % per year.

Thus, the neuronal processing and the conduction of information slows down with increased age, combined with decreased sensory information due to neurone loss (Maki and McIlroy, 1996; Welford, 1984).
2.2.2. The Ageing Muscle-Skeletal System

Age-related changes of the muscle are summarised by Martini and Timmons (1995). In general, the skeletal muscle fibres become smaller in diameter and loose elasticity. The reduction in diameter is mainly due to a decrease in myofibrils, whereas the increasing stiffness is related to the increase of collagen fibres. Decreased joint moments, forces (Winter et al, 1990) and extensor power (Bassey et al, 1992) reflect these age-related changes in muscle structure.

Gender and ethnic differences have also been found in elderly populations. In a large cross-sectional study Gallagher et al. (1997) among other things demonstrated that elderly African-Americans had a higher percentage of appendicular skeletal muscle mass than their Caucasian counterparts. Furthermore, the absolute decrease in appendicular skeletal muscle mass with increasing age was larger in men than in women for both ethnic groups. Nevertheless, the gender differences persisted but were smaller in magnitude than in the young populations. Age, gender, body height and weight were taken into account when the authors did the comparison between the ethnic groups.

The most important changes in the ageing skeletal system are a reduction in bone mass and a decline in mineral content, resulting in a thinner and hence more fragile bone structure. These reductions start between ages 30 and 40 years and are more prominent in women (8% per decade) than in men (3% per decade) (Martini and Timmons, 1995). This fact may explain the increase of hip fractures among females. The rate of hip fracture among women starts to increase around the age of 40 years and doubles subsequently with each five to six years in an exponential curve (Kellogg International Work Group, 1987). It
should also be mentioned that hip fractures, although often cited as the most important morbidity and mortality factor, occur in only about 1 to 2% of all falls (Kellogg International Work Group, 1987; King and Tinetti, 1996).

Marcus (1995) pointed out that probably the most important manifestations of age-related bone loss and skeletal fragility result from a fundamental inefficiency in bone remodelling that may progress with age. Nutrient intake and hormones have an influence on bone turnover and are related to skeletal strength.

2.2.3. The Ageing Cardiovascular System

The major features of the ageing cardiovascular system are a reduction in the maximal cardiac output, an increased inelasticity of the arteries combined with calcification (arteriosclerosis) and a decreased haematocrit (Martini and Timmons, 1995). Furthermore, pooling of blood occurs in the leg veins, as valves do not function as efficiently. Due to these changes, tissue oxygen supply is reduced, a fact which may have the biggest implications for the brain. Thompson (1976) showed that regional cerebral blood flow is correlated with the degree of dementia, pointing out that metabolic rate differs between cerebral regions.

2.2.4. The Ageing Visual System

Reduced acuity, contrast sensitivity and depth perception, as well as a decline in dark adaptation, are characteristics of the ageing visual system (Caranasos and Israel, 1991; Maki and McIlroy, 1996), reflecting structural and compositional changes of the eye. Deguine et al. (1997) analysed the ageing effect on the vitreous body. They stated that vitreous body syneresis, which is
most pronounced between 40 and 50 years of age, might be due to chemical reaction initiated by UV radiation and metabolic changes. A synerised vitreous body can lead to detachment of the retina due to voluminal changes (Deguine et al, 1997).

Gao and Hollyfield (1992) quantified the impact of ageing on the retinal cell structure. They demonstrated that cell losses were dependent on cell type and retinal region. The different ageing effects on the different cell types were remarkable. For example, numbers of rod cells were found to decrease curvilinearly with the largest decline between the age of 40 and 60 years, whereas an observed linear decline of cone cells was not significant between ages 20 and 90. The authors concluded that the differential cell losses could cause the decline of visual function. However, neuronal processes and loss of neurones in the visual cortex have to be taken into account as well (Gao and Hollyfield, 1992).

Rubin et al. (1994) demonstrated the effect of visual impairment on different disability categories. For example, persons with reduced acuity were 1.36 times more at risk of being restricted in their mobility and up to 2.70 times while driving a car. They were also 4.00 times more at risk when exposed to resolution problems such as reading signs or identifying faces while walking. The above mentioned odds ratios were adjusted for age, gender, race and number of chronic medical conditions. These results demonstrated that visual acuity is playing an important role and should be considered, when analyzing locomotion.
2.2.5. The Ageing Gait

The above mentioned changes of the different systems do not occur in isolation. They are inter-linked and, together with individual characteristics, they contribute to the typical gait pattern of healthy elderly people. This is characterised by a decreased walking speed caused by a reduced push-off (Winter et al., 1990). Judge et al. (1996b) demonstrated that their older participants were unable to increase plantar flexion power at maximal speed but increased hip flexor power to compensate. A lower push-off results in a shorter step and stride length (Costes-Salon et al., 1996; Elble et al., 1991). The lower push-off is combined with a more flat-footed landing (see review by Alexander, 1996b; Winter et al., 1990). Both may reflect the reduced joint motion in the elderly (Caranasos and Israel, 1991). However, Alexander (1996b) pointed out that joint motion differences between elderly persons (aged ≤70 years) and the young are generally less than 30% and often less than 10%. Furthermore, it has to kept in mind that full range of motion is not required during normal walking speed.

Cadence decreased significantly in the elderly participants of Costes-Salon et al. (1996) and Waters et al. (1988) when compared with young adults. However, the cadence difference remained non-significant in the group of Winter et al. (1990), whereas in the group of Judge et al. (1996b), older people showed a faster cadence than the young persons. The results of Costes-Salon et al. and Waters et al. contrast with the results of Judge et al. and Winter et al. This may be due to the fact Judge et al. and Winter et al. were testing fit and active elderly
people compared to the elderly participants of Costes-Salon et al. and Waters et al.

An additional feature of elderly gait was the increase in stance phase due to the extension of double limb support (Baumann, 1994; see review by Sudarsky, 1990). This modification may reflect the slower COM transfer from the propelling to the stance leg (Costes-Salon et al., 1996). In general, elderly people showed an enlarged walking base to improve stabilisation (Vieregge, 1997). Gehlsen and Whaley (1990) evaluated the distance between the heels during walking in two different elderly groups: the control group consisted of 30 participants with no history of falls (mean age of 71.3 years) and the test group consisted of 25 participants who had had at least one fall within the ten months before the investigation took place (mean age of 72.4 years). The participants were evaluated on a treadmill at a speed of 4 km/h and 6 km/h. The group with a history of falls showed a significantly larger distance between the heels at both speeds than the control group. In both groups however, the distance between the heels was reduced at higher walking speeds. For the control group the width at 4 km/h was 7.19 cm compared to 6.41 cm at high speed. In the test group the average width range was 7.77 cm and 7.39 cm at the normal and high speed respectively. Kawamura et al. (1991) analysed the stride width in healthy young men during level and slope walking. The average stride width of their participants was 14 cm when walking on the level. This was slightly increased when walking up a 6° slope. Interestingly, the width decreased when the slope was further increased and was even smaller than for level walking when the participants were walking up a 12° slope. The decrease of walking width with age has been
previously reported. Gabell and Nayak (1984) reported a difference of 2.12 cm between the young (aged 21 to 47 years) and the elderly (aged 66 to 84 years) during normal level walking. The above-mentioned results contrast with the general consensus that elderly people tend to increase their walking width for safety purposes. However, the increase in the walking width seems to be particularly true for frail, elderly people, as documented by Gehlsen and Whaley (1990) and Guimaraes and Isaacs (1980).

All the above-mentioned changes are also correlated with walking speed. This opens the possibility that observed age-related gait changes are a result of reduced walking velocities rather than direct physiological changes (see review by Alexander, 1996b; Elble et al., 1991). Muscle-skeletal, neurological and cardiovascular symptoms are associated with a decreased walking speed (see review by Alexander, 1996b; Judge et al., 1996a). Sudarsky (see review 1990) stated that the gait of elderly people is more strongly influenced by an onset of a disease than by chronological age, a statement which is supported by Horak et al. (see review 1989) and Alexander (1996a). But the transition from normal age-related to pathologically induced changes is not easy to identify (Dobbs et al., 1993; Maki, 1997; Winter, 1985) as the elderly represent a heterogeneous group (Caranasos and Israel, 1991; see review by Horak et al., 1989, see review by Sudarsky, 1990). Gait disorders in the elderly are common and are mostly due to neurological pathologies such as sensory imbalance, Parkinsonism and myelopathy (see review by Alexander, 1996b; Bopp and Six, 1991; Nutt et al., 1993).
2.3. GAIT TERMINATION

Situations in daily life require the capability of turning and stopping. Terminating gait, as a specific part of the walking process, makes special demands as a transition occurs from a dynamic situation (walking) to a quasi-static situation (standing). As discussed in the previous sections, the ageing process affects all bodily systems and results in their functional decline. Elderly people show difficulties in stopping their gait (Cao et al 1997 and 1998). It is unknown, however, if the difficulties worsen for elderly people with impaired foot sensitivity such as elderly people with diabetes. Although stopping represents an important event, only a handful of publications consider this part of the locomotor task. In the following section, the six available gait termination studies are discussed critically. Only one of these studies includes elderly persons and none of them includes elderly persons with diabetes suffering from peripheral neuropathy.

Yamashita and Katoh (1976) analysed, among other variables, the COP trajectories in the anterior/posterior (A/P) and medio/lateral (M/L) directions during steady walking and during starting and stopping. The authors developed a special force plate shaped as a right isosceles triangle. Its base was long enough to measure the vertical ground reaction force during a full stride, i.e. one step for each leg. During the stopping trials the participants walked at natural cadence along an auxiliary walkway and stopped at the end of the force plate with the feet placed in parallel. The authors demonstrated that once the participant has
reached his standing pose, the resultant COP described a M/L movement. Compared with the COP starting trajectory, the M/L movement of the stopping COP trajectory was delayed and more pronounced. The authors related the M/L movement to the positioning of the COM between the two feet. Their results are based on four young men aged between 23 and 34 years (median 25 years).

In the above mentioned study, the participants were asked to stop with parallel feet. Hence, the same foot positions at the stop were achieved as at the start. The similarity obtained between the two conditions (starting, stopping) could therefore be due to the experimental set-up only. No force analyses in either the A/P or M/L directions could be performed because this special force plate was sensitive to vertical forces only.

Jaeger and Vanitchatchavan (1992) analysed the vertical and horizontal ground reaction forces in ten young persons (mean age 28.7 years) during gait termination under two conditions: 1) stopping as quickly as possible after a sound signal, regardless of foot position, and 2) stopping as quickly as possible after a sound signal but feet placed in parallel. The stopping signal was delivered at different times during the cycle. The authors demonstrated that the main characteristics for stopping were increased braking and decreased propulsion forces during the stance phase prior to gait termination. Furthermore, the time taken to terminate gait was dependent on the signal intervention during the gait cycle. Under the first condition, an increased time was observed when the signal was given 10% before completion of the gait cycle. This increase was due to the required additional step. An additional step was also required under the second condition of a signal intervention between 15 to 30% before completion of the gait
cycle. In other words, if their participants were allowed to stop regardless of their foot position, they stopped more quickly because another step was not necessary 90% of the time. As no kinematic data were recorded, the interaction between the COM and the COP trajectories could not be analysed.

Jian et al. (1993) compared gait termination patterns of the COP and the COM with the COM and COP trajectories during gait initiation in four young men aged between 25 and 31 years. The stop was controlled as the participants were asked to stop on force plates #2 and #3, once the visual stopping signal occurred (Figure 1b). The visual stopping signal was triggered by heel contact (HC) at force plate #1.

![Figure 1b. Experimental set-up of Jian et al. (1993).](image)

The authors divided the stopping time into three phases. Phase 1 was initiated by the left foot, which released the stopping signal and completed with the right heel contact (force plate #3). During this time a 10% reduction in gait velocity was achieved. Phase 2 was the main braking phase (right heel contact and second left heel contact; force plates #3 and #2) with a 73% reduction in gait velocity during this second step. Phase 3 included the fine-tuning of the COM by
the COP. During Phase 3, the COM was brought into the final position, a position equivalent to standing still. The general shape of the COP versus the COM trajectories were similar but exactly opposite in direction to that of gait initiation. By toe-off of the left foot (phase 2), the COP position was forward and lateral of the COM. This resulted in a rapid deceleration of the COM in the walking direction but an acceleration in the medial direction. Once the left foot has been positioned (phase 3), the COP moves anteriorly and towards this new stance foot. The COP was then controlled to take a position directly in front of the COM trajectory to slow down the forward and medial velocity to near zero. At the end of phase 3, the COP and the COM positions were nearly the same. Hence, the authors concluded that gait termination is virtually a mirror image of gait initiation, supporting, in part, the results found by Yamashita and Katoh (1976).

Nevertheless, the conclusion of Jian et al. (1993) could just be due to their set-up of the testing procedures. As in the study of Yamashita and Katoh (1976), their participants were asked to stop with their feet placed parallel. Furthermore, each foot had to be placed on a different force plate so that the authors could analyse the COP trajectory for each foot. However, the authors did not take into account the possible influence of foot positions and gait velocity on the COP or COM trajectory during gait termination. It could be that the COM and the COP trajectories depend on gait velocity prior to termination and on foot position during stopping.

The categorisation of Jian et al. stimulated in part the categorisation of the stopping procedure analysed in this present study. Phase 1 of Jian et al. corresponds to the Approach Phase. However, the phases 2 and 3 proposed by
Jian et al. have been combined in this study under the heading of the Stopping Phase. This combination is the logical conclusion of the results of Jian et al. As mentioned above, the main braking occurred during phases 2 and 3, hence these phases represent the Stopping Phase.

Cao et al. (1997) studied the abilities of 20 young and 20 elderly persons to execute a sudden $90^\circ$ turn. The participants were requested to walk along a walkway and to turn either right or left according to a flashing light (Figure 1c). The lights were given at different time intervals and at different light poles to avoid any anticipation.

![Figure 1c. Experimental set-up of Cao et al. 1997](image)

The elderly persons had significantly more difficulty in fulfilling the task as indicated by their lower success rate. The authors demonstrated that 99% of the failures were due to their participants’ incapacity in stopping the COM forward linear momentum. To achieve a success rate of 50%, young persons required a reaction time of 408 ms. Older people however required 523 ms, an increase of 115 ms, to achieve the same level of success. The capability to turn suddenly is
based on two main characteristics: a sufficient COM velocity reduction in the walking direction and the ability to execute a 90° turn. The latter depends on the amount of walking velocity reduction. As the results of Cao et al. clearly demonstrate, elderly people have difficulties in reducing their walking velocity sufficiently. Therefore, stopping becomes more difficult with increased age.

In another publication, the same authors (Cao et al., 1998) demonstrated the sudden stop characteristics of the same participants. The participants were visually cued to stop suddenly by lights arrayed in vertical lines, creating a virtual wall ahead of them. These lights were activated at different time intervals resulting in different distances before the participant reached the virtual wall. The authors modelled the abdominal surface velocity history, from comfortable walking speed to zero velocity in three sections (indicated with dashed lines in

![Figure 1d. Abdominal surface velocity of a typical sudden stopping trial according to Cao et al. (1998) (with the authors' permission)]](image-url)
Figure 1d) with their corresponding time intervals T1, T2 and T3.

The duration of T1 was from the light cue until peak post-cue velocity was reached. T2 was the time taken from peak post-cue velocity until 50% of the comfortable walking speed was reached, whereas T3 described the time taken from 50% comfortable walking speed to zero velocity. Compared with the young participants, elderly participants had a significantly longer T1 resulting in a higher post-cue acceleration. A higher post-cue acceleration is not desirable for a sudden stop as it would either take more time to decelerate the whole body or require a larger force. The overall results showed that elderly people need significantly more time to execute a sudden stop than young people. This difference was mainly due to a prolonged T1. Keeping the fixed distance in mind, the second main contributor for the differences found were difficulties in responding adequately to the higher acceleration resulting from the prolonged T1. Only elderly men were able to compensate, in part by responding with a higher deceleration during T2. This deceleration was also significantly higher when compared with young men. The authors mentioned that a possible reason for the gender differences found among the elderly participants could be due to the fact that elderly women are less able to develop ankle torque rapidly. Plantar flexors are needed during gait termination to absorb energy. Hence, the capacities of the plantar flexors to produce torque quickly might be a critical determinant of the ability to stop suddenly.

Hase and Stein (1998) also performed analyses of rapid stopping. They combined force sensor recording underneath each foot with electromyography (EMG) to evaluate the different strategies used to terminate gait rapidly. The
stopping cue was given by an electrical stimulation of the superficial peroneal nerve in the anterior surface of the right leg, near the crease of the ankle joint. The electrode was placed on the dorsal surface of the right foot where participants reported a strong radiating paresthesia. When stimulated, it gave the impression that an object was hitting the top of the foot. The stimuli were given randomly and at any time during the gait cycle while the participants walked for a twenty-minute period. The participants were asked to stop as soon as they felt the stimuli. Briefly, when the stimuli occurred within 35-70% of the gait cycle (from right late stance to mid-swing) the right leg was put forward and a full stop was achieved. When the stimuli was applied within 85-20% of the gait cycle (from right late swing to early stance phase) the left leg was put forward and full stop was achieved. When the stimuli was given within 20-35% or 70-85% of the gait cycle (early stance to mid-stance of either leg), a motor response had to be made whether to take an additional short step.

The authors identified three different mechanisms to stop suddenly: braking mechanisms in the forward leg, reduced push-off in the other leg and a conversion of kinetic to potential energy. During late swing, up to mid-stance stimulation, the heel contact (HC) of the forward leg occurred in a shorter distance, as would be the case if the person continued walking steadily. Soleus muscle activity was strong enough to achieve a rapid foot flat opposing further forward movement. Together with the vastus lateralis, the soleus helped to keep the leg straight and hence, the body behind the forward leg. The gluteus medius and erector spinae activation prevented hip flexion and forward trunk movement.
The reduced push-off mechanism was observed in the other leg. It showed a complementary muscle action pattern when compared with the forward leg. There was a large burst from the tibialis anterior muscle and a reduced soleus activity. This created a backward momentum. Biceps femoris and gluteus medius activity helped to keep the leg straight and hence behind the body. However, if the forward movement of the COM was too great, or the activities of all the muscle groups described above too weak, the person was required to take an additional step in order to achieve a full stop.

If the effect of these two mechanisms (braking mechanism and reduced push-off) was not efficient enough, i.e. the COM tended to pass over the extended forward leg, then the participants rose onto the toes converting some kinetic energy into potential energy as the COM rises. If the COM could be stopped before it came in front of the supporting leg COP, a stop was achieved by using this third mechanism. Otherwise an additional step had to be taken to avoid a fall.

To sum up, stopping one’s gait is a very important task and can lead to serious problems if not executed properly. Situations in daily life require the capability to stop in front of unexpected obstacles, for example at the pavement curb or when approaching descending stairs. Gait termination can be induced by external, environmental, stimuli or by internal stimuli. Furthermore, the final foot placement at gait termination might be forced or unconstrained. Forced foot placement position, feet placed in parallel for example, may be determined by the environment due to a space restriction such as on an escalator or because the person has reached a pavement curb.
Gait termination strategies seem to vary according to the tasks demanded. They seem to be a virtual mirror image of gait initiation when a stop with feet in parallel is executed (Jian et al., 1993; Yamashita and Kato, 1976;). However, the feet are placed randomly if sudden stops are demanded (Hase and Stein, 1998; Jaeger and Vanitchatchavan, 1992). Furthermore, a stop depends on the time at which the stopping stimuli is given during the gait cycle. Stopping stimuli applied early in the gait cycle lead to a stop within the next step. Whereas stopping stimuli applied in the later part of the gait cycle lead to yet an additional step to complete a full stop.

The trajectories of two key variables in biomechanics, the COM and COP during gait termination, have only been reported once. This experiment was carried out on young persons and under strict conditions, i.e. stopping on the following step after the light cue occurred and with feet in parallel (Jian et al., 1993). However, a detailed analyses of the overshoots of these trajectories is lacking. As mentioned in the literature review, the overshoots are an indicator of the co-ordination abilities. Therefore, analyses of these overshoots in the population of the present study will give an insight of young and elderly co-ordination behaviour. Furthermore, due to the group of elderly persons with type 2 diabetes and peripheral neuropathy, the possible influence of peripheral neuropathy can be tested.
2.4. DIABETES MELLITUS AND ITS COMPLICATIONS

Diabetes mellitus is one of the most common chronic diseases in the elderly population of the western industrialised world. Its implications are tremendous and the social burden enormous. In the following section, the complications of diabetes mellitus and the resulting effects on gait are presented. In the first part, diabetes and its general effects are introduced. Diabetic neuropathy and its effects on gait are discussed in the following two sections. The problem of foot ulceration is explained in the fourth section. Finally, diabetic retinopathy and its complications are presented.

2.4.1. Introduction

At the core of every diabetes induced pathology is the disease Diabetes Mellitus (DM) itself. DM is a chronic disease and includes all forms of glucose metabolic disorders with different aetiologies and symptoms. It is also the most frequent endocrinological disorder (Pschyrembel, 1995). DM is characterised by a relative (Type 2) or absolute (Type 1) lack of insulin. Type 1 accounts for roughly 10-15% and Type 2 accounting for 85-90% of persons with diabetes (Sherwin, 1996).

Type 1 diabetes affects mainly younger persons under 40 years of age. As it is characterised by an absolute lack of insulin production, type 1 diabetes patients need insulin treatment for survival. The onset of type 1 diabetes occurs predominantly in youth and is often abrupt (Pschyrembel, 1994; LaPorte et al., 1995). However, it is believed that type 1 diabetes has a long asymptomatic pre-
clinical stage, during which the pancreatic beta cells are gradually destroyed by an auto-immune attack (Sherwin, 1996, WHO Study Group, 1985) or possibly by viral infection (Pschyrembel, 1995; WHO Study Group 1985). The latter is believed to be especially true in young children.

Type 2 diabetes typically affects persons over 40 years and men slightly more than women (Martini and Timmons, 1995; Statistic Canada, 1996). The disease is characterised by a chronic insulin-resistant state with four major components: decreased peripheral glucose uptake, impaired insulin secretion, increased hepatic glucose output and a general glucotoxicity resulting in chronic hyperglycaemia (Canadian Diabetes Association Recommendations, 1998). The treatment depends on the clinical variation, but normally does not involve insulin injections. As mentioned previously, type 2 diabetes represents one of the top six chronic diseases in Canada (Statistics Canada, 1996). Diabetes affects roughly 5% of the Canadian population, with a prevalence rate slightly higher in the elderly people (Tan et al., 1997). For each diagnosed person with type 2 diabetes, there is expected to be another, yet undiagnosed person (Harris et al., 1992; Kenny et al., 1995). This high percentage of undiagnosed people might be due to the fact, that type 2 diabetes is mainly asymptomatic, even though it is accompanied by micro-and macro-angiopathies. If the undiagnosed people are taken into account, about 3 million Canadians are affected by diabetes (Tan et al., 1997).

DM is not a single disease with a single cause. Its most general features are a chronic elevated blood glucose concentration and other biochemical abnormalities, which are due to the deficient production or action of the insulin
WHO Study Group, 1985). Insulin is a hormone which is produced in the beta cells of the pancreatic Langerhans islets (Pschyrembel, 1994). It is responsible for the suppression of hepatic glucose production, the stimulation of hepatic glucose uptake and the acceleration of glucose uptake in the peripheral tissues, especially in muscles. It facilitates intracellular metabolism, promotes glycogen formation by stimulating glycogenesis and supports glucose oxidation by decreasing lipolysis (Pschyrembel, 1994; Sherwin, 1996). Insulin secretion is triggered by the blood glucose concentration. However, the initial triggering process is poorly understood (Sherwin, 1996).

The hormone glucagon balances the metabolic action of insulin (Martini and Timmons, 1995). This hormone is also produced in the pancreas, but in the alpha cells of the pancreatic Langerhans islets. It stimulates hepatic glycogenolysis (the break down of glycogen), hepatic gluconeogenesis (a synthesis of glucose via non-carbohydrate preliminary stages such as Lactate and Glycerine) and hepatic ketogenesis (a building-up of ketone bodies, which are used as energy deliverers by peripheral tissue) (Pschyrembel, 1994; Sherwin, 1996). Glucagon is normally inhibited by hyperglycaemia. But this is not the case in DM, despite the presence of chronic hyperglycaemia (Sherwin, 1996).

Due to the chronic elevated blood glucose level, long-term complications result in nearly every tissue of the body (DCCT Research Group, 1996; WHO Research Group, 1985). These complications are categorised into two main sections: micro- and macro-angiopathy (DCCT Research Group, 1996; Bertin et al., 1997). Diabetic neuropathy, nephropathy and retinopathy are classified as micro-angiopathies, whereas diabetic cardio-vascular disease, cerebral vascular
disease and peripheral vascular disease are considered as macro-angiopathies (Sherwin, 1996; Seaquist 1998).

In the following paragraphs only the two diabetic induced diseases, which are considered to have a direct influence on the gait termination test procedure, will be further discussed. These are diabetic neuropathy, implicated in foot ulceration, and diabetic retinopathy.

2.4.2. Diabetic Neuropathy

Diabetic neuropathy is the most common complication people with diabetes have to deal with. Its occurrence ranges from 5 to 80%, depending on the author (Cavanagh et al., 1993; Dyck et al., 1992; Eastman, 1995; Fernando and Boulton, 1992). Eastman et al. (1997) developed a model to predict complications of non-insulin-dependent diabetes mellitus (NIDDM – in general type 2 diabetes) in the American population. According to their mixed ethnic group results, symptomatic sensorimotor neuropathy is predictable in 31% of the patients. The mixed ethnic group was composed of 70% non-Hispanic Caucasian, 20% African-American, 5% Hispanic American, and Asian and Native American with 2.5% each.

The exact cause of diabetic neuropathy remains unclear (Vinik et al., 1992; Sherwin, 1996; Malik, 1997). It appears to be the result of micro-angiopathy (Pschyrembel, 1994; Sima and Greene, 1995). The underlying mechanisms are believed to be a combination of structural nerve alterations, nerve metabolic disturbances, impaired nerve fibre regeneration, and micro-vascular dysfunction resulting in nerve hypoxia (Anand et al., 1996; Sima and Cherian, 1997; Malik, 1997).
Structural nerve alterations show a wide range of pathological changes and differ from early to late neuropathy. They include axonal atrophy of both myelinated and unmyelinated fibres, and axonal degeneration, leading to a progressive nerve fibre loss with duration of diabetes (Sima and Cherian, 1997). Furthermore, axonal atrophy leads to wrinkling of the myelinated sheath, further contributing to an impaired nerve conduction velocity. But structural nerve changes also affect the Ranvier nodes, periodic breaks in the myelin sheaths. Nodal swelling, probably produced by axonal oedema, causes detachment of paranodal myelin loops. This leads to a regeneration with two separate nodes and a thin myelin sheath in between, a new internode (Sima and Cherian, 1997). As the nerve-electrical impulse has now an additional internode to pass, conduction velocity is slowed down, especially if these regenerations occur at consecutive nodes along a given fibre.

Metabolic changes include non-enzymatic glycation of structural and functional nerve proteins (Sima and Cherian, 1997). These changes induce alterations of the nerve structure and culminate in impaired micro-vascular and axonal transport function (Younger et al., 1998). At the root of impaired micro-vascular function are the AGE (advanced glycosylation end products) (Brownlee et al., 1988). These chemically reactive AGE accumulate on matrix proteins as a function of time and glucose concentration resulting in vessel wall thickening and an associated in-elasticity (Brownlee 1995). Disordered lipid metabolism, caused by chronic hyperglycaemia leads to further neuronal damage (Löffler, 1997; Younger et al., 1998).
The response to nerve fibre regeneration is markedly suppressed and might
be an expression of decreased neurotrophic factors (Sima and Cherian, 1997).
The same authors stated that this impaired response to nerve injury is due in
particular to macrophages, which are necessary to initiate nerve fibre
regeneration.

Martini and Timmons (1995) also relate neuronal dysfunction to blood supply
disturbance in the neural tissue. Micro-vascular disturbances are often caused by
a decreased endoneurial blood flow (Sima and Cherian, 1997). The small
endoneurial vessels undergo basement membrane thickening, showing
proliferation and swelling of endothelial cells (Malik, 1997). Thickening of the
membrane may lead to increased diffusion distances for oxygen, potentially
leading to endoneurial hypoxia (Sima and Cherian, 1997). Therefore, neuronal
micro-vascular complications lead to axon loss as well as pathological changes in
Schwann cells (Cavanagh et al., 1993). Malik (1997) demonstrated that in mild
neuropathy, capillary density is already significantly reduced compared with his
control patient group. The density decreases even further with increased
neuropathic severity. The author stressed that there was no significant difference
in measures of micro-angiopathy between patients with type 1 and type 2
diabetes. This has also been reported by Sima and Cherian (1997).

In conclusion, neuro-pathological damage results in sensory and motor
deficits, with the sensory neurones being affected first (Boucher et al., 1995;
Cavanagh et al., 1992; Valk et al, 1992). Once neuropathy is established, the
disease progresses. The prevalence of diabetic neuropathy is correlated with
diabetes duration (Eastman, 1995; Vinik et al., 1992). Therefore, type 1 diabetes
patients are more likely to present with severe diabetic neuropathy than type 2 diabetes patients. But not only the duration of diabetes has an influence on the severity of diabetic neuropathy. The results of the DCCT research group (1996) and the results of UKPDS (1998) clearly demonstrate, that a good glycemic control has a significant influence on the disease development. A fact which is supported by Gaster and Hirsch’s exhaustive literature review regarding glycemic control and complications in type 2 diabetes (Gaster and Hirsch, 1998).

Because neuropathic mechanisms are heterogeneous and not clearly understood, neuropathies are classified according to the areas affected (Sherwin, 1996). The different resulting complications are therefore characterised by these areas and are dependent on the nerve fibres involved (Eastman, 1995; Ziegler; 1996).

Vinik et al. (1992) proposed a very detailed classification based on the consensus statement of the ‘San Antonio Conference on Diabetic Neuropathy’ in 1988. This classification divides diabetic neuropathy into three main groups: subclinical neuropathy, clinical neuropathy and focal neuropathy. Each of these main groups has several sub- and sub-subgroups. The authors mentioned at the same time that these classifications are subject to continual revision. This is due to the fast growing knowledge of the aetiologies of the different diabetic neuropathies.

Sherwin (1996) proposed a simpler classification, in which neuropathies are sub-divided into two main groups only: polyneuropathy and mononeuropathy. These two terms are well defined and therefore this classification is preferred. They will be presented in the following paragraphs and, where necessary,
complemented with additional information. For an easier understanding, please refer to Table 1.

**Table 1: Classification of Diabetic Neuropathy according to Sherwin, 1996**

<table>
<thead>
<tr>
<th>Polyneuropathies</th>
<th>Mononeuropathies</th>
</tr>
</thead>
</table>
| Distal symmetrical  
  - Chronic sensorimotor  
  - Acute sensory  
  Proximal motor  
  Autonomic | Isolated nerve lesions  
  - Peripheral  
  - Cranial  
  Radiculopathy |

Polyneuropathies, the first main group, are the most common forms found in the population with diabetes (Eastman, 1995; Sima and Greene, 1995). Within this group, the subgroup of the distal symmetrical polyneuropathy contains the most common type, the chronic sensorimotor polyneuropathy (Pschyrembel, 1994; Sherwin, 1996; Ziegler, 1996). This chronic sensorimotor polyneuropathy is characterised by decreases in axonal density and myelin sheath thickness (Pschyrembel, 1994). The degenerative process involves all somatic nerves. However, the distal parts of the body, especially the sensorimotor nerve fibres of the feet, are most affected (Vinik et al., 1992). Typical symptoms are burning, numbness, tingling in the extremities, fatigue and cramping (Sherwin, 1996; Ziegler, 1996). Symptoms generally worsen at night. But in early cases, chronic sensorimotor polyneuropathy can be asymptomatic.

Signs of chronic sensorimotor polyneuropathy are symmetrical distal loss of sensation combined with variable loss of distal reflexes, e.g. triceps-surae reflex, and muscle wasting of the intrinsic hand and feet muscles (Sherwin, 1996). Once
the disease is established, the nerve function declines with time and from distal to proximal (Pschyrembel, 1994).

The second subgroups of the distal symmetrical neuropathies are acute sensory neuropathy. It can occur at any time in both types of diabetes, but affects predominantly men (Vinik et al., 1992). The acute sensory neuropathy is a less common form and is characterised by a loss of small sensory fibres. These small sensory fibre injuries occasionally leave vibratory and position sense as well as motor function intact (Sherwin, 1996). Typical symptoms are severe pain, which is worse during the night and hyperaesthesia (Sherwin, 1966). The lower legs may be extremely tender to the touch with any disturbance of the hair follicles resulting in very severe pain (Vinik et al., 1992).

The second subgroup of the polyneuropathies is the proximal motor neuropathy. This subgroup is also known as diabetic amyotrophy or femoral neuropathy (Sherwin, 1996). This form of neuropathy is more common in elderly patients affected with type 2 diabetes (Fernando and Boulton, 1992; Karam and Forsham, 1994). It is characterised by an asymmetrical proximal muscle weakness of the extremities and the pelvis muscle group (Sherwin, 1996). Predominantly, the iliopsoas, the quadriceps and the adductors are involved (Vinik et al. 1992). The resulting symptoms are problematic when rising from kneeling or sitting positions and when climbing stairs. In severe cases, when the upper girdle is occasionally affected too, problems with unsupported standing may occur (Vinik et al., 1992). Proximal motor neuropathy resolves spontaneously and in most cases, within a year (Fernando and Boulton, 1992).
The autonomic neuropathies are the last subgroup of the polyneuropathies, affecting the parasympathetic and sympathetic nervous system. Autonomic neuropathies produce a wide range of problems, as this type of disease may involve any system in the body that is innervated by the autonomic nervous system (Sherwin, 1996; Vinik et al., 1992). Autonomic neuropathies cause pupillary and cardiovascular abnormalities, as well as motor disturbances of the gastrointestinal tract. Furthermore, they create disturbances in the genito-urinary tract and cause sweat disturbances and metabolic problems (Vinik et al., 1992). The autonomic neuropathies are present in both types of diabetes and often without symptoms (Checkliste de Médecine, 1996). Once an autonomic neuropathy manifests itself, the anticipated five year mortality rate is 15-40% (Vinik et al., 1992).

According to the system proposed by Sherwin (1996), the other main diabetic neuropathy classification is mononeuropathy. This group is subdivided into isolated nerve lesions, including peripheral and cranial nerve lesions, and into radiculopathy. Painful radiculopathy may involve one or more spinal roots, presenting a well-defined dermatome that may be confused with abdominal or cardiac disease (Sherwin, 1996). The most commonly affected peripheral nerves are the radial nerve, the median nerve and the external sciatic popliteus nerve (Checkliste de Médecine, 1996). The most commonly affected cranial nerves are the oculomotor, trochlear and the abducens nerves (Sherwin, 1996).

The usually sudden onset of pain in mononeuropathies is typical (Checkliste de Médecine, 1996) and occurs most often asymmetrically. The cause of the lesions is unknown, but the sudden onset is believed to have a vascular
component (Sherwin, 1996). It could also be that acute nerve ischaemia is implicated (Vinik et al., 1992).

2.4.3. Effect of Diabetic Neuropathy on Posture and Gait

The influence of peripheral neuropathy on gait and posture have been the topic of many studies (e.g.: Cavanagh et al., 1993; Courtemanche et al., 1996; Lord et al., 1993). They all agree that persons affected with peripheral neuropathy are more impaired than their age-matched controls. Cavanagh et al. (1993) compared, among other variables, the postural COP range in A/P and M/L directions of neuropathic persons with diabetes, non-neuropathic persons with diabetes and normal individuals. Each group consisted of 16 participants between the age of 40 and 70 who were age, gender, weight, and height matched. Furthermore, the groups with diabetes were also matched for diabetes duration. The authors demonstrated that the increased A/P and M/L COP range in the people with diabetes and neuropathy were significantly different when compared to normal persons and to persons with diabetes and no neuropathy. However, there was no significant difference in any variable between the normal persons and the persons with diabetes and no neuropathy. They concluded that diabetes per se did not affect postural stability.

These results have been confirmed in part by Katoulis et al. (1997). They analyzed their people with diabetes and neuropathy in more detail dividing them into two groups: persons with diabetes and neuropathy and with (DNU) and without a history of foot ulceration (DN). Normal controls (NC: no diabetes, no neuropathy) and controls with diabetes (DC: diabetes, no neuropathy, no history
of ulceration) completed the test set. Each of the four groups was composed of 20 persons matched for age, gender and BMI. The authors also found no significant differences in A/P and M/L COP trajectories between NC and DC. In addition, there was also no significant difference between the DC and the DN, a result, which contrasts with the findings of Cavanagh et al. (1993). However, the increased A/P and M/L COP trajectories found in the DNU were significantly larger than the ones of the DN. The authors therefore concluded that the demonstrated increased sway in persons with diabetes, neuropathy and with a history of foot ulceration might increase the risk of minor trauma and hence foot ulceration.

Courtemanche et al. (1996) investigated gait in persons with diabetes and neuropathy by exposing them to an auditory stimulus during walking. The reaction time (RT) was measured from the onset of the stimulus until the verbal response occurred and compared with the results obtained by the healthy group. The group with diabetes and neuropathy had a significantly longer RT than the healthy group. Furthermore, for people with diabetes and neuropathy, stride length, walking velocity and the time spent in single support were all significantly different. Their stride length was shorter, walking velocity slower and the percentage of the single limb support smaller than the corresponding variables in the healthy group. The authors demonstrated that persons with diabetes and neuropathy walked with a more conservative gait. In addition, this gait required additional attention. The results are based on 12 participants with diabetes and neuropathy and seven healthy participants in the same age range.
To access possible clinical consequences of impaired gait and posture due to diabetic peripheral neuropathy, Cavanagh et al. (1992) analyzed falls and injuries related to falls in young persons with diabetes. The 100 participants were chosen from the Pittsburgh Epidemiology of Diabetes Complication Study. They were divided into two groups: the 50 participants with the lowest vibratory threshold (VT) served as 'non-neuropathic' control groups whereas the 50 participants with the highest threshold were designed as the neuropathic group. Although this selection method did not require a cut-off value for inclusion in a given group, there was no overlap in VT values between the groups. In a telephone interview they were asked about falls and injuries due to falls while walking, if they worried about slipping, tripping or falling and if they had made any changes in activities in order to prevent slips or falls. They were also asked to rate their safety feelings on an ordered scale in the following special circumstances: descending unfamiliar stairs, standing in the shower without support, standing or walking on uneven ground, and standing and walking in an unfamiliar dark room. The results revealed that the neuropathic group was 15 times more likely to report injuries during walking when compared to the control group. They felt also significantly less safe in unusual conditions. The authors concluded that peripheral neuropathy has an effect on gait and posture which is clinically significant.

2.4.4. Foot Ulceration

One of the main problems for people with diabetes is foot ulceration. It is 156 times more common in persons with diabetes during their fifth decade than in age-matched controls (Hunt, 1990). Diabetic foot problems account for more
hospital inpatient days than do any other diabetic problems (Bertin et al., 1997; Reiber et al., 1995; see review of Shaw and Boulton, 1997).

All studies are in agreement that ulceration risk increases with increased plantar pressures (e.g. Katoulis et al., 1996; Mueller, 1996; Sarnow et al., 1994; Stess et al., 1997). Reasons for foot ulceration are bone deformity, limited joint mobilities, clawing of the toes, pes cavus and lack of soft-tissue cushioning (Katoulis et al., 1996; Payne, 1998; Stess et al., 1997; Veves et al., 1992). Furthermore, persons with diabetes seem to be unable to constantly shift the pressure distribution during walking due to lack of afferent input (Baumann et al., 1992; Katoulis et al., 1996). However, the results of Cavanagh et al. (1998) contrast with the general consensus. These authors measured in-shoe plantar pressure variability in three different groups: persons with diabetes and significant peripheral neuropathy, persons with diabetes and without peripheral neuropathy and controls without diabetes. The participants were matched according to their age, gender and weight/height ratio. The authors demonstrated that the step-to-step pressure variability at the chosen points (heel, first metatarsal head, second metatarsal heads, lateral metatarsal heads, and hallux) did not differ significantly among the groups during a fifty-step trial. There was also no significant variability among the groups when comparing the results from running-shoe trials with the results obtained from leather shoe trials. However, the authors stressed that shear stresses, not measured in this study, might be different between persons with diabetes and neuropathy and persons without neuropathy. Shear stresses are believed to have considerable influence on the occurrence of foot ulcers (Payne, 1998).
While walking, people with diabetes and a history of foot ulceration appeared to use a hip strategy rather than an ankle strategy, when compared with age-matched controls (Mueller et al., 1994). The same authors also demonstrated that the chosen hip strategy of these patients reduced plantar pressure.

2.4.5. Diabetic Retinopathy

Retinopathy constitutes another major problem for the person with diabetes. This pathology is present in 63% of persons with type 1 diabetes and in 33% of persons with type 2 diabetes in the Canadian diabetic population (Tan and MacLean, 1995). The ten-year incidence of blindness is up to 4.8% in persons diagnosed with diabetes at or after the age of 30 years (Moss et al., 1994). About 20% of type 2 diabetes persons already have evidence of diabetic retinopathy at diagnosis of diabetes (Harris, 1995). And after 10 years of diabetes, retinopathy is present in roughly 71% of persons with diabetes (Blom et al., 1993).

Retinopathy is a non inflammatory pathology caused by micro-angiopathy (Blom et al., 1993; Pschyrembel, 1994). Micro-angiopathy of the retinal capillaries is responsible for ischaemia, haemorrhages, arteriosclerosis and retinal hyalinosis (Blom et al., 1993; Christensen et al., 1978, Le Granier Delmare, 1995). One possibility for these microcirculatory changes could be an altered retinal blood flow. Christensen et al. (1978) have observed a positive correlation between decreased blood flow and the severity of retinopathy. These results are supported by Güven et al. (1996). Güven et al. also demonstrated that the pre-retinopathic group had a significantly higher blood flow than patients with well presented retinopathy.
Retinopathy can be categorized in two main sections: non-proliferative and proliferative retinopathy. Non-proliferative retinopathy is found mainly in type 2 persons with diabetes. It is characterized by the following changes: expansion of the blood vessel wall, i.e. hyalinose, oedema and haemorrhages (Pschyrembel, 1994). The result is a gradual decline in vision acuity.

Proliferative retinopathy is more prevalent in the population with type 1 diabetes as they normally have a longer history of the disease. It is present in 15.5% of persons having histories longer than 15 years of diabetes (Klein et al., 1984). Proliferative retinopathy is characterized by the same changes as non-proliferative retinopathy: hyalinose, oedema, and haemorrhages. But in addition, there is a growing number of misplaced new vessels, which may even grow into the vitreous body. These new vessels are delicate and bleed often, causing a shaded vision of a density relative to the severity of the lesion (Verougstraete, 1995). In addition, fibrillation of the newly grown vessels causes tension in the retina, and can lead to its detachment, resulting in functional loss. In a general way it can be summarized that damaged and leaky capillaries cause the retina to bleed and swell, resulting in blurred vision and reduced acuity.

The vitreous body is also affected. Structurally, metabolically induced changes of the vitreous body result in a reduced volume (Deguine et al., 1997; Sebag et al., 1992; Tagawa et al., 1986). This, again, may cause functional disturbances and retinal detachments.

Other causes of decreased vision that occur more frequently in persons with diabetes are cataract, glaucoma, and corneal disease (Klein and Klein, 1995). In general terms, clouding of the lens is called cataract, independent of its aetiology.
Glaucoma is the term used to describe damage that has been caused to the optical nerve due to increased intra-ocular pressure.

Spaulding et al. (1994) stated that people with reduced vision were found to walk more cautiously in general, but their gait pattern showed only minor changes when compared with normal gait. The authors related the more cautious gait to environmental adaptation caused by their set-up of the test procedure. However, Kuyk et al. (1996) demonstrated that persons with acuity loss did have bigger problems in low light conditions than their field-loss counterparts, or persons with a combination of acuity and field loss.
3. OBJECTIVES AND HYPOTHESES OF THE STUDY

The present study aims to analyse biomechanical characteristics of gait termination in healthy young and healthy elderly persons, and in people with type 2 diabetes affected by peripheral neuropathy. More specifically, the objectives of the study are:

1) To analyze differences in the width of the base of support during walking and the width of the base of support at gait termination between the young and the healthy elderly persons.

2) To determine the effect of age on some biomechanical variables related to gait termination. These biomechanical variables include foot placement, COP and COM maximal overshoots, and force related variables. They will be presented in detail in section 4.2.

3) To explore the impact of peripheral neuropathy, caused by type 2 diabetes, on some biomechanical variables related to gait termination.

4) To establish in each group and to compare between groups:

   4.1) The relationship between the COM velocity at HC1, HC2 and HC3 and the foot placement during gait termination (The terminology will be presented in detail in section 4.2, for a short definition please refer to the Glossary of gait termination specific terms, pages x to xi);

   4.2) The relationship between the COM velocity at HC1, HC2 and HC3 and the COP and COM maximal overshoots in the anterior/posterior and medio/lateral direction during gait termination.
Four hypotheses based on the knowledge presented in the literature review are formulated:

1) The difference between the base of support at gait termination and the base of support during walking will be larger in the healthy elderly people than in the healthy young people.

2) People with type 2 diabetes and peripheral neuropathy will show an increase in COP and COM overshoots in the A/P (anterior/posterior) direction, when compared with healthy elderly people.

3) In the healthy elderly group and in the group with type 2 diabetes, the A/P COM velocities at HC1, HC2 and HC3 will be related to:
   a) a larger foot placement,
   b) an increased COP overshoot in the A/P and M/L directions,
   c) an increased COM overshoot in the A/P and M/L directions.

4) In the young group, the A/P COM velocities at HC1, HC2 and HC3 will be related to the COP overshoot in the A/P direction only.
4. METHODOLOGY

The methodology chapter is subdivided into seven sections. First, the participants selection, their eligibility criteria, and recruitment procedure are presented. Next, the variables, the justification of their choice and their corresponding measurement instruments are described. The data collection procedure is presented in the third section followed by the statistical analyses section and the section dealing with the sample size. Finally, the methodology chapter terminates with the discussion of ethical considerations.

4.1. PARTICIPANTS

The population under study was composed of three groups each containing 15 participants: 1) healthy young people, 2) healthy elderly people and 3) elderly people with type 2 diabetes and peripheral neuropathy. Because of gender differences in gait, men and women were equally represented in the three groups, according to the following eligibility criteria.

4.1.1. Eligibility Criteria

Inclusion Criteria

Participants were accepted if they met the following inclusion criteria. All participants had to be able to walk unassisted. The young participants must be aged between 20 and 40 years. The healthy elderly people were included if they are aged between 60 and 75 years. The healthy elderly participants were aged,
gender, and BMI (Body Mass Index) matched with the persons affected with type 2 diabetes. The participants with type 2 diabetes were included only if they had been diagnosed with peripheral neuropathy. This criterion was verified by using the scoring system developed by Valk et al. (1992) for the diagnosis of diabetic polyneuropathy by clinical examination (Appendix 5). The Valk-Test is a clinical examination instrument and gives a global view over the neurological status (sensory and motor) of the lower extremities. The different nerve groups of the lumbo-sacral plexus and their particular functions are tested through the following seven elements: 1) Pin-prick sense and 2) light-touch sense applied with a cotton wool ball to test the low frequency sensory capacities of the patients. 3) Light-touch sense is further defined by the anatomical level at which the sensation still occurs. 4) High frequency sensory capacities of the ankle (vibration sense) are tested via a tuning fork. 5) The strength of the extensor muscle hallucis longus, 6) the strength of the gastrocnemius muscle and 7) the ankle jerk give an indication of the patients motor nerve capacities. Nerves that have their origins in the lower lumbal and earlier sacral region, innervate the muscles extensor hallucis longus and the gastrocnemius. The ankle jerk is a reflex of the gastrocnemius and the muscle soleus, the second biggest calf muscle.

The testing sites for the pin-prick and the light-touch sense were the dorsum of the foot. Together with the ankle vibration sense these elements are scored as: 0 points = no abnormalities, 2 points = impaired sensation in comparison with proximal sensation and 4 points = absent sensation. The anatomical level, where light-touch sensation is still detected, is scored the following way: 0 = no abnormalities, 1 = toe level, 2 = mid-foot level, 3 = ankle level, 4 = mid-calf level
and 5 = knee level. The strength of extensor hallucis longus and gastrocnemius muscles are scored on three levels: 0 = normal strength, 2 = impaired and 4 = no strength. Ankle jerks are also scored on three levels: 0 = normal reflex, 2 = impaired in comparison with other reflexes and 4 = no reflex at all. A total score of 0 was graded as no polyneuropathy, 1-9 as mild, 10-18 as moderate and above 19 scoring points as severe polyneuropathy. According to Valk et al. (1992), the score range for grades of severity have been determined on the clinical deficits that could be expected on the basis of daily clinical practice. Unfortunately, the authors did not define these clinical deficits based on daily clinical practice. However, the authors report results of neurophysiological measurements conducted on the same diabetic population of 78 participants on which the Valk-test was developed (Valk et al., 1992). The individual scores for the clinical examination (=Valk-test) and the neurophysiological examination were compared in all participants. The correlation was significant \((r=0.7; p<0.0005)\) indicating that a good agreement exists between the Valk-test and the neurophysiological outcomes.

The healthy elderly and the elderly persons with diabetes were screened for polyneuropathy according to this test by the study co-ordinator (M.M.).

**Exclusion Criteria**

The exclusion criteria are all factors that negatively influence gait and hence are also expected to negatively influence gait termination. The following criteria applied to the healthy young and the healthy elderly participants: they were excluded if they presented with musculo-skeletal or neurological defects, or any
cardiac diseases. An additional exclusion criterion for these two groups was the presence of diabetes mellitus type 1 or 2. For the healthy young participants, a short questionnaire ensured that they were free from diabetes. However, due to the high prevalence of undiagnosed diabetes in the elderly population (Tan et al., 1997), the absence of diabetes was tested via a laboratory analysed blood test. The elderly persons with diabetes were excluded if they presented with musculo-skeletal or neurological defects other than peripheral neuropathy, or any cardiac diseases. These criteria were verified by questions asked by the examiner when recruiting the participants (keywords mentioned in Annexe 5, Sociodemographic Data). In addition, for the group with type 2 diabetes, a further exclusion criterion was the presence of any foot ulceration. The examiner verified the foot health on the data collection day.

Furthermore, participants were excluded if their visual acuity was below 6/21 (metric) of the Snellen acuity chart, the threshold for low vision (Ministère des affaires sociales, 1982). This applies for the better eye and under corrected conditions.

4.1.2. Recruitment of the Participants

All participants were recruited from the population of the city of Sherbrooke, QC, Canada and its surrounding area.

They were recruited by a non-probabilistic strategy to minimise the study time scale and budget. The healthy young people, the healthy elderly people, and the people with type 2 diabetes were volunteers. It was taken into account that volunteers favour a study's topic or are at best neutral (Satin and Shastry, 1993).
The young people were recruited from students, employees, and researchers of the Centre de recherche en gérontologie et gériatrie (CRGG), Sherbrooke, QC, Canada. A short questionnaire ensured that they were free from diabetes. Should the questionnaire have lead to a positive result in any of the young participants, the person would have been referred to their family physician.

The elderly people were recruited from participants of previous studies carried out at the CRGG. Therefore, data regarding age, gender, height and weight were already available. The matching age range was ± 2 years with the preference for the elderly to be as close as possible to the diabetic pair. The Body Mass Index (BMI) of the potential participants was calculated before recruitment took place. Care was taken not to violate the standard BMI classification of normal, over-weight and obese. They were matched as close as possible with the corresponding diabetic pair. Preference was given to those potential participants whose BMI was closest to the BMI of the participant with diabetes. However, their final acceptance was made on the basis of a blood sample test (FPG – fasting plasma glucose - determination; normal range between 3.8-6.1 mmol/l, CMJA 1998). Again, should this test have lead to a positive result in one of the elderly people, i.e. values not falling in the normal range, this person would have been referred to their family physician.

Due to the collaboration of the Association des diabétiques de l'Estrie, Sherbrooke, and the physicians of the Groupe de recherche en diabétologie du Centre universitaire de santé de l'Estrie (CUSE), pavilion Fleurimont, Sherbrooke, the databases of the participants with diabetes were available. The members of the Association des diabétiques were contacted by a letter through the
association secretary. A preliminary screening of the interested members was done by phone. They were asked (by M.M.) about their diabetes-induced problems and if they presented with any of the typical symptoms of diabetic neuropathy such as numbness, tingling, burning and/or no real temperature sensation in their feet. If this was the case, the potential participant was invited for the clinical examination test according to Valk et al. (1992) and the vibration sensitivity threshold testing to verify the inclusion criteria. To ascertain whether the patients with diabetes of the CUSE met the inclusion criteria, the medical files of the potential participants were screened prior to their recruitment (by M.M.). To be eligible for the recruitment procedure, the medical files had to mention that the person had been, in the best case scenario, diagnosed with neuropathy, or that he or she had been diagnosed with nephropathy or retinopathy. As mentioned in the literature review, diabetic nephropathy or retinopathy are classified as microangiopathies, like diabetic neuropathy. Therefore, persons presenting with nephropathy and retinopathy are most likely to have neuropathic problems as well. Persons, who did not have a medical file at the CHUS, were placed aside. They were considered for screening only if not enough participants could be found among the persons with medical files. This was not the case. All participants with diabetes were recruited among persons with medical files at the CHUS and among persons who responded to the letter sent by the Association des diabétiques de l’Estrie.
4.2. VARIABLES, THEIR JUSTIFICATION AND THE RELATED MEASUREMENT INSTRUMENTS

The variables have been divided into three groups: 1) sociodemographic, 2) control and 3) biomechanical variables. The sociodemographic and anthropometric variables include participant age, height, weight, smoking status and activity level. The control variables are the vibration sensitivity threshold and the A/P COM velocity prior to gait termination. These are termed 'control variables' as it is considered that they will have an influence on the biomechanical variables.

Note: In the study's particular goal-orientated stopping task, the A/P COM velocity predominant is determining over the braking forces and not visa-versa. The following three points have to be considered: 1) The person is in motion when entering the Approach and Stopping Phases. 2) The target is fixed (stopping line) and its position is therefore known to the participant. 3) Because the target position is given, the distance from the participant to the target is also known. These three points, the walking velocity, the target position and hence the distance to reach it, have to be taken into account in order to develop appropriate braking forces. If these three points are not taken into account, the person will not be able to stop at the indicated stopping line. Therefore, the A/P COM velocity is classified as a 'control variable' with an influence on the braking forces.

The biomechanical variables are the foot placement (width and length), the COP and COM maximal overshoots in the A/P (anterior/posterior) and M/L (medio/lateral) directions during gait termination, and the force-related variables.
The force related variables include impulses, and maximal braking and propulsion forces during the Approach and Stopping Phases, and their timing.

These variables, their justification and their corresponding measurement instruments are described in the following sections.

4.2.1. Sociodemographic and Anthropometric Variables

In order to be able to address certain inclusion criteria and to give a global description of the participants, the following sociodemographic and anthropometric variables were chosen: age, gender, height, weight, the BMI (Body Mass Index), smoking status, self-estimated activity level and self-perceived health status.

Height was measured in centimetres using a stadio-meter. The participants were asked to take off their shoes. If they preferred to keep them on, the heel heights were subtracted from the measured height. The weight was measured in kilograms by a medical balance. For the weight determination, however, the participants were asked to wear their shoes, so that the same conditions as during the walking trials were maintained. As mentioned in the literature review, height and weight influence gait. Therefore, matching persons only by height would not take into account the influence of possible weight differences on gait. The same applies for matching persons only by their weight. The BMI (Body Mass Index) includes both, the weight and the height as it is equal to the weight divided by the height squared \((\text{BMI}=\text{kg/m}^2)\). This was the reason why the BMI was chosen to match the healthy elderly persons with the elderly persons affected with diabetes.
Smoking status was simply determined by ticking the appropriate box on the sociodemographic data sheet (Appendix 5). More detailed questions were not asked about the amount of consumed cigarettes for two reasons: First, it is generally known that drug consumption is often underreported to avoid stigmatisation. Therefore, to get accurate data a more detailed approach would be necessary, but this was beyond the scope of the present study. Second, Wiles et al. (1991) demonstrated that smoking was not a factor that influenced vibration sensitivity threshold. Their results are based on 1365 healthy volunteers aged between 8 to 91. It was therefore considered sufficient to class the participants into smokers and non-smokers only.

Self-estimated activity level and self-estimated health status were determined by a short questionnaire (Annexe 5). The questions evaluated self-perception of health status and activity level in relation with other persons of the same age. In order to verify the answer according to the activity level, detailed questions about the kind of activities and their frequencies were asked. For the self-perception of health status, the participants were asked questions about any history of medication, fractures, falls, joint problems or vertigo. The advantage of this 'in-house' questionnaire is its simplicity. It is quick, easy to handle and therefore time saving. However, an analysis of the asked self-perceived health status is not possible, because detailed questions regarding the different aspects which influence health are lacking. Furthermore, its validation is not assured and the answers therefore have to be interpreted with caution.
4.2.2. Control Variables

The Vibration Sensitivity Threshold

This variable is important for two reasons. First, the vibration sensitivity threshold is an indicator of peripheral neuropathy. It serves as an inclusion criteria for the elderly people with type 2 diabetes. Second, as discussed in the literature review, peripheral neuropathy has a significant influence on gait and posture. Hence, the vibration sensitivity threshold, as an indicator of peripheral neuropathy, is assumed to have an indirect influence (control) on the biomechanical variables.

The vibration sensitivity threshold is the most practical indicator for detecting peripheral neuropathy, but is not as accurate as nerve conduction velocity (Redmond et al., 1992). However, it is the first choice when non-invasive methods are used. A non-invasive determination of the peripheral neuropathy is given priority in this study for safety purposes. In addition, it is a method, which is easy to apply once the examiner is familiar with the instrument. These are the reasons why the vibration sensitivity threshold has been chosen to determine peripheral neuropathy.

To determine the vibration sensitivity threshold, the vibration sensitivity of the big toe on each foot was tested according to the method of limits (MOL). This method has a good test-retest reliability ($r = 0.81$) (Gerr et al., 1990).

The MOL relies on detecting the vibration sensitivity threshold by increasing and decreasing an applied vibration stimulus. The stimulus is applied at the dorsal part of the big toe, near the nail, which is one of the standard vibration test points on the foot (Bloom et al., 1984; Halar et al., 1987; Sosenko et al., 1989).
This location was chosen because it seems to be less affected by the possible presence of oedema than the malleoli or the dorsal part of the first metatarsal head. Three ascending and three descending trials are performed, taking the average as the threshold value. The tested person identifies this threshold as the minimal detectable amplitude of an applied vibration. The vibration is measured in microns and thereafter the age-corrected deviations from the mean (DfM) are calculated as indicated by the manufacturer, allowing intra-and inter-group comparison (For details, please refer to page 95).

Wilcoxon Signed Ranks tests are used to determine the difference between the vibration sensitivity thresholds of the right and left limb in each group. If there is no statistical difference between the limbs, the results are combined and used for all further statistical analyses.

The instrument used to test the vibration sensitivity threshold was the Vibrameter, Type IV, Somedic AB, Sweden. The calibration precision is ± 3% of the maximum scale reading, read in microns.

For an easier understanding of the following variables (the A/P COM velocities prior to gait termination and the biomechanical variables) a short summary of the gait termination data collection procedure is presented. For a detailed description, please refer to section 4.3.4. In order to be able to determine the COM, and hence its trajectory and velocity, special markers were placed on the participant (Figure 2, page 73). The participants were requested to walk along an indicated walk-way and to stop in front of the marked stop-line. The distance from the starting point and the first force plate was three metres (Figure 7, page
88) and roughly four meters to the stop-line. The markers placed on the body sent infra-red pulses, which were registered by the sensors of the OPTOTRAK system. The marker co-ordinates allow the COM and hence its trajectory to be calculated. The detailed calculations will be presented in the following paragraph. The A/P COM velocity and the biomechanical variables were chosen to analyse the procedure of terminating gait.

*The A/P COM Velocities Prior to Gait Termination*

The A/P COM velocity is calculated at heel contact one, two and three (HC1, HC2 and HC3), i.e. at the beginning of the Approach Phase (HC1), at the beginning of the Stopping Phase (HC2) and at the visual stop of the walking trial (HC3). The Approach Phase is defined as the step prior to gait termination. It starts from HC1 and ends with HC2. The Stopping Phase is defined as the phase at which full stop is reached. It starts with HC2 and ends when the A/P COM velocity is less than 0.05 m/s. Heel contact 1 (HC1) represents the start of the Approach Phase and the beginning of the first step considered for analyses. It is carried out with the ipsilateral limb. HC2 represents the end of the Approach Phase, the end of the first step and the start of the Stopping Phase and the start of the second step. HC1 to HC2 is executed with the contra-lateral limb. HC3 is the end of the second step and is therefore executed with the ipsilateral limb. HC3 is the event at which walking appears to stop.

As mentioned above, the A/P COM velocity is calculated at HC1, HC2 and HC3. The COM velocity at time t_i in the x direction (Vx_i), i.e. A/P direction, is derived from the displacement data according to the formula:
\[ V_{x_i} = \frac{(x_{i+1} - x_{i-1})}{2\Delta t} \]

where \( x_{i+1} \) and \( x_{i-1} \) are the COM positions at time \( t_{i+1} \) and \( t_{i-1} \), and \( \Delta t \) represents the time between samples. The three dimensional displacement data of the participants were recorded at 60 Hz with the OPTOTRAK-3020 optical system, Northern Digital Inc. This system consists of three towers each equipped with three sensors.

Figure 2. Marker Positions

Note: Markers and digitized points are for the right and left limb at the same position.
A = real markers: 1;2 = medial malleoli. 3,4 = knee joints. 5;6 = hight of trochanter major. 7;8 = acromii. 9;10 = big toes.
B = digitized markers: 1';5' = shoe tips; 2';6' = metatarsali V. 3';7' = lateral heels. 4';8' = posterior heels.
The sensors capture the infrared pulses from the IREDs (infrared light emitting diodes; referred to simply as ‘markers’ in the following text) which were placed at specific anatomical points on the participant’s body (Figure 2). Because the markers are turned on sequentially, the sensors are able to pick up the spatial co-ordinates (x-, y-, z-direction) of each activated marker. The result is a series of points, which give a temporal and spatial history of a segment’s movement. This information, combined with the anthropometric tables of Dempster (1955), makes it possible to calculate the location of the body’s total COM.

The body’s total COM is obtained by adding all the different segmental COMs together. The following formula is used:

\[
x = \frac{(m_1x_1 + m_2x_2 + \ldots + m_nx_n)}{(m_1 + m_2 + \ldots + m_n)}
\]

where \(x\) represents the unknown distance in the x-direction from the coordinate origin to the total body COM; \(m_1\) is the mass of the corresponding segment, and \(x_1\) is the distance in the x-direction from the origin of the segmental co-ordinates to the corresponding segmental COM. The location of the segmental COM is expressed as a percentage of the segmental length and is either located proximally or distally from the corresponding joint-centre. The segmental mass is expressed as a fraction of the total body mass \(m_b\) (\(m_b=m_1+m_2+\ldots+m_n\)).

Because \(m_1 = f_1m_b, m_2 = f_2m_b, \ldots m_n = f_nm_b\) the above formula is rewritten as

\[
x = \frac{(f_1m_bx_1 + f_2m_bx_2 + \ldots + f_nm_bx_n)}{m_b}
\]

which gives

\[
x = \frac{m_b(f_1x_1 + f_2x_2 + \ldots + f_nx_n)}{m_b}
\]
and reduces to \[ x = (f_1 x_1 + f_2 x_2 + \ldots + f_n x_n). \]

The distance \( x \) of the total body COM is calculated using the distances \((x_1, x_2, \ldots x_n)\) defined by the data of the OPTOTRAK system. Because the markers are placed on the articulation centres (Figure 2, page 73) the segmental length and hence \( x_1, x_2, \ldots x_n \) can be determined using the anthropometric tables compiled by Winter (1990). Note that the head, the upper extremities and the trunk form one segment. This segment is defined by the markers placed at the greater trochanter (Figure 2, marker 5 and 6) and by the markers placed at the acromii (Figure 2, markers 7 and 8).

As the results of Cao et al. (1998) demonstrate, elderly people have difficulty in executing sudden stops due to an insufficient decrease in walking speed. Based on these results and also on the fact that movement cannot exist without velocity, the A/P COM velocity has been chosen as a control variable. Because the highest speed occurs in the walking direction, i.e. in the A/P direction, the A/P COM velocity and not its M/L velocity is chosen.

The OPTOTRAK sensors, which were used to register the limb movements, have anamorphic lenses with a resolution of 1: 200 000 (~ 0.01 mm) and a precision to within 0.005%. The accuracy in the x-, y- direction (horizontal and vertical) is between 0.03 mm and 0.1 mm RMS according to the tower positioning. In the z-direction (depth), the RMS value of the accuracy lies between 0.15 mm and 0.45 mm and is also dependent on the tower positioning.
4.2.3 Biomechanical Variables

The biomechanical variables are the foot placement, the maximal COP and COM overshoot in the A/P and M/L directions and the force related variables.

The Foot Placement (base of support): Width and Length

The foot placement width is defined as the maximal M/L distance (cm), between the furthest lateral points of each foot (Figure 3A). The length is defined as the maximal A/P distance (cm), between the tip of the big toe and the contra-

![Figure 3. Definition of foot placement](image)

Width: maximal distance between the furthest lateral points of each foot (Example A: distance between points 1 and 2)
Length: distance between the tip of the big toe and the contrary heel (Example B: distance between points 3 and 4)

lateral heel as illustrated in Figure 3B. The width and length are determined at HC3, whereas the width of the walking base is determined during double support. The foot placement is calculated from the digitized points (1'-8') recorded during
calibration and the marker positions of markers 2, 4, 9, and 10 via a customized program (for details, please refer to chapter 4.4. Data Processing).

The foot placement variable is chosen based on the following consideration. There are two main strategies to enhance posture stability: enlargement of the base of support or lowering of the COM position (Allard and Blanchi, 1996). The latter is rarely the case under normal walking and stopping conditions. Therefore, it has been assumed that persons with diabetes, due to their disease-induced difficulties, will increase this foot placement. The instrument used to register the marker co-ordinates is the OPTOTRAK-system. Its characteristics are described in the section presenting the A/P COM velocity, page 73.

_The COP and COM Maximal Overshoots_

The COP and COM overshoots are determined once the participant has reached his or her final stop. The end of gait termination is defined as having a A/P COM velocity lower than 0.05 m/s (Cao et al., 1997). The COP and COM overshoots are calculated with a second customized program, which allows the identification of the overshoots visually. The overshoots of both the COP and COM trajectories in both directions are determined with respect to the motion area centre. This centre is visually defined. It represents the centre of the motion area that the COM and the COP describe during quiet standing after gait is terminated. As the participants were asked to stand still after they reached the final stop for at least 15 seconds, this motion area is well defined. The end of gait termination is defined by a A/P COM velocity lower than 0.05 m/s (Cao et al., 1997).
The COP and COM maximal overshoots in the A/P direction (Figure 4, distances $a$ and $b$ respectively) is measured to within ± 1 mm. The same applies for the COP and the COM maximal overshoots (Figure 4: distances $c$ and $d$ respectively) in the M/L direction. A custom designed software allows these distances to be calculated for the overshoots of each trajectory.

![Diagram]

Figure 4. The COP and COM maximal overshoots
A/P direction: $a$ = COP overshoot; $b$ = COM overshoot
M/L direction: $c$ = COP overshoot; $d$ = COM overshoot

The COP represents the point of application of the resultant of all ground reaction forces acting upon the foot. Assuming the co-ordinate origin is the force plate, the x-axis is positive in the walking direction (A/P), the z-axis is positive to the right and the y-axis is positive vertically, then the COP is calculated as described below. The force plate origin is located a known distance $y$ beneath the
surface of the force plate centre. The forces are considered to act on the foot and the moments are positive according to the left-hand-thumb rule. The COP, at a distance $x$ from the origin of the axis system, represents the point at which the sum of the moments of forces on the foot is zero. Therefore:

\[
\text{COP in the } x\text{-direction: } M_z + xF_y - zF_x = 0 \quad \text{which yields} \\
x = (yF_z - M_z)/F_y
\]

where $F_x$, $M_z$ and $F_y$ are measured by the force plate and the distance $y$ is a function of individual plates and varies with the surface finish applied to the plate in the laboratory, e.g. linoleum, carpet or rubber matting. The same applies for the COP position in the $z$-direction:

\[
\text{COP in the } z\text{-direction: } M_x + yF_z - zF_x = 0 \quad \text{which gives} \\
z = (M_x + yF_z)/F_y.
\]

Again, $M_x$, $F_y$, and $F_z$ are measured by the force plate and the distance $y$ represents the distance from the force plate surface centre to the origin.

As discussed in the literature review, the precise co-ordination of the COP and the COM is crucial in avoiding a fall. A stopping procedure is successful when a second step is avoided. This would be the case when the COM position is correctly identified and the appropriate COP positioning occurs. The measured overshoots are an indicator of defective co-ordination.

The COP in the A/P and M/L directions is measured during the Approach and Stopping Phases by two AMTI force plates, type OR6-5-1000. The sampling frequency was 60 Hz. The typical force sensitivity for these force plates ranges from 0.168 N to 0.664 N; their moment sensitivity ranges from 1.348 Nm to 2.588
Nm. The hystereses and the non-linearity of the forces are both within ± 0.4% of the maximal scale reading.

**Force-related Variables**

The force-related variables presented below are derived from force-plate data. Only forces applied during the stance phases of the different steps can be registered. Only the A/P forces involved during the Approach and Stopping Phases are considered. As the main movement of walking occurs in the A/P direction, the analyses in the A/P direction are given priority in this study. The force-related variables have been divided into two main sections according to the force profile. The first section covers the force-related variables that occur during the Approach Phase. The Approach Phase is defined as the step prior to gait termination. It starts at HC1 and ends with HC2.

The second section covers the force-related variables during the Stopping Phase. The Stopping Phase is defined as the phase in which full stop is reached. It starts with HC2 and ends when the A/P COM velocity is less than 0.05 m/s, the chosen definition for a stop.

**The Approach Phase**

The Approach Phase consists of initial braking, followed by propulsion, similar to that in normal steady state walking. For an easier understanding of the variable definitions, please refer to Figure 5, page 81.

The braking time is labelled t1. It starts from HC1 and finishes just as propulsion is starting. The maximal braking force during t1 occurs at t2. Hence, t2
represents the time taken until maximal braking force during the braking time is reached. The same principle applies for propulsion: t3 starts when the braking time ends and describes the total time taken for propulsion, i.e. ending with toe off; t4 is the time at which the maximal propulsion force is reached. The variables considered are the following ratios: the braking time of the approach stance phase in relation to the entire Approach Phase: \( t1/(t1+t3) \); the time taken to reach maximal braking force in relation to the approach stance braking time: \( t2/t1 \); the time taken to reach maximal braking force in relation to the entire Approach Phase: \( t2/(t1+t3) \); the time taken to reach maximal propulsion force in relation to the time until toe off: \( t4/t3 \), and the time taken to reach maximal propulsion force in relation to the entire Approach Phase: \( t4/(t1+t3) \). Therefore t1, t2, and t4 are expressed as a percentage of the Approach Phase (t1+t3). In addition, t2 and t4

![Diagram](image.png)

**Figure 5. Definitions of the approach phase's force-related variables**

- \( t1 \): braking time
- \( t2 \): time until maximal braking force is reached
- \( t3 \): propulsion time
- \( t4 \): time until maximal propulsion force is reached
- \( I1 \): braking impulse
- \( I2 \): propulsion impulse
- \( F1 \): maximal braking force
- \( F2 \): maximal propulsion force

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are also expressed as a percentage of the total braking (t1) and propulsion phase (t3) respectively.

The braking impulse variable is labelled as area /1 and represents all the braking or negative forces that occurred during the Approach Phase as a function of time. The propulsion impulse variable is called /2 and represents all the propulsion or positive forces that occur during the Approach Phase as a function of time. Impulses are normalized for the participant's mass and are expressed in units of Ns kg\(^{-1}\).

The maximal forces of either the braking or the propulsion forces are called F1 for the maximal braking force and F2 for the maximal propulsion force.

*The Stopping Phase*

The Stopping Phase is different from the Approach Phase as it consists solely of braking forces as shown in Figure 6, page 83. The time interval from HC2 to HC3 is termed t5. The time at which maximal braking force is reached during the Stopping Phase is labelled t6; t7 represents the time between HC3 and the point where the A/P COM velocity is below 0.05 m/s. The variables considered are the following ratios: t5/(t5+t7), t6/t5, and t6/(t5+t7). t5 and t6 are expressed as a percentage of the total Stopping Phase (t5+t7). In addition t6 is expressed in a percentage of the main braking phase t5. The first braking impulse variable of the Stopping Phase is labelled /3. It represents all the braking or negative forces that occur during the time between HC2 and HC3. The second braking impulse variable is called /4 and represents the total braking or the negative forces that
happen during the time between HC3 and full stop, i.e. the A/P COM velocity below 0.05 m/s.

The maximal braking force developed during t5 is termed F3. Because it is also weight-normalized, it is expressed as N/kg.

![Stopping Phase: A/P Forces of one male](image)

Figure 6. Definitions of the stopping phase's force related variables

- t5=braking time from HC2 to HC3  
- t6=time taken until maximal braking force is reached  
- t7=braking time from HC3 until A/P COM velocity is below 0.05 m/s  
- I3=braking impulse from HC2 to HC3  
- I4=braking impulse from HC3 until the A/P COM velocity is below 0.05 m/s  
- F3=maximal braking force during t5.

Force plate measurements normally include analyses of forces. The chosen force related variables describe the most important features of the force curves in the A/P direction. Maximal forces are an indicator of the magnitudes needed to terminate gait, whereas the impulses give a more detailed picture of how the forces have been developed. Impulse, by definition a change in momentum, may be created by a change of speed, a vector change of velocity or a change of
mass (Hannah and Hillier, 1988). Impulses are generally related to a change in velocity, as a change in mass does not normally occur. Hence, the braking (negative) and propulsion (positive) impulses during the approach phase are an indicator of how much the A/P COM velocity has changed.

HC3 was chosen to subdivide the Stopping Phase. At HC3, stopping has occurred visually because both feet are stationary and no further step is executed. Therefore, I4 gives an indication of how much a person brakes using both limbs and how long it takes (t7) to reach the defined stop of A/P COM velocity < 0.05 m/s.

Overall function of the body is measured by time variables, as stopping has to be executed in a certain time. A longer time needed to complete a task may indicate difficulties in the bodily system, especially when compared with age matched controls.
4.3. DATA COLLECTION PROCEDURE

This section is divided into four parts. The first parts cover the data collection procedure of the young participants, followed by the participants with diabetes and the healthy elderly persons. Finally, the gait termination data collection procedure is described, which is the same for all participants.

All participants signed a written consent form, in either English or French, prior to any data collection procedure (see 'Ethical Considerations'). Each participant received ten dollars to cover travel expenses. The data collection procedure lasted roughly two hours in total, breaks included.

4.3.1. Data Collection Procedure for the Young Participants

The data collection procedure started immediately with the gait termination session for the young participants. First, the participants were asked to fill in a questionnaire regarding their activity level and health status. At the same time, sociodemographic data (age, smoking and medication history) were collected, a reverification of the inclusion criteria conducted and the visual acuity determined. Participants were requested to wear their shorts and comfortable walking shoes.

After the gait termination data collection, (described in section 4.3.4.), the participant’s height and weight were measured. Thereafter, they were guided into a quiet room to test their vibration sensitivity threshold.
4.3.2. Data Collection Procedure for the Participants with Diabetes

In a preliminary session, the prospective participants with diabetes were tested for the presence of peripheral neuropathy using their vibration sensitivity threshold, to ascertain whether they meet the inclusion criteria. A person was considered as having a reduced vibration sensitivity when the measured value of at least one foot was more than two standard deviations above the mean of the norm population. The person was invited for the gait termination session on another day when they met the inclusion criteria.

Visual acuity and the participant’s height and weight were determined before the gait termination data collection (described in section 4.3.4.).

4.3.3. Data Collection Procedure for the Healthy Elderly Participants

In the healthy elderly group, the data collection procedure started with a fasting blood sample. In a preliminary session, the prospective participants were requested to present themselves with an empty stomach at the Centre de prélèvement at the Institut universitaire de gériatrie de Sherbrooke, pavilion D’Youville, Sherbrooke, QC, Canada, at 07:00. A fasting plasma glucose (FPG) analyses was performed. Persons whose result fell in the diabetic range were referred to their treating physician and were excluded from the study.

If the results obtained from the FPG-determination satisfied the inclusion criteria, the participants were invited another day for the gait termination session, described in the following paragraph. Visual acuity and the participant’s height and weight were determined before the gait termination data collection. After the
gait termination data collection, they were guided into a quiet room to test their vibration sensitivity threshold.

4.3.4. Gait Termination Data Collection Procedure

The data collection procedure for the gait termination was the same for all participants. Two evaluators, including the author, organized the gait termination session. The camera towers were positioned in such a way that their sensors registered the pulses of the placed markers optimally. The participants had 3 m to walk before one of their feet reached the first force platform. The experimental set-up is illustrated in Figure 7, on the following page. Both evaluators prepared the participant for the experiment: 10 markers were placed at specific anatomical points as illustrated in Figure 2, page 73. A familiarisation period proceeded the experiment to ensure that none of the marker adhesives impeded the participants' movement. During this period, the optimal starting position was determined to ascertain that the participant's feet landed properly onto the force plates. After the alignment of the reference axes and digitizing the additional points on the foot (Figure 2, page 73), the data acquisition was started.

The experiment itself consisted of at least eight trials in which the participants were simply asked to walk at a normal pace along the indicated walk-way and to stop in front of the marked stopping-line. To avoid the hip markers being hidden by the armswing, the participants were asked to hook their thumbs into the strober belt attachment. They were further requested to stay immobile after full stop was reached. This allowed the motion area of the COP and the COM during quiet standing to be determined. The end of each trial was indicated by one of the
evaluators. During data acquisition, one of the two evaluators operated the computer while the other walked behind the participant, holding the computer-subject connection cable for safety purposes.

![Diagram of laboratory setup](image)

*Figure 7 Laboratory overview and experimental set-up*

At least eight trials were performed so that the data analyses could be based on the five most representative trials (for a definition please see below). Trials in which the participant stepped on the edge of one of the force plates or if the same foot was not used to enter the Approach Phase were repeated. Additional trials were held if the participant had some problems keeping a constant walking speed or keeping the feet immobile at gait termination.

The five most representative trials were chosen according to the following criteria. For each participant, the COP and COM trajectories of all successfully
collected trials are processed by the customized program and thereafter visually analysed. Trials with similar COP and COM trajectories were grouped. According to the size of the groups, one or more trials were chosen from each of them until five trials were selected. These five trials were considered to be the most representative trials of the particular participants. For further details, please refer to chapter 4.4. Data Processing.
4.4. DATA PROCESSING

Each trial generated a vast amount of kinematic (OPTOTRAK) and kinetic data representing the marker positions as a function of time and the force plate response respectively. This data had to be extensively processed to extract the relevant information. This complex multi-step process can be divided into two main stages: computer manipulation of the data so that it could be visualized and the manual identification of the critical parameters from the graphics. Finally, statistical analyses of these and the socio-anthropometric data was performed. The data processing flowchart is shown in Figure 7a, page 91. Throughout the whole chapter, encircled numbers indicate the link with this diagram, to facilitate the readers understanding.

For the kinetic and the kinematic data, five different programs were used to perform the data processing: 1) OPTOFIX, a sub-routine of the OPTOTRAK program package; 2) a customized program "#1" that runs in MATLAB, allowing the calculation of the COP and COM overshoots, the A/P COM velocity and the impulses; 3) another customized program "#2" that runs in Norton Commander, Version 1, for the calculation of the width and the maximal M/L distance of the walking base; 4) Notespad, a text-editing program needed to prepare EXCEL files for the Norton Commander program; and 5) MS EXCEL for all complementary calculations.
Figure 7a. Processing Flowchart
For each trial, a kinematic (OPTOTRAK) and a kinetic (force platform) data set was collected. The kinematic data were initialized ¹, and than combined with the kinetic data ²-⁶. The normalization process ⁷-⁹ and the calculation of the width during walking and at gait termination ¹⁰-¹² are presented below. These processed data could then be statistically treated with the SPSS program ¹³.

Each marker (IRED) trajectory (kinematic data) of all successful trials of a participant was analysed first by OPTOFIX, a sub-routine of the OPTOTRAK program package ¹. IRED co-ordinates that were undetermined were recovered by interpolating over the missing section using manual curve fitting. The high-resolution display allowed an accurate curve fitting of the affected IREDS in the x, y and z directions. After recovery of the marker co-ordinates, the data were transformed from binary to ASCII format.

These ASCII format files were then combined with the corresponding kinetic data in the customized program "#1" ². This program allows visualization of the COP and COM trajectories during the Approach and the Stopping Phases, and calculates the A/P COM velocity, the COP and COM overshoots and the associated impulses. Each kinematic file and its corresponding kinetic file had to be processed twice. During the first iteration ², specific output files were produced which where used for the second iteration ³.

The aim of the first iteration was to obtain the A/P-COM velocity output file and to visualize the COP and COM trajectories during the Approach and the Stopping Phases. Visualisation of the COP and COM trajectories was necessary for the selection of the participant's five most representative walking trials. During
this first iteration, all successful walking trials of a participant were processed. Walking trials with similar COP and COM trajectories were grouped. According to the size of these groups, one or more trials were chosen until the five trials necessary for the final analyses were selected.

Next, the corresponding A/P COM velocity output files were analysed. The frame at which the A/P COM velocity reached a value below 0.05 m/s was identified and artefacts removed. The artefacts especially occurred at the beginning of each trial due to the starting position of the participants. The starting line of the walking path was located at the peripheries of the camera registration fields and therefore the IREDs were difficult to detect (Figure 7, page 88). The closer the participant was to the sensors, the better the registration of the IREDs. Therefore, missing data were less likely to occur at the end of a trial.

A preliminary data processing iteration determined HC3. In each of the five chosen ASCII files of the kinematic data, the A/P co-ordinates of the malleoli IREDs (Figure 2, page 73, marker 1 or 2 according to the participant's braking limb) were visually analysed. HC3 was defined as the frame at which the malleolus IRED was stationary in the A/P direction, minus 1 cm. The correction factor of 1 cm corresponds to the A/P displacement of the malleolus IRED after HC3.

Once HC3 was determined, the force plate data could then be processed. The raw data of the force plate responses were converted from plate response (V) into force (N) using the manufacturer recommended formulas from the corresponding force plate manuals:
Force plate #1: A/P forces: Force (N)=Response (V)/(0.000001×0.657×10×4000)
Force plate #2: A/P forces: Force (N)=Response (V)/(0.000001×0.664×10×4000)

Thereafter, HC1, TO and HC2 were determined by visually analysing the converted force plate files. The critical events of the five walking trials are now identified (HC1, TO, HC2, HC3 and A/P COM<0.05 m/s) and hence the second iteration could be started . During this second iteration, the COP and COM overshoots and the impulses were calculated. The final calculation of the averaged data was performed in EXCEL®. Finally, this mean was entered into the statistical program SPSS®.

The main processing of the data was now complete. But further refinements such as normalization were required. First, the force plate data were time normalized so that HC1 and TO, which are the stance phase of the Approach Phase, totalled 100%. The entire Stopping Phase was also normalized to 100% (3-point-rubber banding using Matlab). The Stopping Phase normalization was different for each group. For example, the first part of the Stopping Phase (HC2 to HC3) in the young group was normalized to 49%, the second part (HC3 to A/P COM velocity<0.05 m/s) to 51%, totalling 100%.

Once these data were time normalized, the values were weight normalized. The values, expressed in Newtons were divided by the participant's weight allowing the maximum A/P forces to be determined . The weight and time normalized values allow comparisons between participants.

The force related variables were calculated in an EXCEL spreadsheet. The event specific frame numbers determined in the force plate data files were
transformed into seconds and correlated with the corresponding phases. For the
definition of these phases and a detailed explanation, please refer to section
4.2.2. The results of the force related variables were entered into the spreadsheet
of SPSS.

The A/P COM velocity was also time normalized (3-point rubber banding
using Matlab). This normalization was different for each of the groups. For
example, the Approach Phase (HC1 to HC2) in the young group was normalized
to 35% and the Stopping Phase (HC2 to A/P COM velocity<0.05 m/s) to 65%,
totalling 100%.

To measure the base of support, point co-ordinates additional to the IRED co-
ordinates were determined around the foot circumferences before the trials. Since
these points were relative to the IRED co-ordinates, the base of support could be
reconstructed during walking and at gait termination. The customized program
"#2" reconstructed the base of support during walking and at gait termination. The
customized program #2 also needed file initialisation in order for the program to
function correctly. The walking trials (kinematic data) were first prepared in
EXCEL: Only the marker co-ordinates of the feet, i.e. marker 1, 2, 9 and 10
(Figure 2, page 73) and the corresponding frame numbers were considered, the
other co-ordinates were deleted because this data was not necessary for the
determination of the width. The resulting new file was edited in Notepad to
eliminate all EXCEL created column tabs so that the program Norton Commander
could recognise the file. The width at gait termination and the maximal M/L
distance of the base of support during walking were then calculated and the
results saved in an output file. The mean of each participant was calculated \(^\circ\) and the results entered into the statistical program SPSS \(^\circ\).

The vibration sensitivity thresholds had to be age-corrected \(^\circ\). This correction was necessary to allow inter-group comparisons because nerve conduction velocity declines with age. Hence, comparing the expected higher amplitude measured in an elderly person with the results of a younger person does not necessarily mean that the elderly show a pathological value. Therefore, to determine if the measured amplitude corresponds to a non-pathological value, age has to be taken into account. The age-dependent regression equation given by the manufacturer is:

\[
\text{Age-corrected deviation from the mean (DfM)} = \left( \log(VT) - b \times \text{Age} - a \right) / s
\]

where VT represents the amplitude of the vibration sensitivity threshold measured in microns, \(a\) represents the logarithm of VT at Age=0 (intercept), \(b\) equals the coefficient of relation between Age and the log(VT), and \(s\) represents the standard deviation around the normal regression line. The corresponding values are: \(a=-1.204, \ b=0.026\) and \(s=0.344\). This indicates how the measured value stands in relation with the normal population on which the regression equation is based. The age-corrected standard deviations were then entered into SPSS \(^\circ\) for further statistical analyses.

The data processing terminates with the entering of the socio-and anthropometric data \(^\circ\) into SPSS \(^\circ\).
4.5. Statistical Analyses

All statistical analyses are performed using the statistics package SPSS for Windows, Standard Version 8.0 of SPSS Inc., 444 North Michigan Avenue, Chicago, IL 60611, USA.

First, the sociodemographic and anthropometric characteristics of the participants are described for each group using the mean and standard deviation for continuous and normally distributed variables. If the variables show an asymmetric distribution, the median and the semi-interquartile are stated. For categorical variables, frequency and percentage are reported.

To test the overall characteristics of the continuous variables, Kruskal-Wallis tests, the non-parametric equivalent to an ANOVA simple regression, are performed. When one of the variables reach significance, two-by-two tests are executed to identify the inter-group differences. The tests chosen to perform this identification are again determined by the distribution characteristics of the variables. They also depend on whether inter-group differences are tested between independent or paired groups.

Wilcoxon Signed Ranks tests are used to determine the difference between the vibration sensitivity thresholds of the right and left limb in each group. If there is no statistical difference between the limbs, the results are combined and used for all further statistical analyses.

Multiple significance testing gives a higher probability of finding a significant difference just by chance. Each test has a 5% probability of a false positive result,
i.e. to reject \( H_0 \) when in reality \( H_0 \) is true (a Type 1 error). Performing two-by-two tests in the three groups increases the probability of at least one false positive result. The more groups involved the greater the chance to falsely reject \( H_0 \). One of the methods proposed to control this problem is the Bonferroni method: the significance level of 0.05 is divided by the number of two-by-two tests, which have to be performed to identify inter-groups differences. In the present study this method is used, leading to a significance level of 0.016 (\( =0.05/3 \)).

To determine the age effect on the biomechanical variables (objectives 1 and 2), the COP and COM maximal overshoots in A/P and M/L directions and the foot placement (width and length) are compared between the young and the two groups. To test these comparisons, two-tailed t-tests for independent groups are used if the data are normally distributed. In the case of an asymmetrical distribution, the rank sum test (Mann-Whitney) is used.

To analyse the impact of neuropathy (objective 3), the vibration sensitivity threshold and the COP and COM maximal overshoots in the A/P and M/L directions are first related to each other by calculating the Spearman correlation coefficient. Secondly, the COP and COM maximal overshoots in the healthy elderly group are compared with the corresponding maximal overshoots in the group with diabetes. In addition, the width and the length are compared between the elderly participants and participants with diabetes. The results of both groups are also compared with the young group, which serves as the control. To verify differences in these variables between the healthy elderly people and the people with diabetes, a paired t-test is used in the case of a normal data distribution. Otherwise, the Wilcoxon signed ranks test is used.
To test objective 4, i.e. the relationship between the control variables (COM velocities prior to gait termination and the vibration sensitivity threshold) and the biomechanical variables (foot placement during gait termination, the COP and COM maximal overshoots and the force related variables) for each group, the Pearson correlation coefficient is determined for normally distributed data. Otherwise, the Spearman correlation coefficient is calculated.

All data showed an asymmetrical distribution with unequal variances, which could not be corrected by statistical transformation. Therefore, non-parametric tests have been used throughout, i.e. Kruskal-Wallis, $\chi^2$ (Chi squared) and Spearman's rho ($\rho$).
4.6. SAMPLE SIZE

Objectives 1 and 2: Assuming standardised differences of 1.0, with a two-tailed type 1 error $\alpha$ of 0.05 and a power of 0.75, the sample size of 15 participants per group is required for a total of 45 people.

With this sample size, only large differences between the groups can be detected, which might be clinically more relevant. Large differences are expected and this not only between the young and the elderly persons. Significant differences are reported in postural sway and in walking when people with diabetes were compared with age-matched people without diabetes (Boucher et al., 1995; Courtemanche et al., 1996). As gait termination represents a transitional task, i.e. from dynamic to quasi-static, the combined effect of peripheral neuropathy and age is expected to be even more pronounced. On the other hand, small differences are not detectable with the chosen statistical power.

Objective 3 is the analysis of the differences in paired sample groups. Assuming the same number of participants per group as for objectives 1 and 2 (15 persons) and holding the standardised difference at 1.0, a two-sided type 1 error $\alpha$ at 0.05 gives a statistical power of 0.95. Holding the power at 0.75 as in objectives 1 and 2, together with a two-sided type 1 error $\alpha$ at 0.05 gives a standardised difference of 0.75. Thus, smaller changes will be detectable, reaching a statistically significant difference more quickly.

Objective 4: Objective 4 correlates the controlled variables and the biomechanical variables for each of the three groups. With the chosen sample
size of 15 participants per group, a two-sided type 1 error $\alpha$ at 0.05 and a power of 0.75 will result in a correlation coefficient significance level of 0.65. Any correlation coefficient below this value is not considered significant.
4.7. Ethical Considerations

The first contact with the young participants was an official letter to avoid pressuring the participants. All participants gave their written consent in either English or French. In the case of an elderly participant's blood glucose level not falling within normal parameters (3.8-6.1 mmol/l), the person would have been recommended to see her/his family physician.

There was a minimal risk associated with taking part in this study. A possible tiredness caused by the duration of the test should have disappeared on the same day. The adhesives used to fix the markers were anti-allergic and one-way stickers. Despite this fact, they may have caused a light temporal irritation on the skin.

All information, medical or other, recorded in the course of this study was treated with the utmost confidentiality and was not made accessible to anyone not associated with this project. The participants' names were coded. The results were used solely for scientific and professional publications with rigorous respect for anonymity.

This project has been approved by the Comité d'éthique de la recherche de l'Institut universitaire de gériatrie de Sherbrooke, Sherbrooke, QC, Canada.
5. RESULTS

This chapter is divided into two main parts. The first part covers the sociodemographic and anthropometric characteristics of the participants, followed by the presentation of the control and biomechanical variables. Thereafter, in the second main part, the hypotheses will be confirmed or rejected.

Throughout the whole chapter only the group abbreviations will be used, i.e. 'Young' for the healthy young participants, 'Elderly' for the healthy elderly participants and 'Diabetics' for the elderly participants affected with type 2 diabetes and peripheral neuropathy.

In the presented tables, only the overall p-value of the $\chi^2$-test (chi-squared-test) or the Kruskal-Wallis analyses are stated. If significance is reached then, where applicable, the results of the two-by-two tests are presented in the paragraph of the corresponding variable.

For statistical reasons, i.e. asymmetrical distribution of the data, the results presented in the tables state the median and the semi-interquartile range. However, for the graphical representation of the results, the mean and the standard deviations are plotted, because such a representation is standard in biomechanical research.
5.1. Sociodemographic and Anthropometric Characteristics of the Participants

There was no participant in either the Young or the Elderly group who showed glucose levels above normal values. All Diabetics were affected by peripheral neuropathy, ranging from a mild (3 scoring points according to the Valk test) to a severe (23 scoring points) graduation level, with 'moderate' as a mean level (10.67 scoring points) (Table 2a). The vision acuity of all participants corresponded to the inclusion criteria, i.e. vision acuity not below 6/21 on the Snellen acuity chart. More specifically, the results of the visual acuity evaluation was as follows: Young: 6/6 (median; semi-interquartile range: 1.5), Elderly: 6/7.5 (median; semi-interquartile range: 3.0), and Diabetics: 6/9 (median; semi-interquartile range: 2.2).

The sociodemographic and anthropometric characteristics are summarized in Table 2 on page 106.
5.1.1. Continuous Variables

Age

As expected the median age of the Young was significantly different (p<0.001) from the median age of the Elderly and the Diabetics. The Elderly were age matched with the Diabetics. Therefore, no differences were expected between the two groups (p=0.875).

Height

The Young were significantly taller than the Elderly (p=0.002) and the Diabetics (p=0.01). However, there was no statistical height difference between the Elderly and the Diabetics (p=0.712).

Weight

There were no significant weight differences between the three groups. Nevertheless, the Young was the group that showed the lowest value combined with the biggest variability, which might cause the non-significant results obtained.

Body Mass Index (BMI)

The BMI value of the Young was significantly different from the one found in the Elderly and the Diabetics (p-values<0.001). No statistical differences (p=0.733) were found between the Elderly and the Diabetics since the Elderly were matched with the Diabetics on this variable too.
5.1.2. Categorical Variables

**Gender**

All three groups were composed equally of women and men. In addition, the Elderly were gender matched with the Diabetics.

Table 2. *Sociodemographic and anthropometric data of the participants*

<table>
<thead>
<tr>
<th>Sociodemographic and Anthropometric Data</th>
<th>*Group (n=15)</th>
<th>Young</th>
<th>Elderly</th>
<th>Diabetics</th>
<th><strong>p-value</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Continuous Variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>28‡</td>
<td>67</td>
<td>66</td>
<td>(7)</td>
<td>(2)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.70</td>
<td>1.63</td>
<td>1.63</td>
<td>(0.010)</td>
<td>(0.005)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>68.40</td>
<td>80.00</td>
<td>76.60</td>
<td>(12.10)</td>
<td>(9.70)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>25.21</td>
<td>30.65</td>
<td>30.17</td>
<td>(3.17)</td>
<td>(3.37)</td>
</tr>
<tr>
<td><strong>Categorical Variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td>7 (46.7)‡</td>
<td>7 (46.7)</td>
<td>7 (46.7)</td>
<td></td>
<td>1.000</td>
</tr>
<tr>
<td>Men</td>
<td>8 (53.3)</td>
<td>8 (53.3)</td>
<td>8 (53.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoking status</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non</td>
<td>13 (86.7)</td>
<td>14 (93.3)</td>
<td>11 (73.3)</td>
<td></td>
<td>0.314</td>
</tr>
<tr>
<td>Smoker</td>
<td>2 (13.3)</td>
<td>1 (6.7)</td>
<td>4 (26.7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-estimated activity level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Very Active</td>
<td>3 (20.0)</td>
<td>7 (46.7)</td>
<td>2 (13.3)</td>
<td></td>
<td>0.075</td>
</tr>
<tr>
<td>3. Active</td>
<td>8 (53.3)</td>
<td>5 (33.3)</td>
<td>6 (40.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Slightly Active</td>
<td>2 (13.3)</td>
<td>3 (20.0)</td>
<td>4 (26.7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Sedentary</td>
<td>2 (13.3)</td>
<td>0</td>
<td>3 (20.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-perceived health status</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Excellent</td>
<td>6 (40.0)</td>
<td>7 (46.7)</td>
<td>1 (6.7)</td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>3. Good</td>
<td>7 (46.7)</td>
<td>8 (53.3)</td>
<td>4 (26.7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Fair</td>
<td>2 (13.3)</td>
<td>0</td>
<td>6 (40.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Poor</td>
<td>0</td>
<td>0</td>
<td>4 (26.7)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Group abbreviations: Young = Healthy young participants, Elderly = Healthy elderly participants, Diabetics = Elderly type 2 diabetic participants affected by peripheral neuropathy.

**p-value associated with Kruskal-Wallis and χ² (chi-squared)**

‡Continuous Variables: Median (± semi-interquartile range)

Categorical Variables: Frequencies (percentage)
**Smoking Status**

There was no significant difference between the three groups regarding smoking status. In all three groups non-smokers were in the majority. Only in the Diabetics group were more smokers present, but they were not sufficient in number to be significantly different.

**Self-estimated Activity Level**

No statistical differences in the self-estimated activity level between the groups were found. However, there was a clear tendency that the Diabetics considered themselves less active than the Elderly.

**Self-perceived Health Status**

The differences in the self-perceived health status were significant between the Elderly and the Diabetics (p=0.003) and between the Diabetics and the Young (p=0.002). However, between the Elderly and the Young no significant difference was found.

To sum up, the participants sociodemographic characteristics reveal that the Elderly and the Diabetics were similar in age, smoking state, weight, height and BMI. They were equal in their gender distribution and self-perceived activity level, but significantly different in their self-perceived health status.

Comparing the Young with the Elderly and the Diabetics showed that the Young were similar in smoking state, weight, and activity level. They were significantly different in their health status compared to the Diabetics, but were
similar when compared to the Elderly. The Young were also significantly different from the Elderly and the Diabetics when comparing their height, BMI and, of course, their age. The Young were equally gender distributed just as the Elderly and the Diabetics were.
5.2. CONTROL VARIABLES

5.2.1. A/P COM Velocity

The A/P COM velocities were different at all three events (HC1, HC2 and HC3) and in all three groups (Table 3). The Young and the Elderly A/P COM velocities were different at HC1 (p=0.001), at HC2 (p=0.004) and at HC3 (p=0.009). The A/P COM velocities were also significantly different between the Young and the Diabetics at all three events (HC1 and HC2: p<0.001; HC3: p=0.004).

Table 3. Control Variables

<table>
<thead>
<tr>
<th>Control Variables</th>
<th>*Group (n=15)</th>
<th>Young</th>
<th>Elderly</th>
<th>Diabetics</th>
<th>**p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Group abbreviations: Young = Healthy young participants  Elderly = Healthy elderly participants Diabetics = Elderly type 2 diabetic participants affected by peripheral neuropathy  **p-value associated with Kruskal-Wallis  $^5$Median (± semi-interquartile range)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A/P COM Velocity (m/s) at</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC1</td>
<td>1.48  $^5$</td>
<td>1.13</td>
<td>0.75</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.19)</td>
<td>(0.18)</td>
<td>(0.16)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC2</td>
<td>1.11</td>
<td>0.80</td>
<td>0.61</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.18)</td>
<td>(0.14)</td>
<td>(0.11)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC3</td>
<td>0.33</td>
<td>0.28</td>
<td>0.29</td>
<td>0.007</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.01)</td>
<td>(0.02)</td>
<td>(0.01)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vibration Sensitivity Threshold (DfM)</td>
<td>0.37</td>
<td>-0.97</td>
<td>2.90</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.41)</td>
<td>(1.42)</td>
<td>(0.66)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The difference in the Elderly and the Diabetics A/P COM velocities at HC1 and HC2 were significant as well (p=0.002, respectively p=0.015). However, there was no statistical difference at HC3 (p=0.414). For the A/P COM velocity profiles
of each group, please refer to Figures 8a to 8c. Figure 8d shows the combined A/P COM velocity profile of all three groups, allowing an easier comparison. This figure illustrates very clearly the different A/P COM velocities of all participants during the Approach and the Stopping Phases. Group differences were most pronounced during the Approach Phase, but diminishes rapidly thereafter and became negligible at an A/P COM velocity of 0.4 m/s.

5.2.2. Vibration Sensitivity Threshold

The results presented in Table 3 are based on the age-corrected deviation from the mean (DfM) of the norm population. These deviations relate the results obtained from the present study with the data of the norm population. The sensitivity of the Young was within 0.37 DfM of the mean value of the corresponding norm population. The negative DfM obtained in the Elderly indicates that this group had a lower sensitivity threshold than the mean of the corresponding norm population. The same applies for the Diabetics. Their sensitivity threshold was with 2.90 DfM above the norm population mean value indicating that their sensitivity was drastically reduced.

Statistical differences in the vibration sensitivity threshold were found between all three groups. The difference between the Young and the Elderly was smallest (p=0.013), whereas the differences between the Elderly and the Diabetics and between the Diabetics and the Young were the same (p=0.001).
Figure 8a. \textit{A/P COM velocity profile during the Approach and Stopping Phases: Young}

Figure 8b. \textit{A/P COM velocity profile during the Approach and Stopping Phases: Elderly}
A/P-COM Velocity of the Elderly Diabetic Participants' Approach and Stopping Phase (n=15)

(Appl. Phase. (HC1 to HC2) = 37%; Stop. Phase (HC2 to COM<0.05m/s) = 63%)

Figure 8c. A/P COM velocity profile during the Approach and Stopping Phases: Diabetics

A/P COM Velocity Profile of the Approach and Stopping Phase (all three groups)

Figure 8d. A/P COM velocity profile of all three groups during the Approach and Stopping Phases
To sum up, the A/P COM velocity was significantly different at HC1 and HC2 between all three groups. However, at HC3 it was non-significant only between the Elderly and the Diabetics.

As expected, differences in the vibration sensitivity threshold were significant between the Elderly and the Diabetics and also between the Diabetics and the Young. Unexpected however was the significant difference found between the Elderly and the Young. The results demonstrated that the Elderly showed a lower sensitivity threshold when age corrected compared with the Young.
5.3. BIOMECHANICAL VARIABLES

The results of the biomechanical variables are presented in Tables 4a to 4c. The corresponding figures are Figures 9a to 9c for the Approach Phase and Figures 10a to 10c for the Stopping Phase.

5.3.1. Foot Placement

No statistical differences between all three groups were found in the width or length of their foot placement (Table 4a).

5.3.2. COP and COM Maximal Overshoots

A/P COP Overshoot

There was no significant difference in the A/P COP overshoots between the Young and the Elderly (p=0.056) and the Elderly and the Diabetics (p=0.027). However, the difference reached the significance level when comparing the Diabetics with the Young (p<0.001) (Table 4a).

M/L COP Overshoot

Significant differences were found in the M/L COP overshoots between the Young and the Elderly (p=0.011) and the Diabetics and Young (p<0.001). Again, there was no significant difference between the Elderly and the Diabetics (p=0.029).
Table 4a. Biomechanical Variables

<table>
<thead>
<tr>
<th>Biomechanical Variables</th>
<th>Young</th>
<th>Elderly</th>
<th>Diabetics</th>
<th>**p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Group (n=15)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Foot Placement (cm)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width</td>
<td>30.27$</td>
<td>26.62</td>
<td>26.08</td>
<td>0.503</td>
</tr>
<tr>
<td></td>
<td>(4.35)</td>
<td>(2.57)</td>
<td>(3.93)</td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>29.69</td>
<td>29.88</td>
<td>29.49</td>
<td>0.978</td>
</tr>
<tr>
<td></td>
<td>(2.38)</td>
<td>(1.68)</td>
<td>(2.05)</td>
<td></td>
</tr>
<tr>
<td><strong>COP and COM Maximal Overshoots (cm)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A/P COP Overshoot</td>
<td>1.87</td>
<td>3.02</td>
<td>3.11</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>(0.40)</td>
<td>(0.68)</td>
<td>(0.62)</td>
<td></td>
</tr>
<tr>
<td>M/L COP Overshoot</td>
<td>1.53</td>
<td>2.55</td>
<td>3.14</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>(0.48)</td>
<td>(0.64)</td>
<td>(1.45)</td>
<td></td>
</tr>
<tr>
<td>A/P COM Overshoot</td>
<td>1.03</td>
<td>1.38</td>
<td>1.59</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>(0.24)</td>
<td>(0.41)</td>
<td>(0.46)</td>
<td></td>
</tr>
<tr>
<td>M/L COM Overshoot</td>
<td>0.79</td>
<td>1.49</td>
<td>1.69</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>(0.19)</td>
<td>(0.39)</td>
<td>(0.50)</td>
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</tr>
</tbody>
</table>

*Group abbreviations: Young = Healthy young participants  Elderly = Healthy elderly participants  Diabetics = Elderly type 2 diabetic participants affected by peripheral neuropathy  **p-value associated with Kruskal-Wallis  \$ Median (± semi-interquartile range)

**A/P COM Overshoot**

No significant differences were found in the A/P COM overshoots between the Elderly and the Diabetics (p=0.083). However, the differences reached significance between the Young and the Elderly (p=0.004) and between the Young and the Diabetics (p<0.001).

**M/L COM Overshoot**

Significant differences were found between the Elderly and the Young and between the Diabetics and the Young (p-values<0.001). Again, no statistical difference was found between the Elderly and the Diabetics (p=0.256).
To summarize, all three groups placed their feet in a similar manner, i.e. neither age nor the tested pathological fact seem to have an influence on the foot placement during stopping. No difference in the analysed COP and COM overshoots in either directions were found between the Elderly and the Diabetics. However, the difference approached the significance level of 0.016. Between the Young and the Elderly and the Diabetics and the Young the COP and the COM overshoots were significantly different in all directions except in one. This exception was a non-significant difference in the A/P COP overshoots between the Elderly and the Young.

5.3.3. Force-related Variables

The Approach Phase (Table 4b)

Time Ratios

There was a significant difference in t1/(t1+t3) between the Elderly and the Diabetics (p=0.004) and between the Young and the Diabetics (p<0.001) but not between the Young and the Elderly (p=0.106).

A significant difference was also found in the t2/t1 ratios between the Elderly and the Diabetics (p=0.002) and between the Young and the Diabetics (p=0.004). There was no significant difference in the t2/t1 ratio between the Young and the Elderly (p=0.325).

However, the t2/(t1+t3) values were not significantly different between the Elderly and the Diabetics (p=0.023) or the Young and the Elderly (p=0.935). Only a comparison between the Young and the Diabetics showed a significant difference (p=0.004).
During the propulsion time, no significant differences were found in t4/t3 and t4/(t1+t3) between all three groups.

Table 4b. Biomechanical Variables

<table>
<thead>
<tr>
<th>Biomechanical Variables</th>
<th>*Group (n=15)</th>
<th>Young</th>
<th>Elderly</th>
<th>Diabetics</th>
<th>**p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force-related Variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approach Phase</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t1/(t1+t3) (%)</td>
<td>62$</td>
<td>60</td>
<td>56</td>
<td>$&lt;0.001$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(4.5)</td>
<td>(3.5)</td>
<td>(4.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t2/t1 (%)</td>
<td>29</td>
<td>32</td>
<td>42</td>
<td>$&lt;0.001$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2)</td>
<td>(4.5)</td>
<td>(6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t2/(t1+t3) (%)</td>
<td>18</td>
<td>19</td>
<td>22</td>
<td>0.013</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t4/t3 (%)</td>
<td>51</td>
<td>54</td>
<td>54</td>
<td>0.654</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(8.5)</td>
<td>(3)</td>
<td>(3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t4/(t1+t3) (%)</td>
<td>83</td>
<td>83</td>
<td>81</td>
<td>0.103</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2)</td>
<td>(1.5)</td>
<td>(3.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>l1 (Nskg$^{-1}$)</td>
<td>-0.49</td>
<td>-0.42</td>
<td>-0.33</td>
<td>$&lt;0.001$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.04)</td>
<td>(0.05)</td>
<td>(0.06)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>l2 (Nskg$^{-1}$)</td>
<td>0.11</td>
<td>0.13</td>
<td>0.17</td>
<td>0.096</td>
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</tr>
<tr>
<td></td>
<td>(0.05)</td>
<td>(0.02)</td>
<td>(0.04)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1 (N/kg)</td>
<td>-1.91</td>
<td>-1.59</td>
<td>-0.98</td>
<td>$&lt;0.001$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.37)</td>
<td>(0.23)</td>
<td>(0.28)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F2 (N/kg)</td>
<td>0.83</td>
<td>0.76</td>
<td>0.68</td>
<td>0.291</td>
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</tr>
<tr>
<td></td>
<td>(0.39)</td>
<td>(0.21)</td>
<td>(0.09)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Group abbreviations: Young = Healthy young participants  Elderly = Healthy elderly participants  Diabetics = Elderly type 2 diabetic participants affected by peripheral neuropathy  **p-value associated with Kruskal-Wallis  $ Median (± semi-interquartile range)

Impulses

Between the Elderly and the Diabetics and between the Young and the Diabetics, l1 was significantly different ($p=0.005$, $p<0.001$ respectively). There was no significant difference between the Elderly and the Young ($p=0.033$).

l2 was non-significant between all three groups.
Maximal Forces

There are significant differences in F1 between all three groups (Table 4b). The difference between the Young and the Elderly is significant at p=0.006, between the Elderly and the Diabetics at p=0.011 and between the Young and the Diabetics at p<0.001 (refer also to Figures 9a to 9c).

![Graph: A/P Forces of the Young Approach Phase](image)

Figure 9a. Approach Phase: A/P forces of the Young

F2 was not significantly different between the Young and the Diabetics (p=0.142), between the Young and the Elderly (p=0.467) nor between the Elderly and the Diabetics (p=0.820).

Comparisons of Figures 9a to 9c clearly show that the Young braking impulses (l1) were the biggest and also had the largest variability. As expected, l2 was smaller than l1 in the Young as well as in the Elderly. However, the Diabetics
showed nearly no difference between I1 and I2, indicating that they had not yet initiated the stopping procedure.

Figure 9b. Approach Phase: A/P forces of the Elderly

Figure 9c. Approaching Phase: A/P forces of the Diabetics
To summarize, the relative braking time, expressed in percent (%) of the stance time during the Approach Phase (t1/t1+t3), was similar between the Young and the Elderly. However, the relative braking time was significantly shorter in the Diabetics compared with the Elderly or the Young. The Diabetics needed significantly longer to develop their maximal braking force (t2/t1) when compared with the Elderly and the Young.

During propulsion there was no significant difference found in either group, showing that the relative times needed to develop maximal propulsion force (t4/t3) were similar. The t4/(t1+t3) ratio, the relative time taken from maximal propelling force development to the total Approach Phase, was also similar in the three groups. F2, the maximal force developed during propulsion and I2, the impulse of the propelling forces, confirmed this fact as no significance level was reached between all three groups.

_The Stopping Phase_ (Table 4c with the corresponding Figures 10a to 10c)

_Time Ratios_

No significant differences in t5/(t5+t7) and t6/(t5+t7) existed between the three groups. However, t6/t5 was significantly different between the Young and the Diabetics (p=0.001), nearly significant between the Young and the Elderly (p=0.016) and non-significant between the Elderly and the Diabetics (p=0.124).

_Impulses_

I3 and I4 were only significantly different between the Young and the Diabetics (p-values<0.001 for I3 and I4). There was no statistical difference in I3
between the Young and the Elderly (p=0.029) and between the Elderly and Diabetics (p=0.061). The same applies for I4: no statistically significant difference was found between the Young and the Elderly (p=0.026) and between the Elderly and Diabetics (p=0.023).

Table 4c. Biomechanical Variables

<table>
<thead>
<tr>
<th>Biomechanical Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Group (n=15)</td>
</tr>
<tr>
<td><strong>Force-related Variables</strong></td>
</tr>
<tr>
<td>Stopping Phase</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>I3 (N/kg$^{-1}$)</td>
</tr>
<tr>
<td>I4 (N/kg$^{-1}$)</td>
</tr>
<tr>
<td>F3 (N/kg)</td>
</tr>
</tbody>
</table>

*Group abbreviations: Young = Healthy young participants Elderly = Healthy elderly participants Diabetics = Elderly type 2 diabetic participants affected by peripheral neuropathy. **p-value associated with Kruskal-Wallis § Median (± semi-interquartile range)

Maximal Force

F3 was significantly different between the Elderly and the Diabetics (p=0.008), between the Young and the Diabetics (p<0.001), and also between the Young and the Elderly (p=0.015).
Figure 10a: Stopping Phase: A/P forces of the Young

Figure 10b: Stopping Phase: A/P forces of the Elderly
Figure 10c. Stopping Phase: A/P forces of the Diabetics

Note: The increase in negative forces around 50% in the Figures 10a to 10c are due to HC3, which occurred on the same single plate form as HC2.

To summarize, the relative time taken to develop maximal stopping force was dependent on age but not on health status. The impulses, however, differed. As expected there was a significant difference in the Young and the Diabetics, but not between the Elderly and the Young, nor between the Elderly and the Diabetics. The maximal force reached during the single support of the Stopping Phase, i.e. t5, was significantly different in all three groups, with the Diabetics having developed the weakest force.
5.4. HYPOTHESIS TESTING

5.4.1. The First Hypothesis

The difference between the base of support at gait termination, i.e. width, and the base of support during walking will be larger in the healthy elderly than in the young persons.

As mentioned in the methodology section, the width is defined as the maximal M/L distance between the furthest lateral points of each foot. The same applies for the walking base: it is defined as the maximal M/L distance between the furthest lateral points of each foot during double support of the step before the Approach Phase. Hence the difference is obtained by subtracting the walking base from the width. The results are summarized in Table 5 below.

<table>
<thead>
<tr>
<th>Width, Walking Base and its Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Group (n=15)</td>
</tr>
<tr>
<td>--------------</td>
</tr>
<tr>
<td>Width (cm)</td>
</tr>
<tr>
<td>Walking Base (cm)</td>
</tr>
<tr>
<td>Difference: Width - Walking Base (cm)</td>
</tr>
</tbody>
</table>

*Group abbreviations: Young = Healthy young participants, Elderly = Healthy elderly participants
\*p-value associated with Mann-Whitney (Bonferroni method: \( p<0.016 \))
§ Median (± semi-interquartile range)

The results demonstrate that the difference between the Young and the Elderly width-walking base difference reached the significance level (\( p=0.016 \)).
Therefore the first hypothesis is confirmed: the difference between the walking base maximal M/L distance and the width seems to be larger in the Elderly than in the Young. The walking base of the women in both elderly groups was significantly smaller than that of the men (mean values of 20.74 cm versus 25.23 cm). The same effect is also observed in the Young (21.57 cm versus 28.23 cm).

5.4.2. The Second Hypothesis

*People with type 2 diabetes and peripheral neuropathy will show an increase in COP and COM overshoots in A/P direction, when compared with healthy elderly people.*

The results are summarized in Table 6 below.

Table 6. Hypothesis 2: Increase in A/P COP and COM overshoots

<table>
<thead>
<tr>
<th>Increase in A/P COP and COM overshoots</th>
<th>*Group (n=15)</th>
<th>Elderly</th>
<th>Diabetics</th>
<th>**p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/P COP overshoot (cm)</td>
<td>3.02$ (0.68)</td>
<td>3.11 (0.62)</td>
<td>0.027</td>
<td></td>
</tr>
<tr>
<td>A/P COM overshoot (cm)</td>
<td>1.38 (0.41)</td>
<td>1.59 (0.46)</td>
<td>0.083</td>
<td></td>
</tr>
</tbody>
</table>

*Group abbreviations: Elderly = Healthy elderly participants  Diabetics = Elderly type 2 diabetic participants affected by peripheral neuropathy.

**p-value: Bonferroni method; significance level: p<0.016.

\$ Median (± semi-interquartile range)

The results demonstrate a near-significant difference in the A/P-COP overshoots between the Elderly and Diabetics. However, the difference in the A/P-COM overshoots was clearly non-significant. The second hypothesis is
therefore rejected, indicating that there seemed to be no difference between the Elderly and Diabetics A/P-COP and A/P-COM overshoots.

5.4.3. The Third Hypothesis

*In the healthy elderly group and in the group with type 2 diabetes, the A/P COM velocities at HC1, HC2 and HC3 will be related to

a) a larger width,
b) an increased COP overshoot in the A/P and M/L directions,
c) and an increased COM overshoot in the A/P and M/L directions.*

The results are summarized in Tables 7a and 7b on the following pages.

<table>
<thead>
<tr>
<th>Spearman Correlation: Hypothesis 3a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group (n=15)</td>
</tr>
<tr>
<td>Hypothesis 3a</td>
</tr>
<tr>
<td>Correlation between:</td>
</tr>
<tr>
<td>Width and A/P-COM velocity at HC1</td>
</tr>
<tr>
<td>Width and A/P-COM velocity at HC2</td>
</tr>
<tr>
<td>Width and A/P-COM velocity at HC3</td>
</tr>
</tbody>
</table>

*Group abbreviations: Elderly = Healthy elderly participants. Diabetics = Elderly type 2 diabetic participants affected with peripheral neuropathy.

**p-value p<0.05 † Spearman's rho

The results demonstrate that only in the Diabetics was the A/P-COM velocity at HC1, HC2, and HC3 related to the width. The correlation was negative, indicating that in this group a higher A/P-COM velocity lead to a smaller width.
Thus, Hypothesis 3a is partly confirmed. In the Elderly, the A/P-COM velocity seems not to be related to the foot placement width.

In Hypothesis 3b only the A/P-COM velocity of the Elderly at HC2 was related

Table 7b. *Hypothesis 3b and 3c*

<table>
<thead>
<tr>
<th><em>Correlation between</em></th>
<th>Elderly</th>
<th><strong>p-value</strong></th>
<th>Diabetics</th>
<th><strong>p-value</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hypothesis 3b</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A/P-COM velocity at HC1 and A/P-COP overshoot</td>
<td>0.358†</td>
<td>0.190</td>
<td>0.366</td>
<td>0.179</td>
</tr>
<tr>
<td>A/P-COM velocity at HC1 and M/L-COP overshoot</td>
<td>0.467</td>
<td>0.079</td>
<td>0.109</td>
<td>0.669</td>
</tr>
<tr>
<td>A/P-COM velocity at HC2 and A/P-COP overshoot</td>
<td>0.409</td>
<td>0.130</td>
<td>0.059</td>
<td>0.835</td>
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<td>A/P-COM velocity at HC2 and M/L-COP overshoot</td>
<td>0.667</td>
<td>0.007</td>
<td>0.372</td>
<td>0.172</td>
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<tr>
<td>A/P-COM velocity at HC3 and A/P-COP overshoot</td>
<td>0.178</td>
<td>0.525</td>
<td>0.133</td>
<td>0.636</td>
</tr>
<tr>
<td>A/P-COM velocity at HC3 and M/L-COP overshoot</td>
<td>0.043</td>
<td>0.878</td>
<td>0.524</td>
<td>0.045</td>
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<tr>
<td><strong>Hypothesis 3c</strong></td>
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</tr>
<tr>
<td>A/P-COM velocity at HC1 and A/P-COM overshoot</td>
<td>0.292</td>
<td>0.291</td>
<td>-0.306</td>
<td>0.268</td>
</tr>
<tr>
<td>A/P-COM velocity at HC1 and M/L-COM overshoot</td>
<td>0.306</td>
<td>0.267</td>
<td>0.213</td>
<td>0.447</td>
</tr>
<tr>
<td>A/P-COM velocity at HC2 and A/P-COM overshoot</td>
<td>0.360</td>
<td>0.187</td>
<td>-0.549</td>
<td>0.034</td>
</tr>
<tr>
<td>A/P-COM velocity at HC2 and M/L-COM overshoot</td>
<td>0.571</td>
<td>0.026</td>
<td>0.349</td>
<td>0.203</td>
</tr>
<tr>
<td>A/P-COM velocity at HC3 and A/P-COM overshoot</td>
<td>-0.308</td>
<td>0.264</td>
<td>-0.209</td>
<td>0.455</td>
</tr>
<tr>
<td>A/P-COM velocity at HC3 and M/L-COM overshoot</td>
<td>0.168</td>
<td>0.551</td>
<td>0.484</td>
<td>0.067</td>
</tr>
</tbody>
</table>

*Group abbreviations: Elderly = Healthy elderly participants Diabetics = Elderly type 2 diabetic participants affected with peripheral neuropathy.
**p-value;p<0.05 † Spearman’s rho
to the COP overshoot in M/L direction. Comparing these results with the results of Hypothesis 3c revealed that in the same group the A/P-COM velocity at HC2 was also related with the M/L COM overshoot. Hence, the Elderly overshoots at HC2 were in synchrony. This could indicate that the Elderly detected the displacement of the COM and reacted accordingly with a larger COP overshoot. In the Diabetics the A/P-COM velocity at HC3 was related to the M/L overshoot. No correlation was found in Hypothesis 3c, possibly indicating that the Diabetics COP and COM might not be synchronised. In all other cases the A/P-COM velocities were not related to the COP overshoots. As mentioned in the Statistical Analyses chapter, multiple testing gives a higher probability of finding a significant result just by chance. This seems to be the case because in each group, just one test out of six lead to a significant result. Therefore, hypothesis 3b is rejected. It is concluded that the A/P-COM velocities seem to have no influence on the COP overshoots.

The same applies for Hypothesis 3c. This hypothesis is rejected too. Only one correlation per group was found between the A/P-COM velocities and the COM overshoots in the A/P and M/L direction. For the Elderly the A/P-COM velocity at HC2 and the M/L-COM overshoot were correlated. In the Diabetics however, the A/P-COM velocity at HC2 and the A/P-COM overshoot were correlated. Hence, the A/P-COM velocities also seem to have no influence on the COM overshoots.
5.4.4. The Fourth Hypothesis

In the young group, the velocity prior to gait termination will be related to the COP overshoot in the A/P direction only.

Table 8. Hypothesis 4

<table>
<thead>
<tr>
<th>Spearman Correlation: Hypothesis 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Group (n=15)</td>
</tr>
<tr>
<td>-----------------------------------</td>
</tr>
<tr>
<td><strong>Hypothesis 4</strong></td>
</tr>
<tr>
<td>Correlation between</td>
</tr>
<tr>
<td>A/P-COM velocity at HC1 and</td>
</tr>
<tr>
<td>A/P-COP overshoot</td>
</tr>
<tr>
<td>A/P-COM velocity at HC2 and</td>
</tr>
<tr>
<td>A/P-COP overshoot</td>
</tr>
<tr>
<td>A/P-COM velocity at HC3 and</td>
</tr>
<tr>
<td>A/P-COP overshoot</td>
</tr>
</tbody>
</table>

*Group abbreviation: Young = Healthy young participants  
*p-value: p<0.05  † Spearman's rho

No correlation was found between the A/P-COM velocities and the A/P COP overshoot in the Young. Therefore, the forth hypothesis is rejected, concluding that the A/P-COM velocity seemed to have no influence on the COP overshoot in the Young.

To sum up, hypothesis 1 was confirmed, whereas hypothesis 3 had been partly confirmed and hypotheses 2 and 4 had been rejected. The difference between the width and the base of support during walking was larger in the Elderly than in the Young (Hypothesis 1). However, the Elderly walk with a smaller walking base than the Young. The same applied for the width: the Young in general showed a larger width at gait termination than the Elderly.
No difference was found between the Elderly and the Diabetics in the COP and COM overshoots in either directions (Hypothesis 2).

The A/P-COM velocity prior to gait termination seemed to have little influence on the COP and COM overshoots (Hypothesis 3 and 4). Only the Diabetics showed a correlation between the A/P-COM velocity at HC1, HC2, and HC3 and the width, which lead to the confirmation, in part, of the third hypothesis. In all other cases (Part b and c of the third hypothesis and hypothesis four), there was no correlation between the A/P-COM velocity and the COP and COM overshoots.
6. DISCUSSION

The objective of the study was to analyse biomechanical characteristics of gait termination in the healthy young (Young), the healthy elderly (Elderly) and in elderly persons affected with type 2 diabetes and peripheral neuropathy (Diabetics). More specifically, the objectives of the study were to determine the age effect and the impact of peripheral neuropathy on some biomechanical variables related to gait termination. Furthermore, the study also investigated if a relationship exists between the A/P-COM velocity and the two main biomechanical variables, the COP and COM overshoots.

The main results can be summarized as follows: A clear age effect on the biomechanical variables was demonstrated. The overshoots of the Elderly were up to twice as large as those of the Young. However, no statistical differences in the COP and COM overshoots were obtained between the Elderly and the Diabetics. This leads to the conclusion that under the tested conditions, peripheral neuropathy does not have an influence on the COP and COM overshoots. Nevertheless, the Diabetics walked with a significantly lower velocity, indicating that peripheral neuropathy as a whole did have an impact.

The force-related variables yielded the following results: The relative braking time during the Approach Phase was significantly shorter in the Diabetics than in the Elderly or the Young. The Diabetics also took significantly longer to develop their maximal braking force when compared with the Young and the Elderly. However, the relative time needed to develop maximal propulsion force was similar in all three groups and so were the maximal propulsion forces and the
corresponding impulses. During the Stopping Phase, the relative time taken to
develop maximal stopping force was dependent only on age. The impulses were
only significantly different between the Young and the Diabetics. The maximal
stopping force during the single support of the Stopping Phase was significantly
different, with the Diabetics having the weakest stopping force.
6.1. **Methodological Considerations**

In the following part of this chapter the methodology will be discussed first followed by the discussion of the results (Chapter 6.2) and the forces and limits of the study (Chapter 6.3).

6.1.1. *Effects of the Chosen Sampling Design*

In this study, a non-probability sampling design was chosen. A non-probability sampling design is based on the deliberate selection of the participants (Satin and Shastry, 1993). Compared with a probability design, individuals do not have an equal chance of being selected. This results in a sample set less representative of the population. Thus, the investigator has to prove that all possible biases of known and unknown factors, which may differ between the study groups, did not account for the observed results (Hennekens and Buring, 1987). This is something that is almost impossible to achieve.

Due to the deliberate selection, it is not possible to either estimate the sampling error or determine the biases, as statistical significance tests are based on the assumption that the sample has been selected in a probabilistic manner (Altman, 1997; Hulley and Cummings, 1988). In other words, the standard deviation and the confidence interval are now only indicators of the variability of the results obtained in this particular study. Therefore, generalisation of the results to the whole population is limited (Contandriopoulos et al., 1990). However, the design does not affect the validity of any observed association within the group studied (Hennekens and Buring, 1987).
Despite the inconveniences mentioned above, non-probability sampling is practical, less time consuming and cost-effective (Friedman et al., 1996; Hulley and Cummings, 1988). These are some of the reasons why a non-probability design was chosen for the present study. Furthermore, this design is often used in pilot studies and in exploratory studies. As no studies exist at present that have analysed gait termination in elderly people with type 2 diabetes, the present study also has exploratory characteristics. An additional reason to justify the chosen design.

A non-probability sampling has consequences on the within-group results and also on the results of comparisons between the groups. Due to the non-probability sampling, the groups are much more homogeneous than would be the case had a probability sampling method been chosen. There are three main consequences: 1) less representation of the population, 2) sampling bias, and 3) possible differing levels of significance (Satin and Shastry, 1993).

1) First, the non-probability design results in a weaker sample representation, which differs more from the target population due to its homogeneity. In the present study, the biases in the different groups might be the following.

The group of the healthy young people consisted of students and employees of a research centre, a specific environment. This environment may lead to bias, as the people affiliated to this centre may not be a true representative sample of all the twenty to forty year old people living in Sherbrooke and the surrounding area. The same may apply for the healthy elderly people. This group consisted of mostly elderly persons, who have already participated in other studies. This also leads to selection biases, as former participants may be more active, open
minded and also more interested in research than the average target population. This is indicated by a large number of the elderly participants defining themselves as very active.

The elderly group with diabetes might be affected by two main selection biases. The first bias may occur due to the physician's referral. The physicians of the *Groupe de recherche en diabétologie* could have selected the participants in favour of the study. The second selection bias in the group with diabetes may occur due to the specific population that frequents the CUSE. However, the influence of this last point is minimal. The CUSE is a centre in which all people with diabetes have access to treatment, not only complicated cases. Therefore, the population with diabetes, which frequents the CUSE, is heterogeneous and quite representative.

It is assumed that the members of the *Association des diabétiques de l'Estrie* represent a very heterogeneous group, as their unique interest in joining this association is their disease. Therefore, people with large variations in disease duration and complications are included. Despite this assumed heterogeneity, the association may not be representative of the population with diabetes in the target area, as only persons interested in the association join the group as a member.

2) The second point of possible sampling biases is somewhat related to the first point. Due to the non-probability and hence more homogeneous sampling, the results obtained will be valid only for the particular group and its specific conditions (Altman, 1997). This makes generalisation, in its strictest interpretation, impossible (Hulley and Cummings, 1988). However, trends can be established and will hopefully lead to further investigations.
3) Another effect of a homogeneous group is that the results may reach a significant level, which in reality is not significant, or visa versa (Friedman et al., 1996). This would lead to an over- or underestimation of the variables studied. Therefore, comparisons between groups may result in significant differences, which are perhaps only due to the non-probability sampling design. This might be especially true for significant results close to the non-significant threshold (Altman, 1997). In such a case, a probabilistic sample, with the same statistical power, might have led to a non-significant result or visa versa (Friedman et al., 1996). Another consequence of homogenous samples on statistical analyses is their effect on correlation analyses. The more homogenous the group, the weaker the intra-group correlation. This could be a reason why most of the correlations were non-significant.

As in the probability sampling design, different sampling processes are also available for the non-probability sampling design (Hulley and Cumming, 1988; Satin and Shastry, 1993). This offers the opportunity to choose between several degrees of selection. A consecutive strategy would have been a possible way to reduce biases. A consecutive strategy is a sampling technique, in which every participant that meets the inclusion criteria, is included. It represents the best non-probability sampling design, as the selection is minimal (Hulley and Cummings, 1988).

In the present study, a consecutive sampling strategy might have been most appropriate in the young group. However, because the source of possible participants was limited (a given number of students and employees), selecting appropriate participants became necessary. Another way of reducing the bias in
this homogenous group could have been achieved by increasing the age-heterogeneity in the given age range as much as possible. In the ideal case nearly every age would have been represented. Again, this could not have been performed as the source of possible participants was limited.

The healthy elderly persons were age, gender and BMI matched with the elderly people affected with type 2 diabetes. This resulted in highly selected groups which were dependent on the source of the participants with diabetes (Members of the Association des diabétiques de l’Estrie and the CUSE) with its advantages and disadvantages as described previously.

6.1.2. Sample Size and Participant Group Considerations

The sample size of 15 participants per group is at the upper limit for biomechanical research. In this research field sample sizes of four up to twelve participants per group are normally tested and analysed (e.g. Courtemanche et al., 1996; Jian et al., 1993; Yamasaki et al., 1991; Yamashita and Katoh, 1976). Biomechanical data contain many different variables, which have to be processed before analyses. This data processing is time consuming and is the main reason why small sample sizes are preferred. However, for statistical analyses, 15 participants per group is at the lower limit. The chosen sample size yields a pre-study power of 0.75. The power of a test is the probability that a study of a given size would detect as statistically significant a real difference of any given magnitude (Altman, 1997). In other words, the power indicates the probability of keeping H₀ when in reality H₀ should be rejected. Post-study power analyses of the four main variables, the COP and COM overshoots in the A/P and M/L
directions, leads to the general power of 76%, with a minimal power of 28% (M/L COM overshoots: Elderly, Diabetics) and a maximal power of 99% (e.g. M/L COM overshoots: Young, Diabetics). This indicates that the present study is in general able to correctly identify if H₀ should be rejected in 76% (~75%), roughly in three out of four cases. Nevertheless, in almost one case out of four (~25%), the null hypothesis would not be rejected, because no difference would be detected where in reality a difference exists.

In general, small sample sizes are less sensitive to small differences. As mentioned above, the general power for the main four variables ranges from 28% to 99%. A detailed power analysis between the different groups gives a different picture: The power to detect a difference of 1.02 cm in the A/P and of 2.03 cm in the M/L COP overshoots between the Young and the Diabetics is 98%, respectively 99%. This is very high, indicating that the sample size of 15 participants was sufficient. The power to detect a difference of 0.61 cm in the A/P and 0.89 cm in the M/L COP overshoots between the Young and the Elderly is fair with a power of 62%, respectively 72%. However, the power to detect a difference of 0.41 cm for the A/P COP overshoots between the Elderly and the Diabetics is weak (29%), but fair for the detectable difference of 1.14 cm for the M/L COP overshoots (61%). A similar picture is obtained when analysing the power to detect differences in the A/P and M/L COM overshoots between the three groups. The power to detect a difference between the Young and the Diabetics of 0.70 cm in the A/P overshoots of 0.97 cm in M/L COM overshoots is very high (99%). The power to detect a difference of 0.46 cm between the Elderly and the Young in the A/P COM overshoots is 90%, respectively 98% for a
detectable difference of 0.63 cm in the M/L overshoots. Again, the chosen sample size of 15 per group results in an excellent power. The power remains good (81%) in detecting a difference of 0.34 cm in the M/L COM overshoots in the Elderly and the Diabetics. However, the power to detect a difference of 0.24 cm between the Elderly and the Diabetics in the A/P COM overshoots is weak (28%).

Based on this post-study power analyses it is concluded that the sample size of 15 participants per group was sufficient to detect age-related differences. Two possibilities might account for the weak power in detecting a difference between the Elderly and the Diabetics. First, it could be that the sample size was too small to detect the small differences between the Elderly and the Diabetics. The second possibility could be that under the tested conditions there were not any differences in the A/P COP and A/P COM overshoots between the Elderly and the Diabetics. This second possibility might be further supported by the fact that in the remaining two main variables (M/L COP and M/L COM overshoots), the power to detect a difference between the Elderly and the Diabetics was fair to good.

As mentioned previously, multiple testing increases the possibility of finding a significant difference just by chance. To correct this increased possibility, the Bonferroni method has been chosen. This method divides the significant level of 0.05 by the number of two-by-two test to be performed to identify inter-groups differences. The Bonferroni method is considered to be conservative (Altman, 1997). The significant differences can therefore be considered as real.

In objective 3, paired t-tests are used to identify differences in the Elderly and the Diabetics. In a theoretical sense, these two groups are not paired. Paired
sample tests are normally used to identify possible changes in the same person when comparing results obtained from pre- and post tests. The fact of having chosen paired sample tests means that factors that are not controllable but are normally controlled when testing the same person, might have an influence on the statistical outcome. On the other hand, the two groups have been age, gender and BMI matched and therefore, they do not represent fully randomly chosen participants. Hence t-tests for unpaired groups would not take into account these controlled variables.

Elderly persons have difficulties in stopping suddenly and turning, as the results of Cao et al. (1997 and 1998) demonstrate. To verify if these difficulties worsen in persons who show diminished foot sensitivity, the Diabetics were chosen as a target group. Diabetes is a serious public health problem and the population with diabetes will increase further in the future (CDC, 1995, Tan et al., 1997). To be able to identify changes related to age alone, the Young group is added, which serves as a control group. The age range of the Young (20 to 40 years) covers the age span commonly termed 'adult'. The upper limit has been consciously lowered to distinguish clearly between well-defined groups with different characteristics. The age range of the Elderly and the Diabetics (60 years to 75 years) is based on the biological 'definition' of ageing. The decline in walking performance starts after the age of 60 and has been reported by several authors (Alexander, 1996b (review); Bohannon, 1997; Sudarsky, 1990 (review)). With increasing age, pathologies are more likely to occur. Therefore, the upper limit of 75 years has been chosen to avoid complications. In addition, it has to be
remembered that the testing procedure lasted roughly two hours, including a marker fixation session. This session involved 25 minutes of standing.

6.1.3. Choice of Instruments

There are two well known and widely used types of instruments on the market to test vibration sensitivity threshold. One type is similar to the 'Vibrameter' and the second type is similar to the 'Vibratron' of Physitemp Instruments. The 'Vibratron' consists of two small plates equipped with a vibration probe which are placed in front of the test person. For testing the vibration sensitivity threshold, the participant places her or his index fingers or the big toes onto the probes. During the test, one of the probes is vibrating whereas the other is just simulating the vibration noise. The participant has to detect, which one of the probes is vibrating. The examiner determines the vibration intensity as well as the random choice of the vibrating plate. The advantage of this system is that the tested person has to concentrate on both fingers or on both big toes. However, the examiner has no control as to whether the participant is pressing his or her fingers onto the probes thus changing the detection limits. In addition, the plates are not very practical when foot sensitivity should be tested. As peripheral neuropathy manifests itself in the feet first, foot sensitivity testing should always be performed.

The 'Vibrameter', in contrast, is a rectangular instrument with the vibration unit in its head. The examiner holds this instrument in her or his hands during the testing procedure. The relatively small probe of the vibration unit can be placed without difficulties at any testing point. The big advantage of this instrument is its
indicator for the applied pressure during testing. Accurate repetitions of the applied stimulus, which is variable in intensity as well, are possible. The pressure indicator and the easier access for foot sensitivity testing are the reasons why the 'Vibrameter' has been chosen.

The Snellen acuity chart and the Valk test are commonly used to verify vision and the presence of peripheral neuropathy. The Snellen acuity chart is considered the gold standard in ophthalmology (Kushner et al., 1995). The Valk test (Valk et al., 1992) is a clinical test, which divides the presence of peripheral neuropathy into four categories: non-presenting (0 scoring points); mild (1-9 points), moderate (10-18 points) and severe (19-33 points) presence of peripheral neuropathy. The test includes not only the testing of pinprick, light-touch, and vibration sense, but also muscle strength (hallucis longus and gastrocnemius) and the ankle reflex (triceps surae). It therefore gives a general picture of the disease and its intensity.

The AMTI force plates, used to register the forces applied during walking and stopping, are standard in a modern biomechanical laboratory. They are highly reliable and are therefore widely used all over the world.

The OPTOTRAK-system is one of the most accurate systems available on the market for movement registration. It is termed an active system as the markers are illuminated sequentially and the pulses are registered by the sensors and not vice versa. Active systems allow easy identification of the markers during data analyses as each marker has its own channel and is therefore uniquely identifiable by the system. Unfortunately, a cable connects each marker with the strober unit. The more markers that are used, the more cables have to be placed
on the person, which may hinder the participant's movement. However, after the familiarisation period, all participants felt comfortable. Therefore, the influence of the cables is considered to be minimal.

The infrared markers (IRED) used to determine limb segment positions are very small compared to markers commonly used for video registration. They therefore stick more tightly to the skin and hence small movements of the markers themselves are minimised. This enhances the accuracy of the movement registration.
6.2. Discussion of the Results

The participant sociodemographic characteristics reveal that the Elderly and the Diabetics were similar in age, smoking state, weight, height, BMI and self-perceived activity level. They were significantly different in their self-perceived health status. Comparing the Young with the Elderly and the Diabetics shows that the Young were only similar in smoking state, weight, and activity level. The Young health status was similar to the Elderly but significantly different when compared to the Diabetics.

The significant BMI result between the Young and the Elderly and between the Young and the Diabetics is caused by height alone. As mentioned in the Methodology Chapter, the BMI is calculated by dividing the participants weight by his or her height squared. The Young are similar in weight to the two groups of elderly persons, but are taller by 7 cm. Hence the difference observed in the BMI values.

The non-significant results of the self-perceived activity levels between all three groups are unexpected. The group with the most persons defining themselves as very active is the Elderly. It has to be remembered that the Elderly have been chosen from a database of participants from previous studies. These people clearly feel active and interested enough to participate in other studies. Perhaps the study has selected a group of the 'super' elderly. This however, does not explain the non-significant result between the Elderly and the Diabetics. Diabetes is a pathology, which develops gradually and silently over a long period
of time. It could be, that persons with diabetes do not realistically assess their activity range. This might have resulted in a possible overestimating of their activities.

However, in the self-perceived health status, the Diabetics seem to be aware of the effects of the disease. Ten out of fifteen claimed their health was fair or poor. In contrast, the elderly and young people are nearly equal with their health estimation. An overestimation of the health status in the Elderly is less probable. It was noted that they were just in a very good shape.

An additional feature, which underlies the healthiness of the Elderly, is their vibration sensitivity threshold. The group tested is nearly 1 standard deviation below the value of the corresponding age group norm. The age correcting regression equations presented in the Vibrameter manual are the results of the Goldberg and Lindblom study (1979). They are based on 110 Swedish male participants aged between 10 and 79 years, with a mean age of 41.2 years and a median age of 41.9 years. The sensitivity of this norm population may differ from the population tested here in Sherbrooke. However, the climates of Sweden and Canada are similar, especially in winter. Therefore it is less likely that the sensitivity thresholds of the feet would be higher in the Swedish population. Nevertheless, height is a factor, which is not considered in the equations presented by Goldberg and Lindblom. Dorfman and Bosley (1979) demonstrated that for nerve conduction studies, height has to be considered. The same applies for vibration sensitivity testing (Gerr et al., 1990; Wiles et al., 1991). Wiles et al., however, pointed out that age is the main influence when determining vibration
perception thresholds. Nordic people are in general taller than people from the south and may therefore detect the stimulus later.

A final point regarding the health status and the activity level is the instrument used to measure these variables. This instrument, an 'in-house' questionnaire, was not validated. Although for the self-estimated activity level and the self-perceived health status, additional questions were asked before the central questions were addressed (Annexe 5, Nominative Data, Activity level and Annexe 5, Sociodemographic Data, History of medications and other health-related questions), these additional questions might not have been sufficient to 'validate' the instrument. Therefore, the results have to be interpreted with caution. A further limit of 'in-house' questionnaires is that the results obtained cannot be compared with other results presented in the literature. However, it is generally known that elderly persons affected with type 2 diabetes and peripheral neuropathy have a lower health status than elderly not affected with type 2 diabetes (e.g. Eastman et al., 1997). The results from the present study would therefore agree with this general consensus. Nevertheless, elderly persons affected with type 2 diabetes and peripheral neuropathy are also less active than persons of the same age. This is also generally well known (e.g. Cowie and Harris, 1995) and contrasts with the findings from this study. The reason for this contradictory result clearly lies in the fact, that the 'in-house' questionnaire was not rigorous enough to estimate differences in activity level.

The A/P COM velocities are significantly different, with one exception: a non-significant difference found at HC3 between the Elderly and the Diabetics. The
results of the A/P COM velocities confirm the general consensus that elderly persons walk more slowly than the young (e.g. Bohannon 1997; Buchner et al., 1996; Öberg et al., 1993). Furthermore, Courtemanche et al. (1996) demonstrated a slower walking speed in elderly persons with diabetes compared to their age-matched counterparts without diabetes. The results from the present study are also consistent with the literature in this regard. However, these differences persisted during the Approach and, in part, during the Stopping Phase.

During the Approach Phase, the Young and the Elderly are similar. The Diabetics show a significantly shorter relative braking time than the Elderly and the Young. This indicates that the Diabetics seem not to have initiated their stopping procedure yet, a fact, which is further supported by their similar braking and propulsion impulses (I1 and I2). Two possible reasons for this situation may exist: First, due to their significant slower walking velocity, Diabetics might not need to start their stopping procedure during the Approach Phase. It might be sufficient for them to completely stop their gait during the Stopping Phase. Second, the difference might be disease-induced. Elderly persons affected with diabetes and neuropathy show a prolonged reaction time during walking compared with age-matched controls (Courtemanche et al, 1996). The present study confirms these results. The Diabetics take longer to develop the maximal braking force compared with the other two groups. Therefore, it could be that the Diabetics just did not have enough time to develop a similar relative braking time than the Elderly before the propulsion phase started.
During the Stopping Phase, the relative time taken to develop maximal stopping force is dependent on age and not on health status. The corresponding impulses are different only between the Young and the Diabetics, but maximal force reached during the single support of the Stopping Phase is different in all three groups. Once again, the Diabetics develop the weakest maximal force and the Young the strongest. The reasons for this are similar to those for the Approach Phase, as discussed above.

During the first part of the Stopping Phase the differences in the A/P COM velocities between the Elderly and the Diabetics persisted. Only at HC3, the event at which walking appears to stop, did the velocities between the two elderly groups become similar. Surprisingly, both the A/P forces and the time to complete the stopping procedure were less in the Diabetics after this event. This may be disease related. A closer look reveals that the impulse /4, the stopping force at HC3 and the relative time taken from HC3 until the A/P COM velocity is below 0.05 m/s are reduced in the Diabetics compared to the Elderly although the differences are not significant. Both, the Elderly and the Diabetics have a similar velocity which has to be brought to a full stop. It is unclear why the Diabetics developed smaller A/P forces during the last part of the Stopping Phase or why it took them less time to bring their remaining A/P COM velocity to a full stop. A possible reason might be that a difference in M/L forces may exist between the Elderly and the Diabetic during this last part of the Stopping Phase. This is further suggested by Boucher et al. (1995), who showed during posture analyses that elderly diabetic persons increased their medio/lateral sway when changing from the eyes-closed to eyes-opened condition. Therefore, it could be that the larger
M/L COP overshoots in the Diabetics (Table 4a) are combined with a larger medio/lateral force. This would indicate that healthy elderly people terminate their gait mainly in the A/P direction, whereas elderly diabetic people also use the M/L direction.

A clearly significant age effect on some of the biomechanical variables has been demonstrated. These variables are the COP and COM maximal overshoots. The elderly people in both groups show significantly larger COP (in the M/L direction only) and COM overshoots (in both directions) than the young participants. These overshoots are up to twice as large as in the Young and hence result in a larger motion area. The results concur with other results (Cavanagh et al., 1993; Hageman et al., 1995). However, there is no difference in the A/P and M/L COP and COM overshoots between the Elderly and the Diabetics. These results are unexpected, knowing that people affected with diabetes and peripheral neuropathy always perform worse than their age-matched controls, as demonstrated previously. One reason for these non-significant results could be due to the task requested. The task was an easy goal-orientated daily activity and therefore predictable. They therefore anticipated where to stop and when this would be, as the task was practised during the familiarisation period. If sudden stops had been tested, the above mentioned anticipatory situation would not occur. The participants would have been forced to respond instantaneously to a random stop signal. A sudden stopping situation might have pushed the participants affected with diabetes and peripheral neuropathy to their limits because reactions to sudden events cannot be easily
compensated. This might have lead to a significant difference between the Elderly and the Diabetics.

Interestingly enough, the foot placement in all three groups was similar with the Young showing the largest width. In addition, the length of the base of support between all three groups was nearly the same. It is therefore not expected that the length of the force plate might have an influence on the length of the base of support. It has to be remembered that the stopping procedure was goal orientated: the participants have to stop in front of the indicated stop-line. The force plate was 40 cm long and therefore gives enough space for individual placement of the feet. The nearly identical length obtained in all three groups is more likely due to a specific locomotor pattern than due to length restrictions of the force plate.

Posture analyses have demonstrated that during standing, the functional base of support diminishes with age (King et al., 1994; Kozak et al., 1997). Taking these results into account and the demonstrated larger COP and COM overshoots reveal that the elderly participants in both groups were closer to their stability limit than the Young. Therefore, the possibility for correcting any perturbation during standing is reduced. Hence, the readiness to stop with an additional step was higher in these two groups than in the Young.

Furthermore, the Elderly walking base is smaller than in the Young (Table 5). These results contrast with several studies demonstrating that elderly gait is characterised by a wider walking base in order to increase stability (Baumann, 1994; Guimaraes and Isaacs, 1980; Sudarsky, 1990). However, they support the results of Gabell and Nayak (1984). The reason why the outcome of this study
does not correspond with the general consensus is unclear. Possible explanations could be that the wider walking base is more characteristic of either frail persons, as analysed by Guimaraes and Isaacs, or of older elderly (Baumann, 1994; Sudarsky, 1990). Another possibility is that the difference is related to generation. One participant explained that she had been taught to walk daintily with the feet close together. Indeed, the walking base of the women in both elderly groups was significantly smaller than the one found in men. However, the same effect is observed in the Young. It seems that gender differences are the factor and not generational differences.

The results demonstrate that the impact of peripheral neuropathy (objective 4) seems to be contradictory. No significant correlation was found between the vibration sensitivity threshold and the COP and COM-overshoots in either direction. Vibration sensitivity threshold therefore seems to have no effect on the COP and COM overshoots. However, the elderly persons with type 2 diabetes walked with a significantly slower velocity compared with the healthy elderly persons. A result, which confirms the results found by Courtemanche et al. (1996). These authors also demonstrated that persons with diabetes and peripheral neuropathy walk with a slower walking pace than their controls with diabetes but without neuropathy. Therefore, neuropathy as a whole has an effect on walking characteristics. It seems that the vibration sensitivity determination is not the critical variable when gait termination is considered. A reduced vibration sensitivity is only one feature of neuropathy. It could be that other characteristics such as reduced nerve conduction velocities, reduced muscle forces or a
combination of both may have a larger effect on the overall stopping behaviour than the determined vibration sensitivity threshold. Another possible reason for the non-significant result might be due to the effect of group homogeneity. As discussed previously, homogeneous groups do not produce correlations. It could be that the elderly and diabetic participants were just too homogeneous to be able to detect a significant correlation in each of the group.

The relationship between the A/P-COM velocity and the foot placement is not consistent between the groups. The results reveal that in the Elderly and the Young, the walking velocity prior to gait termination seems to have no influence on the foot placement at stop. In other words, elderly persons do not take the opportunity to enlarge their foot placement at stop for safety purposes. However, in the Diabetics, width is significantly correlated with the A/P-COM velocity. This correlation is negative, a result, which is unexpected: the slower the A/P-COM velocities at HC1 and HC2 are, the larger the width of the foot placement. A possible explanation for this negative correlation may be that, in general, movements get more difficult the slower they are performed. Moreover, these movements become jerky and therefore more difficult to control. The more the A/P-COM velocity decreases, the more a larger width is needed to counterbalance the effects created by the smaller velocity.

There is no relation between the A/P-COM velocity and the COP and COM overshoots, with a few exceptions. It was unexpected that the A/P-COM velocity seems to have minimal influence on the COP and COM overshoots. This could be explained by the fact that all participants had the possibility of choosing their preferred walking speed. The choice for this walking speed might be influenced
by external criteria, such as task and walking distance, and by internal criteria such as age and health status. The task was a relatively easy daily activity, resulting in a relaxed walking speed. Nevertheless, the walking distance was relatively short with a maximum of three metres. Therefore, full walking velocity might not have been achieved, especially in the Elderly and the Diabetics. In addition, the participants were requested to hook their thumbs into the waist belt, which carried the strobes. This walking posture avoided covering the hip markers by the arms while walking. Although the position was comfortable for every participant, it might have had an influence on gait velocity in the Elderly and especially the Diabetics. Furthermore, age and health status have a significant effect on walking velocity. The capability to develop forces in a fast and adequate manner is crucial. This characteristic is impaired in elderly persons (Thelen et al., 1996) and even further reduced in people with diabetes (Mueller et al., 1995). Combining external and internal criteria might have lead to a walking velocity that enables the participants to control their COP and COM trajectories as demonstrated.

Another criteria might be the choice of the A/P COM velocity. Instead of considering A/P COM velocity, A/P COM accelerations might have been more appropriate. To be able to stop, the A/P COM velocity has to be slowed to near zero. This deceleration is a negative acceleration. Cao et al. (1998) demonstrated that stopping difficulties in the elderly persons are related to an insufficient deceleration especially at the time when stopping procedure is initiated. Hence, deceleration difficulties may result in the larger overshoots demonstrated in the Elderly and the Diabetics.
6.3. Forces and Limits of the Study

Forces

The study provides new insights into gait termination by analysing the COP and COM overshoots in both the A/P and M/L directions during goal-orientated stopping. Analyses of the COP and COM trajectories are an important factor in gait and posture studies. However, to date the analysis of these variables has not been addressed in the elderly persons nor in people affected with peripheral neuropathy. The study therefore fills a gap in the literature and will contribute to the understanding of the stopping mechanism. The other tested variables, the control and the biomechanical variables, are all generally used and well-recognised variables.

The chosen sample size of 15 participants per group is in the upper size range of studies analysing gait and posture. As mentioned previously, biomechanical data contain many different variables, which have to be processed in a very time consuming manner. This is the main reason why large sample sizes in gait and posture analyses are rare. The chosen sample size is therefore another strong point of the study. Furthermore, post-power analyses revealed that the chosen sample size leads to a good power for the presented study.

Limits

As mentioned above, the sample size is at the upper limit from a biomechanical point of view. However, the chosen sample size is weak from a statistical point of view. Although the general power of the study is good, the data
showed a non-parametric distribution. A much larger sample size would have probably lead to a near-normal distribution and hence to different and yet more powerful statistical tools.

The non-probabilistic sampling design is an additional limit of the study. As discussed, non-probability samples are less representative as the inference to the target population is restricted.

Due to the 'in-house' questionnaire, comparisons between the self-estimated health status and activity level of this study with the results of previous studies can only be performed with caution. A further limit is the lack of additional health status information in the Diabetics. Knowledge about the duration of diabetes and related complications other than neuropathy would have given a more detailed description of these participants. With this additional information, it might have been possible to explain, or at least to support, certain outcomes of the health status and activity level measured in this study.
7. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to analyse gait termination in the healthy elderly persons and elderly persons with diabetes and peripheral neuropathy. The young persons group served as a control group.

The results of the A/P COM velocities agree with the general consensus that elderly people are walking with a slower pace than young people and that elderly diabetic people are walking slower as their age-matched controls. However, the study reveals that these differences persisted throughout the gait termination process. In both the Approach and the Stopping Phase, the young participants consistently developed the highest braking and stopping forces, whereas the elderly diabetic persons consistently developed the weakest forces. In most cases, the different relative braking and stopping times were prolonged in the diabetics. This indirectly confirms the increased disease-induced reaction time typically found in elderly diabetic persons affected with peripheral neuropathy. However, during the Approach Phase the diabetic participants were closest to the A/P force pattern that characterizes normal walking. This indicates that the diabetic participants did not seem to have initiated their stopping procedure during this phase. Impulse comparisons between the three groups reveal that the persons affected with diabetes and peripheral neuropathy had the smallest braking impulse but the largest propelling impulse during the Approach Phase. These impulse comparisons confirm the results of the force comparisons that these participants had not initiated their stopping procedure yet. During the last
part of the Stopping Phase (HC3 to A/P COM velocity <0.05 m/s), the A/P COM velocity was similar between the healthy elderly participants and the elderly persons affected with peripheral neuropathy. Therefore, impulse differences between these two groups might result from the disease only. However, this conclusion has to be interpreted with caution as it is possible that the diabetic persons compensated in the M/L rather than the A/P direction.

The measured COP and COM overshoots are an indicator of defective coordination. The larger they are the more difficult it was for the participants to fulfil the task. Previous results of posture analyses showed that significant sway differences were found between the elderly and elderly participants with diabetes. Therefore, differences between these two groups have been expected as well because terminating gait is a transitional task between a dynamic and a quasi-static situation. However, the results of this study demonstrate that under the study conditions, healthy elderly and elderly persons with type 2 diabetes and peripheral neuropathy showed no difference in COP and COM overshoots. Hence, under the tested conditions, the diabetic participants were able to compensate for their deficiency. Furthermore, the control variables (vibration sensitivity threshold and A/P COM velocities) have little or no influence on the COP and COM overshoots.

To further establish these results, more studies controlling the velocities prior to gait termination and/or demanding different, more specific tasks will have to be performed. For example, does the stopping behaviour of elderly people (COP and COM overshoots in either direction) depend on the task demanded (approaching
stairs, walking with given velocities) or do the overshoots remain relatively unchanged?

Nerve conduction velocity might be a more precise instrument in analysing the impact of diabetic neuropathy on the COP and COM overshoots than the chosen vibration sensitivity threshold. A further possibility to analyse the impact of diabetes would be to test the capability to develop rapid ankle torque or maximal plantar flexor forces. This, too, may have an influence on the COP and COM overshoots and will contribute to revealing the mechanism behind the COP and COM trajectories during gait termination. EMG-analyses would also give an inside look at the relative time differences between the Elderly and the Diabetics during the Approach and Stopping Phases.
ACKNOWLEDGEMENTS

This study was partly financed by the National Science and Engineering Research Council of Canada (NSERC) and the Medical Research Council of Canada (CRM). Their contribution is greatly appreciated.

My sincere thanks go to Dr. Johanne Desrosiers for her wonderful help in all aspects. I will never forget her "avec plaisir" when I was asking about her willingness to be my additional director. It is never easy to enter an ongoing project and I thank her deeply for sticking at it and for having guided me through turbulent times. Thank you so much, Johanne!

I also wish to express my very special thanks to Prof. Paul Bourassa for his invaluable help. His marvellous programs solved my calculation problems in a wonderfully elegant manner. Paul, thank you very much for your time, and your great scientific and financial support!

Also very sincere thanks go to Dr. Janusz Blaszczyk, Nencki Institute of Experimental Biology, Warsaw, Poland, who helped me in an extraordinary way during his short stay here in Canada. I appreciated our wonderful scientific discussions and your open mind to every new idea so much. Thank you very much for your aid, Janusz!

Another person who helped me in an outstanding way is Dr. Kevin Lenton. His patient and precious help in any way supported me during all my time here in Sherbrooke. Thank you many times, Kevin! Without you, things would have been much more difficult.
Further warm thanks go to Assane Niang, my right hand man for Matlab-problems. His great help was most appreciated. Thank you very much, Assane! Good luck and all the very best for the last bit of your Ph.D. I will keep my fingers crossed for you!

Many thanks also to Michel Raîche and Yves Roy for their help during data collection. Thank you very much, Michel and Yves, for your time!

Special thanks also to Dr. Hamid Lekhel for his efficient help whenever there was any need during data collection in the summer. Thank you, Hamid, for your great help!

I am also very grateful to Dr. Daniel Zlatnki, Institute for Robotics, ETH Zurich, Switzerland, for his continuous support. Your encouraging e-mails were always just wonderful, Dani! Thank you very much.

Special thanks as well to the staff of the Sherbrooke Geriatric University Institute library and documentation unit for their support and wonderful help.

So far, the time as a Ph.D. student has been the most difficult in my life. Without my family I would not have been able to get through it. My warmest and deepest thanks go therefore to my mother, Mrs. Margreth Meier-Hansemann, my brother Richard and my two sisters, Claudia and Barbara. They all supported me in an extraordinary way that I will never forget. Your lovely letters, funny postcards, wonderful parcels and numerous phone calls have cheered me up so many times. You all have been an invaluable source of energy. It was absolutely great to know that on the other side of the world there were some people who understood my difficulties, people on whom I could count and who provided me with the discussion forum I was so used to. A thousand warm thanks to you all!
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APPENDIX 1

Approval of the Ethical Committee
Madame Margrit Meier  
Centre de recherche en gérontologie et gériatrie  
1036, rue Belvédère Sud  
Sherbrooke, Québec  
J1H 4C4

Objet :  Votre projet de recherche « Gait termination in the young, the elderly and type II diabetics affected by peripheral neuropathy »  
N/Réf : 97-28 / Meier

Madame Meier,


Nous vous prions d'accepter, Madame Meier, l'expression de nos meilleurs sentiments.

[Signature]

Dr Charles Leduc  
Président du comité d'éthique

C.c.  Dre Johanne Desrosiers  
Dr François Prince
Le comité d'éthique de l'établissement certifie avoir examiné le projet de recherche suivant :

**Titre :** Gait termination in the young, the elderly and type II diabetics affected by peripheral neuropathy

**Chercheur principal :** Madame Margrit Meier

<table>
<thead>
<tr>
<th>Membres du comité</th>
<th>Champs d'activités</th>
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<tr>
<td>BOURQUE, Monique</td>
<td>Infirmière monitrice, Direction des soins infirmiers, Institut universitaire de gériatrie de Sherbrooke</td>
</tr>
<tr>
<td>BRIÈRE, Élisabeth</td>
<td>Notaire, Étude Sylvestre, Robillard. Membre externe</td>
</tr>
<tr>
<td>DESROSIERS, Johanne</td>
<td>Professeure, Faculté de médecine, Département des sciences de la santé communautaire, Chercheure, Centre de recherche en gérontologie et gériatrie</td>
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<td>LEDUC, Charles</td>
<td>Président. Professeur, Faculté de médecine, Département de médecine de famille</td>
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<td>LORRAIN, Dominique</td>
<td>Professeure, Faculté des lettres et sciences humaines, Département de psychologie, Chercheure, Centre de recherche en gérontologie et gériatrie</td>
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<tr>
<td>O'NEIL, Louis</td>
<td>Personne retraitée</td>
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<tr>
<td>PRÉVIL, Michel</td>
<td>Chercheur, Centre de recherche en gérontologie et gériatrie</td>
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Le comité d'éthique a conclu que le projet de recherche proposé est entièrement conforme aux normes déontologiques, telles qu'énoncées dans les règles de la déontologie de la recherche sur l'humain.

**DÉCISION :**
- Favorable □
- Unanime ☒
- Déniable □
- Majoritaire ☒

Extrait du procès-verbal du comité d'éthique de la recherche du 9 mars 1998

Charles P. Leduc
Président du comité d'éthique

Date : 17 mars 1998
Information Letter for the Members of the Association des diabétiques du l'Estrie
À : Tous les membres du CPADQ

Date : 25 mars 1998

Sujet : Évaluation de l'équilibre et de l'arrêt de la marche des sujets diabétiques avec une neuropathie périphérique

Cher(ère) membre,

Comme vous le savez sans doute, le diabète peut entraîner des complications. La neuropathie périphérique est une des complications les plus importantes. Lorsqu'une personne diabétique a une neuropathie périphérique, elle présente une diminution de la sensibilité aux jambes qui peut entraîner des pertes d'équilibre et des problèmes lors de l'arrêt de la marche. Les chutes suite à ces problèmes peuvent occasionner différentes blessures qui nécessitent souvent des soins médicaux prolongés.

Deux études sont présentement en cours au Centre de recherche en gériatrie de l'Institut universitaire de gériatrie de Sherbrooke. Les chercheurs veulent connaître les relations qui existent entre les problèmes de sensibilité aux jambes créés par le diabète et les risques de chute. Le but de la première étude est d'étudier l'équilibre debout chez les personnes diabétiques atteintes de neuropathie périphérique. L'équilibre stable en position debout est essentiel pour réaliser sans danger toutes les activités de la vie. La deuxième étude évalue l'arrêt de la marche. L'arrêt représente une phase importante de la marche. C'est surtout cette phase qui est plus difficile à réaliser et qui peut causer des problèmes chez des aînés à cause des changements reliés au vieillissement. Si, en plus, une maladie comme le diabète est présente, les problèmes peuvent se multiplier.

Si vous acceptez de participer à l'une ou aux deux études, vous serez invité à une ou deux évaluations d'environ deux heures chacune au laboratoire de posture et de locomotion à l'institut universitaire de gériatrie.
de Sherbrooke au pavillon D'Youville. Lors de ces rencontres, trois types d'évaluations seront faites: 1) un questionnaire sur des informations générales (âge, taille, masse); 2) différentes évaluations cliniques en relation avec votre équilibre et finalement 3) une évaluation de votre équilibre ou de l'arrêt de la marche avec des équipements de laboratoire. Une compensation monétaire de 10 dollars vous sera remise pour chaque déplacement.

L'équipe est donc à la recherche d'homme et de femme âgé(e)s entre 60 et 85 ans :
➢ Présentant un diabète de type II
➢ Présentant des problèmes d'engourdissement ou une diminution de la sensibilité des jambes.

Si vous croyez correspondre à cette description et si vous désirez recevoir plus d'information au sujet de ces études, communiquez au 829-7131 avec Hélène Corriveau pour l'étude sur l'équilibre et Margrit Meier pour l'étude sur l'arrêt de la marche.

__________________________________________

Hélène Corriveau, PT                          Margrit Meier, CPO
Young Participants' Information Letter (French)
Sherbrooke, le

Personnel du Centre de recherche en gérontologie et gériatrie
Personnel de l'Institut universitaire de gériatrie de Sherbrooke

Objet : Participation au projet de recherche
"L'arrêt de la marche chez des personnes jeunes, et âgées et
chez des personnes âgées diabétiques atteintes de neuropathie périphérique"

Madame, Monsieur,

Les activités quotidiennes reliées à la marche demandent la capacité de s'arrêter souvent brusquement. Malgré ce fait, les études qui traitent de l'arrêt de la marche sont rares. L'arrêt de la marche peut causer des problèmes chez les aînés à cause des changements reliés au vieillissement. Si, en plus, une maladie comme le diabète est présente, les problèmes se multiplient. Jusqu'à présent seulement deux études ont évalué l'arrêt de la marche chez des personnes âgées. Aucune étude n'a évalué l'arrêt de la marche chez des personnes diabétiques. Pour comparer les résultats des personnes diabétiques et des personnes âgées, il nous faut des personnes jeunes n'ayant aucun déficit qui pourrait influencer le déroulement de l'arrêt de la marche. C'est pourquoi nous faisons appel à vous.

En acceptant de participer à ce projet de recherche, l'arrêt de votre marche sera mesuré. Pour contrôler les influences possibles sur l'exécution de l'arrêt, un bref questionnaire sur vos activités et votre santé doit être rempli. Ensuite, votre vision, la sensibilité de vos pieds et des mesures corporelles (taille et poids) seront prises avant le test de l'arrêt de la marche. Lors de l'évaluation de l'arrêt, des rondelles lumineuses seront placées sur vos vêtements et votre peau à des endroits spécifiques pour enregistrer le mouvement de vos jambes et de votre corps. Le test d'arrêt de la marche consiste à arrêter devant une linge indiquée au sol. Vous aurez à marcher à une vitesse
normal. Un total de 20 essais doivent être fait. Nous estimons la durée de l'évaluation à deux heures, pauses comprises.


Vous ne retirerez aucun bénéfice direct de cette étude. Mais vous nous aideriez à acquérir des données qui nous permettront d'améliorer les connaissances sur une partie du déroulement de la marche peu connue, malgré qu'elle représente un point critique. Nous pouvons vous assurer que toutes les informations et données recueillies de même que les résultats demeureront strictement confidentiels et gardés sous-clé. Si vous désirez avoir plus d'information concernant cette étude, n'hésitez pas à me contacter au poste # 2287.

D'ici quelques jours, je vous contacterai pour vérifier votre intérêt à participer à cette étude. Il s'agit d'une participation volontaire; un refus ou un retrait n'entraînera évidemment aucun préjudice en regard de votre emploi ou du lien avec votre employeur. Si vous acceptez, nous discuterons du moment qui vous conviendra le mieux.

Veuillez agréer, Madame, Monsieur, l'expression de mes sentiments distingués.

Margrit Meier  
Candidate au Ph.D.  
en sciences cliniques
APPENDIX 4

Consent Forms of the

Young Participants (French)

Healthy Elderly Participants (French)

Healthy Elderly Participants (English)

Elderly Type 2 Diabetic Participants (French)

Elderly Type 2 Diabetic Participants (English)
Formulaire d'information et de consentement

Évaluation de l'arrêt de la marche chez des personnes jeunes, âgées et diabétiques, type 2

1. Informations
La majorité des chutes chez les personnes âgées surviennent pendant la marche et lors de nombreuses activités quotidiennes. L'arrêt représente une phase importante de la marche. C'est surtout cette phase qui serait plus difficile à réaliser et qui pourrait causer des problèmes chez des aînés à cause des changements reliés au vieillissement. Si, en plus, une maladie comme le diabète est présente, les problèmes se multiplient.

Le but de cette étude est d'analyser l'arrêt de la marche chez des personnes âgées en santé et des personnes diabétiques. Pour comparer les résultats de ces deux groupes de personnes, il nous faut des personnes jeunes, comme vous, n'ayant aucun déficit qui pourrait influencer le déroulement de l'arrêt de la marche.

Si vous acceptez de participer à l'étude, le déroulement sera le suivant. En premier lieu, un bref questionnaire sur vos activités et votre santé doit être rempli. Ensuite, votre vision, la sensibilité de vos pieds et des mesures corporelles (taille, poids) seront prises avant le test de l'arrêt de la marche. Finalement, des rondelles lumineuses seront placées sur vos vêtements et votre peau à des endroits spécifiques pour enregistrer le déplacement de vos jambes et de votre corps lors de l'évaluation de l'arrêt. Ce test consiste à arrêter devant une ligne marquée sur le sol. Vous aurez à marcher à une vitesse normale et dès que vous aurez atteint la ligne, vous vous arrêterez. Un total d'environ 20 essais doit être fait. Nous estimons la durée de l'évaluation à une heure et demie, pauses comprises.


Vous ne retirerez aucun bénéfice direct de cette étude. Mais vous nous aiderez à acquérir des données qui nous permettront d'améliorer les connaissances sur une partie du déroulement de la marche peu connue, malgré qu'elle représente un point critique.

Comme reconnaissance à votre participation, un dédommagement de $10,00 vous sera donné.
Nous pouvons vous assurer que toutes les informations et données recueillies de même que les résultats demeureront strictement confidentiels et gardés sous-clé.

Vous pourrez vous retirer de cette étude en tout temps, sans pénalité, même si vous avez signé le formulaire de consentement. Il s'agit d'une participation volontaire; un refus ou un retrait n'entraînera évidemment aucun préjudice en regard de votre emploi ou de lien avec votre employeur.

Pour de plus amples renseignements, vous pouvez contacter la responsable du projet, Margrit Meier au (819) 829-7131, poste 2287.

2. Consentement

Par la présente, (nom du participant/e), j'accepte de participer à l'étude mentionnée ci-haut. Je reconnais avoir été informé de façon satisfaisante sur la nature et le motif de ma participation à l'étude. J'ai été également informé que mon nom n'apparaîtra dans aucune publication concernant cette étude et que pour le traitement des données, mon nom sera codé. J'ai le droit de me retirer de l'étude en tout temps, sans pénalité, même si j'ai signé ce consentement, en avisant simplement la responsable du projet, dont le nom paraît ci-haut. J'accepte que l'information recueillie puisse être utilisée pour fins de communications scientifique et professionnelle.

J'accepte, de plein gré, de participer à cette étude.

____________________________________  ____________________________
Signature du participant/e               Date

____________________________________  ____________________________
Signature du témoin                       Date

____________________________________  ____________________________
Signature du chercheur                    Date
Formulaire d'information et de consentement

Évaluation de l'arrêt de la marche chez des personnes jeunes, âgées et diabétiques, type 2

1. Informations
La majorité des chutes chez les personnes âgées surviennent pendant la marche et lors de nombreuses activités quotidiennes. L'arrêt représente une phase importante de la marche. C'est surtout cette phase qui serait plus difficile à réaliser et qui pourrait causer des problèmes chez des aînés à cause des changements reliés au vieillissement. Si, en plus, une maladie comme le diabète est présente, les problèmes se multiplient.

Le but de cette étude est d'analyser l'arrêt de la marche chez des personnes âgées en santé et des personnes diabétiques. Pour comparer les résultats des personnes diabétiques, il nous faut des personnes âgées en santé n'ayant aucun déficit qui pourrait influencer le déroulement de l'arrêt. Nous faisons appel à vous parce que vous êtes une personne âgée en santé.

Si vous acceptez de participer à l'étude, le déroulement sera le suivant. En premier lieu, une prise de sang à jeun sera fait pour être certain que vous ne faites pas de diabète. Si la valeur de votre taux de sucre est plus élevée que la normale, vous serez référé(e) à votre médecin traitant et exclu(e) de notre étude. Si votre taux de sucre dans le sang correspond à nos critères, vous serez contacté pour le test de l'arrêt de la marche dans le laboratoire de posture et de locomotion.

Pendant la session du test de l'arrêt de la marche, un bref questionnaire sur vos activités et votre santé doit être rempli. Votre vision, la sensibilité de vos pieds et des mesures corporelles (taille, poids) seront prises avant le test de l'arrêt de la marche. Finalement, des rondelles lumineuses seront placées sur vos vêtements et votre peau à des endroits spécifiques pour enregistrer le mouvement de vos jambes et de votre corps lors de l'évaluation de l'arrêt de la marche. Ce test consiste à arrêter devant une ligne marquée sur le sol. Vous aurez à marcher à une vitesse normale et dès que vous aurez atteint la ligne, vous vous arrêterez. Un total d'environ 20 essais doit être fait. Nous estimons la durée de l'évaluation à deux heures, pauses comprises.

Vous ne retirerez aucun bénéfice direct de cette étude. Mais vous nous aiderez à acquérir des données qui nous permettront d’améliorer les connaissances sur une partie du déroulement de la marche peu connue, malgré qu’elle représente un point critique.

Les frais de transport encourus lors de votre visite au laboratoire de locomotion et posture seront défrayés, soit $10,00.

Nous pouvons vous assurer que toutes les informations et données recueillies de même que les résultats demeureront strictement confidentiels et gardés sous-clé. Vous pouvez vous retirer de cette étude en tout temps, sans pénalité, même si vous avez signé le formulaire de consentement.

En cas d’un refus ou d’un retrait, la qualité des soins que vous pourriez éventuellement recevoir n’en sera nullement affectée.

Pour de plus amples renseignements, vous pouvez contacter la responsable du projet, Margrit Meier, au (819) 829-7131 poste 2287.
2. Consentement

Par la présente, (nom du participant/e) ____________________________, j’accepte de participer à l’étude mentionné ci-haut. Je reconnais avoir été informé de façon satisfaisante sur la nature et le motif de ma participation à l’étude. J’ai été également informé(e) que mon nom n’apparaîtra dans aucune publication concernant cette étude et que pour le traitement des données mon nom sera codé. J’ai le droit de me retirer de l’étude en tout temps, sans pénalité, même si j’ai signé ce consentement, en avisant simplement la responsable du projet, dont le nom paraît ci-haut. J’accepte que l’information recueillie puisse être utilisée pour fins de communication scientifique et professionnelle.

J’accepte, de plein gré, de participer à cette étude.

_________________________________________  ___________________________
Signature du participant/e                      Date

_________________________________________
Signature du témoin

_________________________________________  ___________________________
Signature du chercheur                           Date
Information and Consent Form

Gait Termination Analysis in the Healthy Young, Healthy Elderly and Type 2 Diabetic People

1. Information
Among the elderly, the majority of falls occur during walking and daily activities. Stopping one’s gait represents an important phase within the gait cycle. This phase can cause problems in the elderly due to age-related changes. If a disease, such as diabetes, is present, these problems are increased.

The purpose of the present study is to analyze gait termination in healthy elderly and diabetic people. As controls for the diabetic group, we need healthy elderly people who do not demonstrate any walking deficits, which may influence gait termination. This is why we are asking for your participation.

If you agree to participate in this study, the procedure will be as follows: first, a blood glucose test, taken on an empty stomach, will be performed, to be certain that you are not a diabetic. Should the blood test indicate values above normal, you will be referred to your family physician and you will be excluded from the study. However, if the blood test result is within our inclusion criteria, you will be contacted again for the gait termination test. This test will take part in the Posture and Locomotion Laboratory here at the Research Center.

During the gait termination test, you will be asked to complete a short questionnaire regarding your activities and your health. Your vision will be tested followed by measurements of the touch sensitivity of your feet. General information such as height and weight will also be taken. After this data collection, the gait termination session will take place. For the analysis of the gait termination, infrared markers will be placed on your clothes and skin at specific points on your body to register the movement of your limbs. The gait termination test consists of several stopping trials. One trial is composed of a walk at normal speed and then a stop. The stop has to be executed in front of a line, which is indicated on the floor. We estimate that the whole evaluation will take about two hours, breaks included.
There are minimal risks associated with taking part in this study. Possible slight tiredness caused by the duration of the test will disappear on the same day. It exists also a small risk for falling. However, the person who will accompany you during the trials will take every precaution against it. The adhesives used to affix the markers are anti-allergic and one-way stickers. Despite this fact they may cause slight temporary irritations on your skin.

If you decide to participate in this study, you will receive no direct personal benefit. However, the knowledge obtained will be used to help our understanding of a part of the gait cycle about which we have little information, although it represents a critical point.

You will receive $10 for travel expenses related to your participation in this study.

All the information, medical or other, recorded in the course of this study will be treated with the utmost confidentiality and will not be made accessible to anyone not associated with this project. The results will be used solely for scientific and professional publications with rigorous respect for anonymity. Your participation is voluntary and you may withdraw from the study at any time without any penalty.

In the case of your withdrawal, your decision will not influence the quality of care you are receiving or will receive.

If you would like to have more information, please contact the responsible of this project, Margrit Meier, at (819) 829-7131 ext. 2287.
2. Consent of participant

I, (name of participant), ________________________________, agree to participate in the study mentioned above. I have been fully informed in a satisfactory way about the nature of my participation and the objectives of this study. I am also aware that my name will not appear in any publications and that for data analysis a numerical code will be used. I have the right to withdraw from this study at any time without prejudice, even after signing the consent form, simply by advising the responsible named above. I agree that the information collected can be used for scientific and professional publications.

I agree of my own free will to participate as a subject in this study.

Signature of participant ________________________________ Date __________

Signature of witness ________________________________ Date __________

Signature of project director ___________________________ Date __________
Formulaire d’information et de consentement

Evaluation de l’arrêt de la marche chez des personnes jeunes, diabétiques, et âgées

1. Informations
La majorité des chutes chez les personnes âgées surviennent pendant la marche et lors de nombreuses activités quotidiennes. L’arrêt représente une phase importante de la marche. C’est surtout cette phase qui serait plus difficile à réaliser et qui pourrait causer des problèmes chez des aînés à cause des changements reliés au vieillissement. Si, en plus, une maladie comme le diabète est présente, les problèmes se multiplient.

Le but de cette étude est d’analyser l’arrêt de la marche chez des personnes âgées en santé et chez des personnes diabétiques. Nous faisons appel à vous parce que vous faites du diabète.

Si vous acceptez de participer à l’étude, le déroulement sera le suivant. En premier lieu, un bref questionnaire sur vos activités et votre santé doit être rempli. Ensuite, votre vision, la sensibilité de vos pieds, et des mesures corporelles (taille, poids) seront prises avant le test de l’arrêt de la marche. Finalement, des rondelles lumineuses seront placées sur vos vêtements et votre peau à des endroits spécifiques pour enregistrer le mouvement de vos jambes et de votre corps lors de l’évaluation de l’arrêt de la marche. Ce test consiste à arrêter devant une ligne marqué sur le sol. Vous aurez à marcher à une vitesse normale et dès que vous aurez atteint la ligne, vous vous arrêterez. Un total d’environ 20 essais doit être fait. Nous estimons la durée de l’évaluation à deux heures, pauses comprises.

Des risques minimaux sont associés à la participation de l’étude : Une fatigue légère causée par la durée de l’évaluation devrait disparaître dans la même journée. Il existe un risque minime de chutes. Mais des précautions seront prises pour éviter des blessures, ceci par l’intermédiaire d’une personne qui va vous suivre lors de la tâche. Les collants utilisés pour fixer les rondelles lumineuses
ne devraient pas créer des irritations à votre peau. Ils sont jetés après chaque usage. Malgré ce fait ils peuvent créer des très petites rougeurs temporaires sur la peau.

Vous ne retirerez aucun bénéfice direct de cette étude. Mais vous nous aiderez à fournir des données qui nous permettrons d’améliorer les connaissances sur une partie du déroulement de la marche peu connu, malgré qu’elle représente un point critique.

Les frais de transport encourus lors de votre visite au laboratoire de locomotion et posture seront défrayés, soit $10,00.

Nous pouvons vous assurer que toutes les informations et données recueillies de même que les résultats demeureront strictement confidentiels et gardés sous-clé. Vous pouvez vous retirer de cette étude en tout temps, sans pénalité, même si vous avez signé le formulaire de consentement.

En cas d’un refus ou d’un retrait, la qualité des soins que vous recevrez ou pourriez recevoir n’en sera nullement affectée.

Pour de plus amples renseignements, vous pouvez contacter la responsable du projet, Margrit Meier, au (819) 829-7131 poste 2287.
2. Consentement

Par la présente, (nom de participant/e) ____________________________, j'accepte de participer à l'étude mentionnée ci-haut. Je reconnais avoir été informé de façon satisfaisante sur la nature et le motif de ma participation à l'étude. J'ai été également informé(e) que mon nom n'apparaîtra dans aucune publication concernant cette étude et que pour le traitement des données mon nom sera codé. J'ai le droit de me retirer de l'étude en tout temps, sans pénalité, même si j'ai signé ce consentement, en avisant simplement la responsable du projet, dont le nom apparaît ci-haut. J'accepte que l'information recueillie puisse être utilisée pour fins de communication scientifique et professionnelle.

J’accepte, de plein gré, de participer à cette étude.

__________________________________________  ____________________________
Signature du participant/e                                           Date

__________________________________________  ____________________________
Signature du témoin                                                  Date

__________________________________________  ____________________________
Signature du chercheur                                               Date
Information and Consent Form

Gait Termination Analysis in Healthy Young, Type 2 Diabetic People and Healthy Elderly People

1. Information

Among the elderly, the majority of falls occur during walking and daily activities. Stopping one’s gait represent an important phase within the gait cycle. This phase can cause problems in the elderly due to physiological age-related changes. If a disease, such as diabetes, is present, the problems are increased.

The purpose of the present study is to analyze gait termination in healthy elderly and diabetic people. Because you are a diabetic, we ask for your participation.

If you agree to participate in this study, the procedure will be as follows: first, a short questionnaire regarding your activity level and your health will be filled in. Your vision will be tested followed by the determination of peripheral neuropathy and the sensitivity of your feet. General information such as height and weight will also be taken. After this data collection, the gait termination session will take place. For the analysis of gait termination, infrared markers will be placed on your clothes and skin at specific points of your body to register the movement of your limbs. The gait termination test consists of several stopping trials. One trial is composed of a walk at normal speed and then a stop. The stop has to be executed in front of a line, which is indicated on the floor. We estimate that the whole evaluation will take about two hours, breaks included.

There are minimal risks associated with taking part in this study. Possible slight tiredness caused by the duration of the test will disappear on the same day. It exists also a small risk for falling. However, the person who will accompany you during the trials will take every precaution against it. The adhesives used to affix the markers are anti-allergic and one-way stickers. Despite this fact they may cause slight temporary irritations on your skin.
If you decide to participate in this study, you will receive no direct personal benefit. However, the knowledge obtained will be used to help our understanding of a part of the gait cycle about which we have little information, although it represents a critical point.

You will receive $10 for travel expenses related to your participation in this study.

All the information, medical or other, recorded in the course of this study will be treated with the utmost confidentiality and will not be made accessible to anyone not associated with this project. The results will be used solely for scientific and professional publications with rigorous respect for anonymity. Your participation is voluntary and you may withdraw from the study at any time without any penalty.

In the case of your withdrawal, your decision will not influence the quality of care you are receiving or will receive.

If you would like to have more information, please contact the responsible of the project, Margrit Meier, at (819) 829-7131 ext. 2287.
2. Consent of participant

I, (name of participant), ____________________________, agree to participate in the study mentioned above. I have been fully informed in a satisfactory way about the nature of my participation and the objectives of this study. I am also aware that my name will not appear in any report and that for data analysis a numerical code will be used. I have the right to withdraw from this study at any time without prejudice, even after signing the consent form, simply by advising the responsible named above. I agree that the information collected can be used for scientific and professional publications.

I agree of my own free will to participate as a subject in this study.

_________________________________  ____________________________
Signature of participant                  Date

_________________________________  ____________________________
Signature of witness                     Date

_________________________________  ____________________________
Signature of project director             Date
APPENDIX 5

Data Forms:

   Socio-demographic Data (French)
   Socio-demographic Data (English)
   Nominal Data (French)
   Nominal Data (English)
   Peripheral Neuropathy Test according to Valk
   Vibration Sensitivity Threshold Test (MOL)
   Vision Acuity determined by the Snellen Chart
L'arrêt de la marche chez des personnes jeunes et âgées et chez des personnes âgées diabétiques de type 2

Données sociodémographiques

Nom ___________________________ Prénom ___________________________

Adresse __________________________________________________________

Tél. ___________________________ Âge _________ Code _________

Groupe: jeunes ☐ âgées ☐ diabétiques ☐
        fumeur/se ☐ non-fumeur/se ☐

Histoires des médicaments, fractures, chutes, problèmes avec des articulations, symptômes persistants de vertige ou d’insécurité

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

Evaluated by _________________ Date _________________
Gait Termination in Healthy Young and Elderly People
and in Type 2 Diabetics

Sociodemographic Data

Surname __________________________ First name __________________________

Address __________________________________________________________________

Phone ______________ Age __________ Code ________

Group:  Young ☐  Elderly ☐  Diabetic ☐
        Smoker ☐  Non-smoker ☐

History of medications, fractures, falls, joint problems, persistent symptoms of vertigo
and/or unsteadiness
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Evaluated by __________________________ Date __________________________
Données nominatives

Code ___________________ Date ___________________

1. Niveau d'activité
Une description de vos activités nous aidera à interpréter les résultats de la présente étude. Quelles sont vos activités préférées ? S'il vous plaît, cochez-les, encerclez cette/celles que vous faites le plus souvent et indiquez la fréquence.

☐ artisanat : ________________ ☐ patinage
☐ cinéma, concert, théâtre ☐ pêche
☐ chasse ☐ randonnée pédestre
☐ danse ☐ ski alpin
☐ golf ☐ ski de fond
☐ quilles ☐ tennis
☐ canot-kayak ☐ vélo
☐ lecture ☐ volley-ball
☐ marche ☐ autres : ________________
☐ natation

※ Par rapport aux autres personnes de votre groupe d'âge, est-ce que vous estimez que vous êtes
☐ très actif/ve ☐ actif/ve ☐ peu actif/ve ☐ sédentaire

2. Autoperception de la santé
※ Comparativement aux autres personnes de votre âge, comment estimez-vous votre santé physique ?
☐ excellente ☐ bonne ☐ passable ☐ pauvre

Evaluated by ___________________

L'arrêt de la marche MM/1998
Nominal Data

Code _______________    Date _______________

1. Activity level
A description of your activities will give us a better understanding of the future results from this study. Which of the following activities do you prefer? Please tick them, circle the one(s) you do most often and indicate their frequency.

☐ handicrafts: ______________
☐ cinema, concert, theatre
☐ hunting
☐ dancing
☐ golf
☐ skittles
☐ canoe-kayaking
☐ reading
☐ walking
☐ swimming

☒ skating
☐ fishing
☐ hiking
☐ downhill skiing
☐ cross-country skiing
☐ tennis
☐ biking
☐ volleyball
☐ others: ______________

∗ Compared with others in your age group, would you describe yourself as
  ☐ very active    ☐ active    ☐ slightly active    ☐ sedentary

2. Self-perception of your health

∗ How would you estimate your health compared with others of your age?
  ☐ excellent    ☐ good    ☐ reasonable    ☐ poor

Evaluated by ______________
### Scoring System for Peripheral Neuropathy

*according to Valk et al., (1992)*

<table>
<thead>
<tr>
<th>Test</th>
<th>Location</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pin-prick sense</td>
<td>Dorsum of the foot</td>
<td>0 (normal) 1 (impaired) 2 (absent)</td>
</tr>
<tr>
<td>Light-touch sense (cotton wool)</td>
<td>Dorsum of the foot</td>
<td>0 (normal) 1 (toe) 2 (mid-foot) 3 (ankle) 4 (mid-calf) 5 (knee)</td>
</tr>
<tr>
<td>Anatomical level of light-touch sense</td>
<td></td>
<td>0 (normal) 1 (toe) 2 (mid-foot) 3 (ankle) 4 (mid-calf) 5 (knee)</td>
</tr>
<tr>
<td>Vibration sense</td>
<td>Ankle</td>
<td>0 (normal) 1 (impaired) 2 (absent)</td>
</tr>
<tr>
<td>Strength of extensor hallucis longus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength of gastrocnemius</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle jerk (triceps-surae reflex)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total Scoring Graduation:**

Total Scoring Graduation: 0 = no polyneuropathy 10-18 = moderate 19-33 = severe

Evaluated by ________________

L'arrêt de la marche MM/1998
Vibration Sensitivity Threshold (amplitudes in microns)
via Method of Limits (MOL) (Gerr et al., 1990)

| Code: ____________ | Date: ____________ |

<table>
<thead>
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<th>Left big toe</th>
<th>Trials</th>
</tr>
</thead>
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<td>VPT</td>
<td></td>
</tr>
<tr>
<td>VDT</td>
<td></td>
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<tr>
<td>VT</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Right big toe</th>
<th>Trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
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<tr>
<td>VDT</td>
<td></td>
</tr>
<tr>
<td>VT</td>
<td></td>
</tr>
</tbody>
</table>

VPT= Vibration perception threshold   VDT= Vibration disappearance threshold
VT= Vibration threshold (average of VPT and VD)

Evaluated by ____________
Visual Acuity
determined by the Snellen Chart

Example:

Legend:

VA : visual acuity
c : with correction
sc : without correction
: right eye
: left eye
6/6 : acuity level with one letter incorrect
6/6 -1 : acuity level with one letter incorrect
(Handler & Ghezzi, 1995)

Code : ____________  Date : ____________

Evaluated by ____________