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IDENTIFICATION OF FALL-RISK FACTOR DEGRADATIONS USING QUALITY OF BALANCE MEASUREMENTS

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"The only thing necessary for the triumph of evil is for good men to do nothing"

Edmund Burke

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ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person, nor material that to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

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ETHICAL APPROVAL

The New Zealand study 'Construction of a physiological model of balance in older adults based on measures of sway' (12/301) was granted ethical approval by the AUT Ethics Committee (AUTEC) on 10 January 2013.

The Indian study was granted ethical approval by Dr. S.N. Medical College, Jodhpur on 28 February 2012.

ABSTRACT

OBJECTIVE:

The aim of the thesis was to develop a model based on balance quality parameters to detect musculoskeletal and sensory degradations in people with balance disorders. The long term objective of such a tool is to facilitate the prescription of a targeted fall-risk intervention programme.

CONTEXT:

More than 30 % of community-dwelling adults aged over 65 years old fall each year. The consequences of falls can be dramatic, including a loss of autonomy due to decreased mobility and a reduced capacity to perform activities of daily living. In addition to decreased autonomy, falls are also the biggest cause of morbidity in the elderly. The financial cost incurred due to falls and their consequences is massive, exceeding two billion euros per year for France alone. The overall cost of falls worldwide has been predicted to reach US$ 175 Billion per year by 2050.

The causes of falls have been widely reported in the literature as multi-factorial, with risk factors grouped as environmental, behavioural and intrinsic. In respect to intrinsic risk factors, one of the main causes is musculoskeletal and sensory degradation leading to a decrease in balance quality.

Lack of quick and autonomous assessment of the intrinsic factors has been a limitation of research into falls and balance problems in the elderly. In the current study, this is addressed by investigating signal processing for the detection of degradation of intrinsic factors. Early identification of decreased balance ability as a result of intrinsic risk factors could enable targeted intervention programmes to be setup that could reduce fall risk. It follows that if such a detection program could identify the specific sensory system affected, the rehabilitation program proposed could then be tailored to the needs of the individual.

The aim of this thesis is to develop a test that could enable the specific sensory degradations underlying the observed decrease in balance ability to be identified. The thesis consists of two different experimental interventions on both control and elderly subjects, carried out at Jodhpur in India and at Auckland in New Zealand.

METHODS:

RECRUITMENT

Fifty young healthy adults (25 in Jodhpur India and 25 in Auckland New Zealand) and 25 elderly adults (Jodhpur India) were recruited to participate in the study.

BASELINE TESTS

Six intrinsic factors were investigated: vision (acuity, contrast, depth and peripheral), vestibular system, joint and muscle proprioception, joint range of motion, leg muscle strength and foot cutaneous proprioception. These intrinsic factors were assessed using clinical tests, namely the Snellen chart (visual acuity), Perceptrix chart (visual contrast), Frisby test (depth vision) and manual perimeter test (peripheral vision), Fukuda stepping test (vestibular), repositioning angle (joint proprioception) and Semmes Weinsten monofilament test (foot cutaneous proprioception). The leg-muscle strength was the only test that differed between

young healthy and elderly population: young healthy adults performed isometric maximal voluntary contraction, whereas the elderly performed sit to stand and heel raise tests.
The participants were also tested for standing balance. They were required to step on a force plate, stand still and step back off the force plate, with a total testing duration of 30 seconds.

DEGRADATION

In order to examine the effect of each intrinsic fall-risk factor on the balance measured on the force plate, it was required to investigate the intrinsic factors separately. Only the healthy population was submitted to temporal degradation of each of the intrinsic factors. The temporal degradations were: wearing blurring googles (visual acuity), bright lights (visual contrast), one eye covered (depth vision), tunnel vision (peripheral vision), vestibular galvanic stimulation (vestibular), vibrators on the tendons (joint and muscle proprioception), wearing joint braces (joint range of motion), leg fatigue exercises (muscle strength) and hypoesthesia (foot cutaneous proprioception).

POST TESTS

The same tests as those performed for the baseline tests were used after the degradations. The measurement of balance on the force plate was also performed after the degradations.

ANALYSIS

Average, standard deviation, minimum and maximum values of the clinical tests of the healthy adults before and after the temporal degradations were computed to attest for the efficiency of the degradation and to compare with elderly data. The data of the clinical test from the elderly population was used to determine the major impairment of each elderly tested.
The data from the force plate was extracted to compute a total of 198 balance quality parameters for the stepping up, standing still, and stepping down periods of the balance tests. The parameters were computed in Matlab.
The balance quality parameters were used to build models with Weka software using logistic regression, artificial neural network, decision tree and support vector machine classifiers. The models were submitted to a feature selection process. They were tested with data splitting and cross validation for internal validation and with additional data (elderly data) for external validity.
The construction of models aimed at recognizing pattern of balance parameters specific to the degradation of each intrinsic factor was performed. The testing of the models aimed to ensure the models were able to detect the correct degraded intrinsic factor within the data tested. The validation aimed at investigating whether the models were able to detect impairment of the intrinsic factor in a real population of impaired elderly. The percentage accuracy and the Kappa coefficient were used to assess the validity of the models.

RESULTS:

The results of the intrinsic factors tests showed that the control subjects had higher scores than the degraded controls. Concerning the elderly, they mainly showed lower score than the control subjects after degradation.
A large numbers of models were built with various combination of conditions included. The models that included all the conditions (10 conditions) were not found relevant. However models including up to five conditions were found to be valid. The construction of the models showed accuracy between 67-86% for training sets and from 70-90% of testing sets for models to classify into control and degraded condition for the young subjects.
The best models built to discriminate between various condition showed accuracy of 81% (0.72 kappa) for three conditions (ankle range of motion, muscle strength and cutaneous

proprioception), 75% (0.66 kappa) for four conditions (Ankle RoM, muscle strength, cutaneous proprioception, and visual contrast) and 64% (0.53 kappa) for five conditions (ankle RoM, muscle strength, cutaneous proprioception, visual contrast, and hip proprioception).
The feature selection reduced the number of parameters from 198 down to a smaller number, which varied from 3-20, depending on the model. After feature selection and data spitting, the models showed accuracy up to 71% (0.63 kappa) for five-condition models, 79% (0.79 kappa) for four-condition models and up to 92% (0.88 kappa) for three-condition models.
Finally, the external testing of the models using elderly data validated six models with three conditions with an accuracy from 75-100%, and one model with four conditions (75% accuracy).

CONCULSION:

The overall study showed that it was possible to differentiate between types of sensory degradations in respect to their effect on balance quality. Patterns of the balance quality parameters were found to be specific to different degradations, with conditions recognized by classifiers and neural network models. The findings provide initial evidence that balance quality measurement can be used as a tool to detect intrinsic impairment. At this point, models are able to differentiate healthy from impaired populations and can also classify impaired participants within a selection of impaired conditions. The results were obtained in the healthy population to whom experimental degradations were performed.
An early detection of impairments could enable preventive action and intervention to be applied in order to reduce the effects of the sensory disorders and possibly improve balance. Future studies are needed to validate the model on real impairments as opposed to the artificial degradations utilised in the current study. A series of longitudinal studies following specific impairments and re-education programs would also be of value.

KEY WORDS

In French

- Sciences de la santé
- Chutes de la personne âgée
- Equilibre (physiologie), Troubles de l'
- Posture
- Diagnostic
- Capteurs de force
- Traitement du signal
- Intelligence artificielle

In English

- Medical sciences
- Fall (Accidents) in older people
- Balance
- Posture
- Diagnosis
- Signal processing
- Artificial intelligence

1. CHAPTER 1 LITERATURE REVIEW

1.1 INTRODUCTION TO THE CHAPTER 1

This thesis is part of an ambitious research programme that aims at making a degradation-specific diagnosis for the prevention of falls. The thesis describes the development of a series of models to detect the impairments responsible for a decrease in the quality of balance, which is one of the main risk factors in falls in older people.
This thesis work investigated the possibility of developing an accurate, easy, quick, and low-cost clinical assessment tool of balance quality. The current study works on validating the concept for building such a tool. The assessment aimed to detect risk factors for falls, which would help a therapist prepare a targeted and personalised programme, with the aim of improving the results of the intervention programmes. In this introductory chapter several subjects are developed. Firstly, a detailed description of the causes and consequences of falls in older people is presented. Secondly, a selection of major risk factors for falls is described, along with their effect on balance quality. Thirdly, methods to assess balance quality are described, along with specific details in respect to parameters extracted from force plate recordings. Fourthly, the use of models for diagnosis and prediction in medicine are quickly reviewed, and finally, the objective and the hypothesis of the thesis are discussed.

1.2 SEARCH STRATEGY

Literature searching was performed on several databases: scopus, science direct and ebsco health database.
The words searched were: fall, risk, consequences, causes, factors, assessment, cutaneous, vision, vestibular, joint range of motion, receptors, stance, elderly, diagnosis, health, muscle, strength, power, proprioception, balance, measurement, postural, sway, posture, age, sway-parameters, model, discrimination, classification, neural network, simple logistic and decision tree and combination of those keywords. Articles written in English or French were included.

1.3 BALANCE IN THE ELDERLY

1.3.1 FALL RISK

Falls in the elderly are a major societal problem with medical, social, and financial consequences. In a review of the incidence of falls, Rubenstein and Josephson (2002) identified both consequences and causes of falls. They reported an incidence of falls ranging from 30 to 60% among community-dwelling adults aged over 65 y. In respect to institutions, rate of falls per year in retirement homes was 1.6 times that of community dwelling elderly, while an incidence of 1.4 for hospitals was reported. The incidence of falls increases with increasing age, with the highest incidence reported among people aged 80 years and over. Tinetti et al. (2006) reported that one third of community living adults aged 65 year and older falling each year, while the proportion of falls in adults aged 80 reached 50%. Similarly, Shumway-Cook et al. (2009) reported 22% of elderly health cover beneficiaries in the USA falling each year, representing 6.86 million people. Recurrent falls occurred in 10% of the population, which represented 3.1 million people.
The problem of falls is only going to increase as a function of the ageing. Indeed, according to the French National Institute of Statistics (INSEE) there are 13 times more 100 year old

people in 2010 compared to 1970, with an estimate that there will be 13 times more in 2060 compared to 2010 (Blanpain 2010). In respect to New Zealand: the population aged 65 and over will increase from 550,000 in 2009 to one million in the late 2020s, which means that from 13% of the population in 2009, the group people aged over 65 years will have increased by 20% in 2020 and 25% in 2050 (Ashley-Jones 2009). Such increases are likely to lead to a parallel increase in the occurrence of fall within the elderly population.

1.3.2 CONSEQUENCES OF FALLS

1.3.2.1 DISABILITY/MORBIDITY

Falls can lead to dramatic consequences for the faller, in term of physical impairment as well as psychological and social problems. The combination of these three consequences is an increased functional decline, eventually leading to morbidity (Lord, et al. 2002). In respect to physical consequences, 10% of elderly fallers sustain serious injuries such as fracture or head injury, resulting in a reduction in mobility and problems performing daily tasks (Rubenstein and Josephson 2002; Tinetti, et al. 2006). In addition, fear of falling can often occur post-fall, with 30 to 75% of elderly affected. It leads to loss of confidence, self-restriction of physical activity and social isolation, all of which further increase functional decline (HAS 2005; MacIntosh and Joy 2007; Tinetti, et al. 2006). The decreased ability for ambulation due to injurious falls, when combined with the lack of activity resulting from fear of falling leads to morbidity. Twenty-five to 75% of the elderly who sustained an injurious fall do not recover the level of mobility they had before the fall (HAS 2005; Rubenstein and Josephson 2002). The direct consequence of the decreased mobility is that 30% of elderly fallers entered a nursing home (Freudenberger Jett, et al. 1996; Rubenstein and Josephson 2002). These data highlight the dramatic consequences of falls and the urgent need for the intervention decreasing the risks of fall.

1.3.2.2 COST

The costs directly linked with falling are substantial for society in general (Lord, et al. 2002). Rizzo and al. (1998) reported that the occurrence of one or more injurious falls led to an annual increase of almost US$20000 in health care costs. A similar study was conducted recently by Shumway–Cook and colleagues (2009). They evaluated the cost of falls among Medicare beneficiaries in the US, and found that health care costs for an elderly faller after one fall were 29% ($2000) higher than for a non-faller, while for recurrent fallers the increase was 79% ($5600) higher without counting the cost of single falls. In respect to injurious falls, the cost increases by 44% ($4100) when compared to non-injurious falls. In one study in which the cost of falls was evaluated in an Irish hospital (Cotter, et al. 2006), in-patient stay was estimated to cost 7.46 M€, with an additional 2.9 M€ required for rehabilitation. The total was approximately 10.8 M€ for one year, and for only one hospital. The total health care costs for falls in the USA has been estimated at 19.5 billion dollars per year (Tinetti, et al. 2006) .
These studies showed a strong association between health care costs incurred with the frequency and severity of the fall. Given the increase in the elderly population, the cost of falls is only going to increase.

1.3.3 CAUSES OF FALLS

A large number of studies have been published on the possible causes of falls. According to various reviews and best guidelines (INPES 2008; Services 2008), fall-risk factors can be classified into three broad categories:

- **ENVIRONMENTAL RISK FACTORS FOR FALLS**

Environmental risk factors of falls are related to all hazards in the environment that could provoke falls, either in the home or outside the home, in the street or any unfamiliar context. Examples of typical environmental hazards are carpet, slippery floors, uneven floors, poor lighting (Banez, et al. 2008; Bleijlevens, et al. 2010; Chang and Ganz 2007; Dominguez and Bronstein 2000; Elley, et al. 2007; Gates, et al. 2008; Hendriks, et al. 2008; Services 2008).

- **BEHAVIOURAL RISK FACTORS OF FALLS**

Several behavioural risk factors have been listed in the literature. Those risk factors included decrease of physical activity (Campbell , et al. 1981; Chang and Ganz 2007; Dominguez and Bronstein 2000; Gates, et al. 2008), inappropriate footwear (Banez, et al. 2008; Hendriks, et al. 2008), polypharmacy (Barker, et al. 2009; Beling and Roller 2009; Boele van Hensbroek, et al. 2009; Cameron, et al. 2010; Campbell , et al. 1981; Chang and Ganz 2007; Gates, et al. 2008) inappropriate nutrition and lack of vitamin D intake (Cameron, et al. 2010; Gates, et al. 2008), presence of chronic disease (Barker, et al. 2009; Cameron, et al. 2010; Chang and Ganz 2007; Dominguez and Bronstein 2000), the lack of social support (Campbell , et al. 1981; Chang and Ganz 2007), the fear of falling (Banez, et al. 2008) and the mental state or cognitive status (Barker, et al. 2009; Beling and Roller 2009; Campbell , et al. 1981; Hendriks, et al. 2008).

- **INTRINSIC RISK FACTORS OF FALLS**

Other risk factors of fall concern the locomotor system and physiological conditions.
Reduction of balance is the most reported risk factor for fall, (Beling and Roller 2009; Boele van Hensbroek, et al. 2009; Brauer, et al. 2000; Chang and Ganz 2007; Hendriks, et al. 2008). Vision disabilities as a risk factor of fall have also been largely reported (Barker, et al. 2009; Beling and Roller 2009; Blain, et al. 2010; Gates, et al. 2008; Harwood, et al. 2005). Other factors have also been listed such as decrease of the strength of the lower limbs (Beling and Roller 2009; Blain, et al. 2010; Chang and Ganz 2007; Dominguez and Bronstein 2000; Elley, et al. 2007), range of motion of the joint (Beling and Roller 2009; Chang, et al. 2004) and reduction of other sensory than vision such as vestibular and somatosensation (Barker, et al. 2009; Beling and Roller 2009; Brauer, et al. 2000; Dominguez and Bronstein 2000).

1.3.4 RISK FACTOR ASSESSMENT

A large number of successful studies addressed the problem of falls in elderly by starting with assessment of the risk of falls and then proposing a fall prevention programme (Beling and Roller 2009; Boele van Hensbroek, et al. 2009; Chang and Ganz 2007; Choy, et al. 2004; Gates, et al. 2008; Lord, et al. 2005; Moreland, et al. 2003; Williams, et al. 2007). The detection of risk factors for falls in an elderly person is designed to seek the reason underlying the falls, and is therefore essential to target an appropriate intervention. Reduction of the risk factors of fall could lead to reduction of fall rate (Banez, et al. 2008; Beling and Roller 2009; Boele van Hensbroek, et al. 2009; Choy, et al. 2004; Gates, et al. 2008; Hedley, et al. 2010;

Lord, et al. 2005; MacIntosh and Joy 2007; Moreland, et al. 2003; Rubenstein 2006; Society 2001b; Tinetti, et al. 2006).
Olvier and al. (2004) concluded their review on risk factor assessment tool by few statement including that there are not so many validate and effective tools and that even the best would not detect all the fallers or risk of falls. They also agreed with other authors (Choy, et al. 2004; Oliver, et al. 2004; Society 2001b) on the conclusion that the key to a successful reduction in falls might be to concentrate on an improvement in standing balance by targeting reversible risk factors in the intervention programme

1.3.5 Investigation of the Intrinsic factor

The previous section identified several risk factors of falls. According to my research interest and my area of study, the project was focused on the investigation of the intrinsic factors of falls. Another reason for choosing to investigate the intrinsic factors is that impairments of some intrinsic factors decreasing balance have been found to be reversible by means of an intervention by health professionals such as physiotherapists. Indeed, a range of different exercise interventions targeting intrinsic factors have been found to increase the quality of balance, such as Tai Chi (Fong and Ng 2006; Hong and Li 2007) which mainly improve strength, joint and foot sole proprioception, muscle or skin stimulations for strength and proprioception (Amiridis, et al. 2005; Rogers, et al. 2001), balance training programmes with multidisciplinary exercises (Banez, et al. 2008; McKeon, et al. 2008; Smania, et al. 2008; Westlake and Culham 2007), and strength training programmes (Bottaro, et al. 2007; Sekir, et al. 2007). Those encouraging results motivate the investigation of the intrinsic factors for the improvement of balance.
The intrinsic factors are in this study the risk factors of fall related to the locomotor and sensory system such as vision, vestibular, musculoskeletal system including joint range of motion or proprioceptive system (Campbell , et al. 1981; Choy, et al. 2004; Sturnieks, et al. 2008). The risk factors of fall relative to the cognitive system or nervous system are not included in this study for the simple reason that the restriction to a few numbers of factors was necessary to conduct such study.

1.4 Sensorial and musculoskeletal intrinsic factors contributing to postural control

1.4.1 Vision

1.4.1.1 Vision, Balance and Age

It has been shown that closing the eyes and thus totally suppressing vision markedly decreases balance quality (Guerraz and Bronstein 2008a; Harwood 2001; Ray and Wolf 2008; Shin, et al. 2008). Furthermore, the presence of visual impairment in challenging conditions such as unstable ground, creates a notable decrease in balance quality (Abdelhafiz and Austin 2003;

Black, et al. 2008; Lord, et al. 1991a; Lord and Menz 2000). Those studies have explored the mechanisms concerning this decrease in balance quality related to vision and have identified different components involved in visual performance. Those visual component are the visual acuity, contrast sensitivity, depth perception, and visual field and shown that poor performance in any one of the components usually affects the others (Chiu, et al. 2008; Harwood 2001; Ivers, et al. 2000; Wist, et al. 2000).

Older adults have normal age-related changes in vision resulting in worsening visual performance with age (Chou, et al. 2009; Ivers, et al. 2000; Lord, et al. 1991a; Wade and Jones 1997). However, in addition to normal ageing, impaired vision is highly prevalent in the elderly population, particularly women and institutional care residents (Abdelhafiz and Austin 2003; Chou, et al. 2009; Harwood 2001; Steinman, et al. 2009).

The visually impaired elderly population tends to exhibit poor functional capacity including poor balance leading to greater morbidity (Chou, et al. 2009; Lee and Scudds 2003; Ray and Wolf 2008; Van Nispen, et al. 2009).

Impaired vision has been found to be a factor in falls in the elderly (Arfken, et al. 1994; Boele van Hensbroek, et al. 2009). The detailed vision component and its implication in balance are detailed in the following sections.

1.4.1.2 VISION COMPONENTS

Vision includes different components that are all related to balance quality and fall risk, all of which are degraded with age (Chew, et al. 2010; Lamoureux, et al. 2010; Lord 2006).

VISUAL ACUITY

Visual acuity, which can be considered as a measure of a person's ability to detect fine details in vision (Harwood 2001; Lord 2006), decreases markedly with age (Bergman and Sjöstrand 2002). Older adults with decreased visual acuity have poorer functional balance compared to elderly with no or low acuity impairment (Lee and Scudds 2003). Ivers and colleagues (2000) found an association between poor visual acuity and daily life self-reported disabilities mostly related to mobility and ability to pursue normal social life. Some studies have found visual acuity impairment to increase the risk of falling with hip fractures (Abdelhafiz and Austin 2003; Harwood 2001). However, others have not shown any correlation between visual acuity and fall risk (Arfken, et al. 1994; Lamoureux, et al. 2010). It seems likely that visual acuity is not the only visual component, which can put people at risk of falls, with other components of vision also playing an important role (Abdelhafiz and Austin 2003). Visual acuity impairment alone might not be sufficient to disturb balance, a loss of balance is either due to a combination of impairments or due to another vision component.

CONTRAST SENSITIVITY

Contrast sensitivity is the ability of a person to distinguish between an object and its background by perceiving the different contrasts between the two. It is of particular importance in the capacity to detect ground level hazards (Chiu, et al. 2008; Harwood 2001; Lord 2006). A decrease in contrast sensitivity is observed with age (Wade and Jones 1997; Wist, et al. 2000). Whenever the ability to detect edges and objects under low contrast condition is impaired, elderly with slow reaction time, muscle weakness and reduced proprioception, would be at greater risk of falling (Lord, et al. 1991a). Contrast sensitivity was also found to be associated with self-reported disabilities in daily life in the study of Ivers et al. (2000). Several authors have agreed that a decrease in contrast sensitivity increases

instability, and that it might be a better predictor for fall then visual acuity (Abdelhafiz and Austin 2003; Anand, et al. 2003a; Lord 2006; Lord, et al. 1991a; Lord and Menz 2000).

DEPTH PERCEPTION

Depth perception relies on many cues including stereopsis, which is the ability to perceive an object in three dimensions using both eyes (Harwood 2001). Stereopsis decreases with age (Wist, et al. 2000), with depth-perception impairment thought to be one of the strongest factors among visual components related to falls (Lord 2006). For instance, a poor stereopsis increases has been shown to increase sway in the elderly when standing on a compliant surface (Lord 2006; Lord and Menz 2000). Lord (2006) and Chiu et al. (2008) also reported depth perception to be important for daily life especially regarding mobility.

VISUAL FIELD

Visual field is a combination of central and peripheral vision. Central vision is thought to be primarily used for object motion perception and recognition, while peripheral vision is more sensitive to moving scenes, meaning it would be more important for perception of self-motion and postural control (Guerraz and Bronstein 2008b). As with other aspects of vision, visual field decreases with age (Wade and Jones 1997). For instance, the Los Angeles Latino eye study showed that central and peripheral field impairments are frequent in elderly, with more severe impairments resulting in a greater chance of falling (Patino, et al. 2010) however vision was the only parameter taken in account to justify fall rate. Instability, as measured by postural sway, is greater in the elderly with visual field loss, with greater difference in sway observed for more compliant surfaces (Black, et al. 2008; Wade and Jones 1997).

1.4.1.3 VISION, SUMMARY

In conclusion, it seems that the four visual factors are highly related, with multiple interactions in terms of the effect on postural sway, fall risk and generally postural control (Abdelhafiz and Austin 2003; Anand, et al. 2003a; Black, et al. 2008; Chiu, et al. 2008; Foss, et al. 2006; Lord, et al. 1991a; Lord and Menz 2000). It seems likely that an overall visual performance might be more important than one component alone.

1.4.2 THE VESTIBULAR SYSTEM

The vestibular system is composed of three orthogonal semi-circular canals and two otolith organ. The structures are composed of hair cells and fluid. The movement of fluid within the semi-circular canals stimulate the hair cells receptors therefore providing information about the acceleration and the inclination of the head, which are interpreted by the brain as postural information (Agrawal, et al. 2009; Fitzpatrick and Day 2004; Matheson, et al. 1999; Mergner, et al. 2009). In addition to the postural information, the vestibular system is thought to have an important role in dealing with sensory conflict (Alpini, et al. 2004). Degradations or impairments in the vestibular system decrease stability and increase the risk of fall (Agrawal, et al. 2009; Buckley, et al. 2005a; Pedalini, et al. 2009; Walther and Westhofen 2007). Elderly with decreased balance have been found to have greater vestibular impairment (Chester 1991; Jacobson, et al. 2008). Furthermore, elderly with vestibular impairment report a greater fear of falling and show a greater tendency to fall (Agrawal, et al. 2009; Gananca, et al. 2006; Herdman, et al. 2000). Jacobson and colleagues (2008) reported that 73% of patients identified as having a fall risk presented vestibular dysfunction.

The vestibular system progressively and consistently degenerates with age, with the effect of ageing effect due to the degeneration of the vestibular system components: less hairs detecting movement and less efficient nerves to send the information (Alpini, et al. 2004; Matheson, et al. 1999; Nyabenda, et al. 2004; Pedalini, et al. 2009; Walther and Westhofen 2007). Agrawal and colleagues (2009) found that 35% of people aged 40 and over presented with vestibular dysfunction.

The vestibular system is an important factor for risk of fall. Contrary to vision, the impairment of the vestibular system alone seems to be sufficient to impaired balance in adult. A large percentage of the elderly population with vestibular dysfunction are therefore at risk of falls.

1.4.3 JOINT RANGE OF MOTION

Several studies expose reduction of range of motion in the elderly population. Kerrigan et al. (1998) found a reduction in hip range of motion in the elderly population. Vandervoot et al. (1999) stated that a decreased mobility of the ankle was a normal characteristic of ageing, while Gras and colleagues (2004) showed that elderly participants presented a reduction of ankle as well as hip range of motion. Finally Soucie et al. (2011) found range of motion of every joint examined to decrease with age, with the greatest decrease observed in the knee joint.

Most daily living task including mobility and especially walking and stepping up and down requires appropriate or at least sufficient range of motion of the lower limb to clear the foot after the foot take off of the gait cycle (Matsumoto, et al. 2012; Menz, et al. 2006; Vandervoot 1999).
Studenski et al. (1991) and Menz et al. (2006) found a significant decrease in ankle range of motion in elderly fallers compare to non-fallers. Studenski et al. (1991) found elderly non faller to have average of 37.8 ° of ankle plantarflexion compare to faller having 29.2° of ankle plantarflexion. Menz et al. (2006) found 34.8° of ankle plantarflexion for non-fallers and 31.37° for faller.
Cunningham et al. (1993) found that independent women and men had significantly greater hip and ankle range of motion compare to elderly living in nursing homes. In their review, Vandervoot et al. (1999) concluded that extensive loss of ankle range of motion predispose older person to stumble and fall. Additionally, Matsumoto et al. (2012) expose the decreased that lack of range of motion. The knee range of motion was 112.7 ° for non-faller and 104.7° for fallers.

1.4.4 MUSCLES AND JOINT PROPRIOCEPTION

Muscle and joint proprioception refers to the information collected by the receptors within the muscles and the joints. The muscle receptors are the muscle spindles thought to provide the movement sense and the position sense (Lephart, et al. 1998; Proske, et al. 2000; Shaffer and Harrison 2007). The joint receptors included the Ruffini endings which mediate the sensation

of the joint position, the Golgi tendon organ which provide the movement direction and movement intensity from the variation of the contractile force and the Pacianian corpuscles which are the receptors sensitive to the small changes within the movement (Proske, et al. 2000; Shaffer and Harrison 2007; Van Deursen and Simoneau 1999).

Injuries, impairment or inhibition of those receptors have been found to perturb the static and dynamic posture in young adult as well as in elderly. Indeed, impairment such as decrease of joint position sense and vibration sense (Lord, et al. 1991b), the anaesthesia of ankle (Hertel, et al. 1996), surgeries of knee or ankle (Lephart, et al. 1998), foot and ankle neuropathy (Van Deursen and Simoneau 1999), ankle and hip pathologies (Missaoui, et al. 2008) and ankle instability (Munn, et al. 2010) were found to be responsible for the decrease of balance in static and dynamic posture often measured with sway from a force plate (Hertel, et al. 1996; Lord, et al. 1991b; Missaoui, et al. 2008; Munn, et al. 2010; Simoneau, et al. 1995; Van Deursen and Simoneau 1999).

The muscle and joint proprioception decreases with age and further increase the decrease of balance. Petrella et al. (1997) investigated the proprioception of the knee and confirmed the decrease with age and the resultant increase risk of falls. Similarly, Hurley et al (1998) showed that muscle receptors for proprioception are deteriorating with age and contribute to increase the frequency of fall in elderly.

1.4.5 LEGS MUSCLES STRENGTH

Several studies have identified the importance of lower leg muscle strength in the maintenance of balance (Fujiwara, et al. 2006; Le Bozec and Bouisset 2004; Pyykko, et al. 1989).
However, only a selection of these muscles has been found particularly important for the control of balance and those muscles only, are detailed in this section.
The ankle dorsiflexor together with hip and knee flexor muscles are relevant to the maintenance of static balance with preventing from backward falling and dynamic balance with clearing the foot while walking and stepping up (Daubney and Culham 1999). The ankle plantar flexion muscle are involved in the maintenance of static balance by stopping the forward motion and the dynamic balance by pushing off during walking and stepping up (Daubney and Culham 1999; Kerrigan, et al. 1998; Pijnappels, et al. 2005; Vandervoot 1999).
When impaired, those muscles have been found to decrease balance and possibly increase the risk of falls. Lord and colleagues (1991b) reported that muscle weakness of quadriceps and ankle dorsiflexor muscles involved increase sway measurement therefore showing a decrease of static balance.
Vuillerme et al. (2002) reported that decrease of strength of the calf muscles due to fatigue increase the sway measured by increase range, mean speed and dispersion of centre of foot pressure displacement which is interpreted as a decrease of balance. Also using fatigue exercises, Corbeil et al. (2003) showed that participants exhibited an increase in postural sway after fatigue of the plantarflexors muscles. Still using fatigue, Noda et al. (2007) found that decrease of strength of the lower limb due to fatigue induced a greater amount of body sway, measured by the time spent swaying in an antero-posterior direction.
Those three last studies cited used fatigue to decrease the strength of the muscle targeted, however the decrease of muscle strength is not the only result of fatiguing exercises, there are also neuromuscular effects which are not discussed here but still need to be taken into

consideration to lessen the relationship between decrease of strength and decrease of balance due to fatigue.
The elderly population with fall issues have been found to show weaker muscle strength of the lower limbs. Daubney et al. (1999) found the muscle strength to be weaker for ankle dorsiflexor and the hip extensor muscles in a population of elderly with history of falls. Skelton et al. (2002) also found elderly female fallers to have weaker ankle dorsiflexors and La Roche et al. (2010) found weaker ankle plantarflexors and dorsiflexors in elderly females fallers. Sieri and colleagues (2004) found in addition to ankle plantarflexor muscles, decrease of strength of the knee flexors for male and knee extensor for female to be prevalent in faller compared to non-fallers. Menz and colleagues (2006) showed a weakness in toe plantar flexors in elderly fallers. Granacher and colleagues (2008) found that the push off force of the legs was smaller in fallers compare to non-fallers inducing the plantarflexor muscles are less efficient in fallers.

Few authors have showed interest in the muscle power instead of strength of the muscles as a risk factor for fall (Foldvari, et al. 2000; Forte and Macaluso 2008; LaRoche, et al. 2010; Perry, et al. 2007; Suzuki, et al. 2001). It seems that power was most relevant for the investigation of the risks of falls then strength. Indeed, being able to perform a strong movement quickly seems more important than performing a strong movement slowly especially for action like recovering from tripping to prevent a fall or keeping up gait speed. The Study of Granacher et al.(2008) discussed the need of power training in order to develop rapid force allowing efficient response to perturbation of static or dynamic balance.

In relation to muscle strength and age, Choy and colleagues (2004) in their review, stated the normal deterioration of muscle strength with age and that muscle strength has been found to be weaker in fallers compare to non-fallers. Pijnappels et al (2005) concluded his study with that lower limb strength could be an underlying factor of fall in elderly. Finally, Granacher et al. (2008) also described the deterioration of muscle capacities with age but also extensively discussed the need of strength training intervention in elderly population to remedy balance impairment.

1.4.6 CUTANEOUS PROPRIOCEPTION

The cutaneous receptors found on the sole of the foot are at particular importance for the control of posture since they provide the only direct information about the contact with the ground during upright stance and locomotion (Menz, et al. 2006; Meyer, et al. 2004; Wang and Lin 2008). There are four categories of cutaneous receptors (Merkel complex, Meissner corpuscles, Ruffini organs and Pacician corpuscles), which provide information about plantar pressure, shear forces, the amount of stretch of the skin, vibration, and any stimulus on the plantar sole of the foot (Goodwin and Wheat 2004; Kennedy and Inglis 2002; Macefield 2005; McGlone and Reilly 2010).
Cutaneous information from the feet is important for balance. Cutaneous receptors are primarily responsible for detecting contact with the ground and also evaluate the surfaces (slippery, soft, hard) which are relevant to balance (Kennedy and Inglis 2002; Maurer, et al. 2001). Foot receptors also help generate postural responses, with several studies reporting inappropriate and ineffective adjustments such as excessive hip movements or cross over steps, as a result of postural perturbation in the presence of anaesthesia or hypoesthesia of the soles of the feet (Horak, et al. 1990; Perry, et al. 2000). Similar results have been found by other studies with, for example, an increase in postural sway (higher velocity of the centre of

pressure and greater time spent near the outer boundaries of the bases of support) for both single and double-leg stance resulting from a loss of plantar sensation (Hohne, et al. 2011; McKeon and Hertel 2007b; Meyer, et al. 2004; Simoneau, et al. 1995; Wang and Lin 2008). Finally, the foot cutaneous receptors are involved in the regulation of pressure under the foot. Two studies found that simulations of pressure under the foot resulted in postural adjustments (Kavounoudias, et al. 1999; Maurer, et al. 2001). Those postural adjustments appeared to be aimed at redistributing pressure over the foot by avoiding the loaded zones of the feet to carry the all body weight which is possibly damaging, but rather share the pressure on the overall feet surface. However, such adjustments were made even if it results in a decrease of balance. It would therefore imply that those responses are reflexes. Automatic responses would come from excessive loading of foot zones, therefore, sensory information will have to be found elsewhere to maintain balance.

Balance is decrease with a reduction of foot sensitivity, several studies demonstrated an increased in sway due to intervention or disease resulting in low foot sensitivity (Lord, et al. 1991b; McKeon and Hertel 2007b; Menz, et al. 2006; Perry, et al. 2000; Simoneau, et al. 1995; Wang and Lin 2008).
Decreased sensory information from the foot has been reported in the elderly population. Indeed, studies observed a decrease in the number of cutaneous receptors with age, with structural changes observed in receptors with age, as well as a reduction in detection threshold and reduced sensitivity (Gescheider, et al. 2004; Iwasaki, et al. 2003; Perry 2006; Shaffer and Harrison 2007; Tanaka, et al. 1995).

1.5 ASSESSMENT TOOL

1.5.1 ASSESSMENT OF RISK FACTOR OF FALL

Several reviews and guidelines have been published on the assessment of risk factors for falls, with all reaching the same conclusion in respect to the absolute necessity for healthcare professionals to determine the causes of falls. Of particular interest are those risk factors that can be modified by means of a targeted intervention programme, thus reducing the risk of falling (Choy, et al. 2004; MacIntosh and Joy 2007; Oliver, et al. 2004; Rubenstein 2006; Society 2001a; Society 2001b). In order to assess risk factors for falls, many different tests have been developed often these have involved laboratory equipment such as: strength dynamometer (Dodrill 1978), accelerometers (Mayagoitia, et al. 2002), force plates (Karlsson and Frykberg 2000; Shimba 1984), 3D motion capture system (Sutherland 2002), gait-mat analysis (Barker, et al. 2006), isokinetic testing machine (Rothstein, et al. 1987), passive rotational chairs for vestibular testing (Fife, et al. 2000). Laboratory measurement techniques are costly, highly technical and often non-portable equipment therefore not suitable for clinical settings or large field population testing (Berg 1989; Emery 2003).

A large range of clinical tests have also been developed, the review of Choy et al. (2004), Olivier et al. (2004) and Delaune et al. (2007) clearly detailed the clinical tests available. The most used and known cited in those reviews are the Timed up and Go (standing up from a chair, walk 3m then return to the chair to sit down, the performance is timed), the functional reach test (the capacity to reach forward outside the base of support), the walking tests (time 2, 3 or 6 minutes or distance 8,20 or 100 feet), the step test (ability to place the foot on a step as many time as possible in 15seconds), the Berg Balance test (14 items to assess the performance at functional task), the Tinetti Performance Oriented mobility assessment (scale for the evaluation of the abilities for balance and gait), as well as other scales such as the Morse Fall risk score and Stratify score (questionnaires and evaluation with score to assess the fall risks).

The timed up and go test is particularly of interest in the current study. It has been found to be reliable and valid test for quantifying functional mobility. In addition, the test is quick and required no equipment or training (Boulgarides, et al. 2003; Podsiadlo and Richardson 1991; Rydwik, et al. 2011). The review of Bohannon (Bohannon 2006) provides normative data for the score obtained at the TUG according to age.

The reviews of Choy et al. (2004), Olivier et al. (2004) and Delaune et al. (2007) agreed that clinical tests require to be performed along with strength, range of motion, sensory integration assessment to find the impairment leading to balance or mobility dysfunction and consequently design intervention tailored to the need of the person tested (Choy, et al. 2004; Delaune and Ciolek 2007; Oliver, et al. 2004).
Attempts have been made to create devices with quality of laboratory equipment but simple to use, unexpansive and portable. The Wii Balance Board was investigated for its possible assessment of balance. Bartlett et al.(2014) found that the device could differentiate static postural sway between healthy and balance impaired population but only when the difference of centre of pressure displacement was greater than 10 millimetres. The device presents

limitation in the accuracy and precision of the centre of pressure measurements. It is less accurate than a laboratory force platform and the reliability and calibration over lifetime is not ensured. Sarabon et al. (2010) created a portable electronic balance which is a portable version of a force platform. They investigate found that the device was reliable tool to detect change in balance

1.5.2 Assessment of Intrinsic factors

1.5.2.1 Assessment of vision

A great numbers of studies have used vision tests to assess the vision quality of participants in their studies. The reviews of Archesson & Sanders (1995) and Margolis et al. (2002) provide comprehensive details of the various tests used to assess vision. Some studies used devices that, although very precise, are highly expensive and not available in a clinical setting. Examples of such devices include the Humphrey field analyser to assess visual field or slit-lamp biometry (Acheson and Sanders 1995; Black, et al. 2008; Cumming, et al. 2007; Uchiyama and Demura 2007). Other assessment techniques include questionnaires or self-report tests, which can easily be performed in clinical setting. However such tests are less accurate, and are often time-consuming due to the large number of questions (Arfken, et al. 1994; Johansen, et al. 2003; Margolis, et al. 2002). Therefore we looked at clinical test with good reliability for each component of vision investigated in this study.

Kniedtedt & Stamper (2003) review the assessment tools for vision acuity. They encourage the use of log Chart (Snellen test) for clinical study which in fact appears to be the most used in the literature (Anand, et al. 2003a; Anand, et al. 2002; Buckley, et al. 2005b; Campbell, et al. 2005; Chew, et al. 2010). For the vision contrast, Acheson (Acheson and Sanders 1995) cited and illustrated the Pelli Robson test. It also seems to be the most used test for vision contrast assessment (Acheson and Sanders 1995; Anand, et al. 2002; Black, et al. 2008; Chew, et al. 2010; Deshpande and Patla 2007; Elliot, et al. 1995; Elliott, et al. 1996; Harwood 2001). However, the Pelli Robson test, in addition is imposing in addition to be costly and therefore difficult to use in clinical setting. Other systems has been develop to test with similar even better reliability such as the Mars Perceptrix test (Arditi 2005; Dougherty, et al. 2005; Haynes, et al. 2006; Thayaparan, et al. 2007).

Concerning the vision depth also called stereopsis or vision 3D, the most used test seems to be the Frisby test (Chew, et al. 2010; Chiu, et al. 2008; Foss, et al. 2006; Harwood 2001).The last vision component of our interest is the vision field. Spector (Spector 1990) fully described methods to evaluate the vision field with perimeter technique. Most of those techniques are automated, indeed the most used system is the Humprhrey test (Black, et al. 2008; Chew, et al. 2010; Cumming, et al. 2007; Elliot, et al. 1995). This automated system is not easily available and quite costly. It seems, however, possible to use a manual system.

1.5.2.2 Assessment of Vestibular

The vestibular system can be tested using various techniques, including caloric irrigation (water or air irrigation of the external ear canal), vibration (high frequencies), subjective vertical perception (reproduction of a vertical/horizontal line in the dark), head rotation (manual rotation), all body rotation (rotating chair), Fukuda stepping test (stepping in place with eyes closed) and the EquiTest (computerised sensory organisation test). Numerous reviews and studies such as those of Asai et al. (1993), Fife et al. (2000), Karlberg et al. (2002), Nyabenda et al. (2004), and Brandt et al.(2005), have described the use of those tests.
However, all of the tests listed above required either an expensive piece of testing equipment such as the rotating chair or the EquiTest, or the presence of a professional for the caloric test or the manual head rotation. The only inexpensive test that is easy to perform seems to be the Fukuda stepping test.
The Fukuda stepping test requires participants to step in place (standing alternately on each leg), with eyes closed while the rotation of the body from the starting position is measured. Rotatory movements appear on the right for the left-hander and on the left for right-hander. People with vestibular deficiencies have a significantly greater amount of rotation or displacement (Grommes and Conway 2011; Nyabenda, et al. 2004). However, it has been noted that the Fukuda test is not able to distinguish between all vestibular impairments. (Grommes and Conway 2011; Honaker, et al. 2009)

1.5.2.3 Assessment of Joint Range Of Motion

The most common device used to assess joint range of motion is a goniometer (Burroughs, et al. 2005; Hayes, et al. 2001; Randall and Gerhardt 1995; Unver, et al. 2009; Watkins, et al. 1991). Other techniques have been used in older studies, such as photography, radiography, inclinometers, or functional tests (Gajdosik and Bohannon 1987; Hayes, et al. 2001; Randall and Gerhardt 1995). Modern and accurate testing can also be performed using a motion analysis system, which allows rotation measurements in addition to flexion and extension (Bullock-Saxton, et al. 2001; Hayes, et al. 2001). Other techniques include the use of digital goniometers (Miller, et al. 2010) or isokinetic dynamometers (Gehlsen, et al. 1991).

1.5.2.4 Assessment of Joint and Muscle Proprioception

The most widely used test to measure muscle and joint proprioception is the repositioning test, which measures the accuracy with which a participant can reposition their joint to a target angle. The studies have used various measurement devices used varying between inclinometers, digital goniometers, isokinetic dynamometers, or motion capture systems (Adachi, et al. 2002; Allen and Proske 2006; Bjorklund, et al. 2000; Eils and Rosenbaum 2001; Fu and Hui-Chang 2005; Garsden and Bullock-Saxton 1999; Tsang and Hui-Chan 2004).

1.5.2.5 Assessment of leg muscle strength

Previous section on the muscle strength as intrinsic factor reveals that the legs muscles are the most important for the maintenance of posture, this section describes test for the assessment of strength.

Several different clinical tests have been used to measure leg muscle strength and/or leg muscle power such as the box stepping test (Forte and Macaluso 2008), the chair rise test, the stair climbing test (Suzuki, et al. 2001), or the five times sit to stand test (Buatois, et al. 2010; Whitney, et al. 2005). Laboratory tests used to measured leg muscle strength and/or power are either leg extension machines or isokinetic dynamometers (Foldvari, et al. 2000; Forte and Macaluso 2008; Neeter, et al. 2006; Skelton, et al. 2002; Suzuki, et al. 2001; Weirich, et al. 2010). Another test that can be used to measure leg muscle power is the counter movement jump, which can either be a clinical or a laboratory test depending on the measurement technique used. Some studies have used tape, which can then be done in clinical setting, while other studies have used force plates, which then requires a laboratory setting (Forte and Macaluso 2008; Markovic, et al. 2004; Slinde, et al. 2008)

Other clinical tests have been developed such as the five times sit-to-stand test that has been described as a reliable test regularly cited in the literature (Bohannon 1995; Whitney, et al. 2005). To measure calf strength, other tests are cited in the literature and they usually involve dynamometric analysis using machines such as isokinetic dynamometers such as the Cybex or the Biodex (Albracht and Arampatzis 2013; Bassey, et al. 1988; Markhede and Nistor 1979). However, using this maximal voluntary test is difficult in population like elderly because of the possible risk of injuries. An alternative was proposed by Weiss et al. (1988), in which a seated heel-raise test was evaluated.

1.5.2.6 ASSESSMENT OF CUTANEOUS PROPRIOCEPTION

A detailed review of cutaneous tactile sensation tests was provided by Kars et al. (2009). A number of different methods were identified to evaluate tactile sensation: vibration perception threshold, touch-pressure sensation threshold, two-point discrimination, or pressure algometry. Vibration perception consists of applying vibration on the subject's skin with an increasing amplitude of the vibration until the subject can perceive it (Bergin, et al. 1995; Lundborg, et al. 2010; McDonnell and Warden-Flood 2000). Two-point discrimination consists of applying pressure on two points and asking the participant whether they feel one or two points. The distance between the two points is increased until the subject feels two distinct points (McKeon and Hertel 2007a). Pressure algometry is used to quantify the amount of pressure applied to the plantar surface of the foot. Pressure is increased until the participant feels it as a mild discomfort, with the final pressure recorded (McKeon and Hertel 2007a). The touch sensation threshold is measured with the Semmes Weinstein mono-filament and is the most commonly-used test (Alfuth and Rosenbaum 2011; Berquin, et al. 2010; Eils, et al. 2002; Gopalakrishna Prabhu, et al. 2001; Lundborg, et al. 2010; Perry 2006; Schabrun and Hillier 2009). The neurological disability score (NDS) is a questionnaire assessing tactile sensation asking the subject about numbness and walking sensation (Dyck 1988). Finally, the Valk score consists of a clinical test that includes the testing sensory modalities of light touch, vibration and pain (Boucher, et al. 1995b).

1.5.3 ASSESSMENT OF BALANCE: POSTURAL SWAY

1.5.3.1 SWAY MEASUREMENT

TOOL:

Various methods have been used to measure postural sway in standing posture. Aalto et al. (1988) mentioned different techniques that can be used for posturography including video-camera recording, magneto-metric methods, force plate recordings, and even electromyography. Berg (1989) described techniques to measure sway at hip and head level, as well as force plate measurement. A more up-to-date description of techniques is provided by Emery (2003), with techniques including force plate analysis, electromyography and motion analysis measurement to record the displacement of the centre of mass and centre of pressure (CoP). Finally, the latest tools available to measure balance via laboratory posturography are described in the study of Chaudry et al. (2011). Three devices are described in this study: the force plate, which measures ground reaction forces and is used to determine CoP, the balance master which has a movable support (force plate) and a visual surround, and the Equitest which has a movable support (force plate) and a moveable visual background.

The technique the most widely cited and the most commonly used is the measurement of CoP using a force plate (Duarte and Freitas 2010). Numerous studies have examined balance using a force plate to measure postural sway, such as Brauer et al. (2000), Meyer et al. (2004), Raymaker et al. (2005), Michel-Pelegrino et al. (2009) , and Carpenter et al. (2010)

DURATION:

Studies investigating the reliability of the sway measurement have used measurement durations from 10 seconds to as long as three minutes duration for quiet standing (Prieto, et al. 1993). Shorter durations have been found to be less reliable (Le Clair and Riach 1996). Several durations have been used and found to be reliable in sway measurement. Lafond et al. (2004) recorded the sway for 2 minutes, Lin et al. (2008) for 75 seconds, Meshati et al. (2011) for 35 seconds, Rogind et al. (2003) for 25 seconds, Swanenburg et al. (2008) for 20 seconds and finally Pinsault et al. (2009) concluded that 30 seconds trial recording were sufficient to ensure excellent reliability of the 12 standard CoP measures they chose.

REPETITION:

The number of repetitions needed to record reliable sway data has also been investigated. Le Clair et al. (1996) repeated sway measurement only once for each duration and condition, Roding et al. (2003) recorded sway once but at four different times of the day. Lafond et al. (2004) concluded that only two trials were necessary but that they needed to be performed within an overall time period of two minutes. Doyle et al. (2007) concluded that five sway trials of 60 s gave the best reliability, while Swanenburg et al. (2008) averaged four sway trials. Lin et al. (2008) averaged three trials of quiet standing, while Pinsault et al. (2009) concluded that an increase in the number of trials averaged increases the reliability, with 10 trials recommended. More recently, Meshkati et al. (2011) averaged sway over three trials.

It seems that the literature do not agree on a specific number of repetition of the sway measurement for the reliability of the measurement.

1.5.3.2 SWAY DESCRIPTION

The postural sway is the recording of the displacement of the centre of pressure in the three axis, antero-posterior, medio-lateral and vertical. When standing still, the human body is unstable due to the position of the centre of gravity located way above the ground and therefore way above the centre of pressure (Chaudhry, et al. 2011; Duarte and Freitas 2010; Prieto, et al. 1993; Winter 1995).
The representation of a force plate measurement is showed in Figure 1.

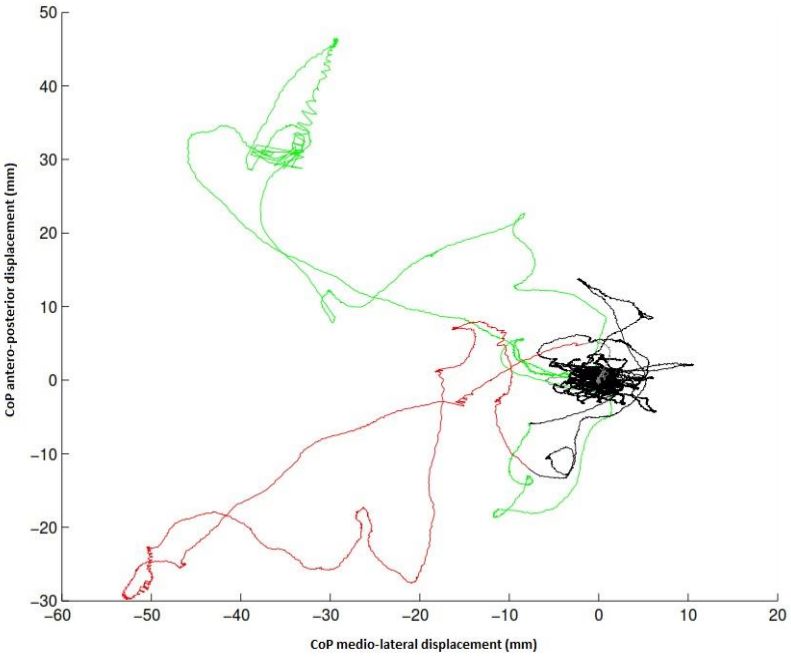


FIGURE 1: REPRESENTATION OF A FORCE PLATE MEASUREMENT: STATOKINESIGRAMME / STABILOGRAMME

1.5.3.3 SWAY VARIABLES

There is a large range of variables that can be computed from the measurement of sway to qualify the different aspect of human standing. The main variables reported in the literature are the sway path, the root mean square, the mean velocity, the acceleration, the amplitude, the displacement and the dispersion of the CoP (Duarte and Freitas 2010; Karlsson and Frykberg 2000).

These variables allow comparison of the quality of balance between populations. It has been widely reported that the postural control toward decrease in balance is found in the elderly population (Freitas, et al. 2005; Prieto, et al. 1993; Tanaka, et al. 1998).
The impairment of balance is even greater in the elderly fallers with the fallers presenting increase in the mean speed of the centre of pressure (Fernie, et al. 1982), increase of the medio-lateral sway (Melzer, et al. 2004), increase of the mean medio-lateral speed, mean medio-lateral amplitude and root mean square of the centre of pressure (Piirtola and Era 2006), differences in the detrented fluctuation and stabilogram diffusion analysis (Amoud, et al. 2007a) and increase of the RMS on the medio-lateral axis (Amoud, et al. 2007a; Fernie, et al. 1982; Melzer, et al. 2004; Piirtola and Era 2006; Sturnieks, et al. 2008; Swanenburg, et al. 2010).

The force platform can therefore assesses the modification of balance and discriminate population young, elderly and fallers. However it is still required to detect the impairment responsible for this degradation of balance.

1.5.4 SWAY AND INTRINSIC FACTORS

The fall risk factors that are of interest in this study have been previously described in the section 1.4. This section investigates the relationship between those risk factors of fall and balance measured on a force plate.

1.5.4.1 SWAY & VISUAL SYSTEM

The balance measured by the sway has been found to decrease when the vision is impaired or temporary altered. Elliot and colleagues (1995) reported that participant presenting real vision impairment (maculopathy) showed root mean square values of displacement in both antero-posterior and mediolateral directions significantly greater than healthy participants. The sway was measured standing on a piece of foam. Therefore the cutaneous proprioception was also impaired but that condition was similar in healthy and impaired participants. Hansson et al.(2010) conducted a study measuring the sway with normal vision and with deprivation of vision (eyes open and eyes closed) as well as other temporary degradation of the cutaneous proprioception (standing on the foam) and the vestibular system (head rotation). They found the COP velocity to increase in the antero-posterior and mediolateral, as well as an increase in the total area covering postural displacement only in the situation where the vestibular system and the cutaneous proprioception where disturbed (head shake and standing on the foam). It therefore seems that deprivation of vision alone is not sufficient to impaired balance but when combined with other impairment, vision induces a greater impairment of balance than the other impairment produces alone. Anand et al. (2003a) simulated blurred vision and cataracts, reporting greater postural sway than control subjects, in particular for antero-posterior displacement. Similarly, Uchiyama and Demura (2007) simulated a decreased of visual acuity and vision field and found changes in the spectral analysis of the sway in both conditions, the spatial characteristic in the mediolateral plan was modified with a loss of acuity and the low frequency of the sway were modified with a reduction of the vision field.
Another study, Buckley et al. (2005b) simulated vision impairment in an healthy elderly population. The vision impairment was performed to match the effect of a cataract by wearing blurred glasses. They showed an increase in the ground reaction forces and the COP displacement in the mediolateral plan decreasing mediolateral stability.

1.5.4.2 SWAY & VESTIBULAR SYSTEM

Vestibular impairment can be simulated by galvanic vestibular stimulation (GVS) which is a small current aiming to disturb the vestibular nerve. Scinicariello et al. (2002) Fransson et al. (2003) and Fitzpatrick et al. (2004) all used GVS to temporary impaired the vestibular system. They measure balance with sway analysis on a force plate and found greater displacement of the COP usually. It seems that disturbance of the information coming from the vestibular nerve decrease balance.

Mergner et al. (2009) investigated the effect of vestibular impairment in the elderly population and found a larger excursion of the body sway compare to elderly with no vestibular impairment.

Pedalini et al. (2009) compared three population, healthy adults, healthy elderly and elderly with vestibular impairment. They found sway differences in each population compare with one another. Vestibular impairment alone seems not to produce very large effect on sway, but when combined with deprivation of vision (testing with eyes closed) the sway is much more affected and therefore the difficulty of maintaining balance is growing.

1.5.4.3 SWAY & JOINT RANGE OF MOTION

To our knowledge no study investigates the effect of range of motion on sway. However few studies measuring sway mentioned the range of motion of the hip, knee and ankle. Wang et al (2006) investigated the ankle injuries in basketball players. They found that players that suffered ankle injuries had greater sway and decrease ankle flexibility and strength. It is therefore possible that reduction of ankle flexibility is partly responsible for degradation of sway. The study of Bird et al. (2009) investigate the effect of training programme on the postural sway and clinical functional test. One of the intervention programmes was based on flexibility training, with stretching of all the major muscles groups. The programme did improve the sway in older adults. Increase range of motion of the joints might have contributed to the improvement of sway, however no measurement could confirmed this idea and there were many others variables that could be responsible of the improvement of sway.

Weirich et al. (2010) found differences in young compare to elderly population for the hip flexion. They also found that sway was greater for elderly. The decrease of hip range of motion can be partly responsible for the increase of sway in the elderly population, but in this study, they measured other variables that seem much more likely to be the reasons of the increase of sway such as strength or bone health. Finally, Spink and colleagues (2011) investigated the characteristics of the foot and the ankle and their contribution in the sway and functional balance test. They associated the strength and range of motion variable with balance but it seems that strength correlate more consistently than range of motion.

Joint range of motion have been described by the literature and described in earlier section as important risk factor of fall, however very few study investigated the effect of range of motion on sway. If it exists, the extent of the contribution of the range of motion to produce of healthy sway is unknown.

1.5.4.4 Muscle and Joint Proprioception

The muscle and joint proprioception can be altered by the application of vibration on the joints or on the muscles. Three studies have investigated the effect of the temporary reduction of muscle and joint proprioception due to vibration. Pyyko et al. (1989) applied vibrations to several different muscles, including triceps surae, tibialis anterior, quadriceps femoris. He reported vibrations to be responsible for a significant increase of postural sway. Yagi et al. (2000) applied vibrations to leg muscles including tibialis anterior and triceps surae. They too reported significantly greater antero-posterior sway. Similarly, Michel-Pelegrino et al. (2006) applied vibration on the tibialis anterior and found a modification in 44 different postural sway parameters, with the greatest differences observed movement in the antero-posterior direction.
It seems that the simulation of reduction of sensory information from joint and muscle with vibration system do increase sway. However no study has investigated the effect of real joint and muscle proprioception impairment on the postural sway.

1.5.4.5 Muscle Strength

To investigate the effect of decrease of muscle strength on the postural sway, all of the study found used temporary degradation of the muscle strength by the mean of fatigue.
Vuillerme and colleagues (2002; Vuillerme and Hintzy 2007) induced fatigue in the calf muscles of healthy adults. The effects on the sway were: change of the mean COP position, increase in the range mean velocity, and the dispersion of CoP displacement.
Corbeil et al. (2003) experimentally reduced the strength of the ankle plantar flexors by means of fatigue-inducing exercises. They reported an increase in the mean velocity of CoP displacement for both mediolateral and antero-posterior directions, as well as changes in the frequency analysis of the sway. Noda et al. (2007) also induced fatigue in the plantar flexor muscles, and reported significant changes in both temporal and spectral parameters of antero-posterior displacements.

Those three studies showed that postural sway is greatly affected by the loss of muscle strength. However those studies used fatigue as a mean of decreasing strength but strength is not the only degradation resulting for fatigue exercises, there are neuromuscular changes after fatiguing exercises that could also be responsible for increase of sway.

1.5.4.6 Foot Cutaneous Proprioception

In order to investigate the effect of the reduction of the foot cutaneous proprioception few authors produce temporary degradation of the foot cutaneous proprioception using various methods. Kavanoudias et al. (1999) applied vibrations to the soles of the feet. They recorded changes in postural sway for the amplitude and the velocity of the COP. Meyer et al. (2004) artificially reduced sensitivity of the fore-foot and the complete sole surface by using anaesthesia. They observed an increase velocity and root mean square displacement of the CoP during unipodal stance. McKeon et al. (McKeon and Hertel 2007a; McKeon and Hertel

2007b) published 2 studies using hypoesthesia in the feet to reduce foot cutaneous proprioception. They found significant change of the sway with reduction in the area of COP excursion and increase time to boundary measurement of the COP. Patel and colleagues (2008) reduced the foot proprioception by requiring the participant to step on the piece of foam fixed on the force platform. They found changes in the sway measurement with the frequencies and the antero-posterior displacement of the COP. However they explained that the magnitude of the change of the sway might be due to the properties of the foam. Similarly, Melzer et al. (2004) induced, in elderly fallers and non-faller, degradation of foot cutaneous by standing on a piece of foam. They found that fallers produce greater sway especially in the medio lateral displacement of the COP.

Simoneau et al. (1995) investigate the effect of real foot cutaneous impairment on the sway. They tested adult presenting neuropathy, a condition known to decrease cutaneous sensitivity in the feet. They found change in the excursion of the COP.

Once again, the study mostly investigated the effect of degradation of intrinsic factors on sway. It seems that degradation of foot cutaneous proprioception induces changes in the postural sway.

1.5.4.7 CONCLUSIONS INTRINSIC FACTORS & SWAY

All the intrinsic factors investigated in the current study have been found to produce greater sway when perturbed (naturally or experimentally).
More studies including real impairment would have been more convincing, but we cannot deny that impairments of the intrinsic factor are inducing a variety of changes on the postural sway. It even seems that different sway parameters are affected by the various intrinsic impairments. If that so, it would be interesting to regroup large variety of parameter and look at the effect of the manipulation of intrinsic factors to see the effects of each sway parameters.

Few studies have indeed used the sway parameters to classify participants within pre-determined classes. Benvenuiti et al.(1999) recruited elderly participants with minimum, moderate and severe balance impairments determined by the FICSIT balance assessment. They measured the balance on a force platform and from the analysis of the sway, they were able to quantify the severity of the balance impairment with accuracy of 96%. The sway parameters used were such as area, standard deviation, velocity of the COP displacement. However, in this study not only sway parameters were used to quantify the balance status but also clinical tests such as postural alignment and motor coordination. Brauer et al.(2000) also recruited elderly participant fallers and non-fallers. The participants performed clinical tests and filled up questionnaires and were also required to stand on a force plate to record the sway. The position, velocity, amplitude and total distance of the displacement of the COP were computed from the sway. The variables from the sway alone were not able to differentiate fallers from non-fallers, but a combination of laboratory measurement provides an accuracy of 77% of correct discrimination between fallers and non-fallers. In a review Piirtola et al.(2006) confirmed that force platform parameters, especially mean speed and displacement of the COP can provide valuable information in predicting future fall. They mentioned however that the studies investigating sway showed a large variation in the equipment used as well at the selection and analysis of sway parameters. Those studies were

able to discriminate fallers from non-faller, but an interesting study of Krafczyk et al. (Krafczyk, et al. 2006) focus on discriminating vestibular impairment with the sway analysis. They recruited four populations with vestibular impairment (postural phobic vertigo, anterior lobe cerebellar atrophy, primary orthostatic tremor, acute unilateral vestibular neuritis). They measure the sway and computed parameters including path, RMS, frequency analysis of the COP. They were able from the sway to distinguish the different impairment with accuracy of 93%.

Several studies have therefore showed it was possible by the analysis of sway to distinguish faller from non-faller and one study have shown that even vestibular impairment could be distinguished. The sway parameters presented in the studies investigating the intrinsic factors and those final studies investigating the discrimination of conditions from the sway are presented a large range of sway parameters making therefore the comparison difficult. The following section is reviewing the sway parameters existing and used in the literature.

1.5.5 SWAY PARAMETERS

A large variety of different parameters have been used in the literature to describe postural sway, as measured by force plates. For instance, during stepping up, quiet standing and stepping down, Amoud (2006) utilized over 150 different sway parameters, including typical parameters of postural sway frequently reported in the literature, as well as less common parameters typically used in other signal processing applications. According to Amoud (2006) there are three different categories of parameters. The first category includes the parameters about the temporal and geometric characteristics of the CoP signal, such as mean velocity or the area of sway. The second category includes the spatiotemporal sway parameters, such as the power spectrum or different frequency parameters, while the third category includes stochastic parameters, which are related to the description of the trajectory of the CoP.

In the scope of this thesis, a large number of studies based on those identified by Amoud have been chosen to describe postural sway. A description of each parameter is found below. In order to avoid repeating the same references for each of the parameters, the studies references, which include detailed calculations to compute the parameters, is presented here. (Amoud 2006; Amoud, et al. 2007a; Amoud, et al. 2008; Baratto, et al. 2002; Bottaro, et al. 2007; Brauer, et al. 2000; Buckley, et al. 2005b; Collins and Luca 1993; Corbeil, et al. 2003; Donker, et al. 2007; Eils, et al. 2002; Lafond, et al. 2004; Michel-Pellegrino, et al. 2009; Michel-Pellegrino, et al. 2008b; Newell, et al. 1993; Noda and Demura 2007; Pascolo, et al. 2005; Piirtola and Era 2006; Prieto, et al. 1993; Prieto, et al. 1996; Raymakers, et al. 2005; Rocchi, et al. 2006; Stacoff, et al. 2005; Swanenburg, et al. 2010; Treleaven, et al. 2005; Uchiyama and Demura 2007; Van Dieen, et al. 2010; Vuillerme, et al. 2002; Yagi, et al. 2000; Yamada 1995; Zemkova 2009)

CATEGORY 1- GEOMETRIC AND TEMPORAL PARAMETERS OF THE CENTRE OF PRESSURE

Postural sway can be measured in three directions, namely antero-posterior (AP), mediolateral (ML), and the resultant two-dimensional axis created by combining the AP and ML signals. The temporal and geometrical parameters are the most widely used in the literature, perhaps owing to the ease in which these parameters can be calculated. All displacement parameters are computed for all three axes, with AP corresponding to the X axis, ML corresponding to the Y axis, and the resultant (RD) corresponding to the combined direction of AP and ML directions.

The resting protocol used by Amoud including two dynamic phases of movement, namely stepping up, when subjects step onto the force plate, stepping down, when subjects step down backwards off the force plate, as well as the quite standing phase that is more typically used in CoP measurement. A number of temporal parameters can be calculated to detect the beginning and end of each of these phases:

First Foot Contact (FC1 and FC1d) is the time when the subject foot first touches the force plate when stepping up (FC1) or his first foot touching the ground when stepping down (FC1d).

Second Foot Contact (FC2) is the time when the second foot touches the force plate.

First Foot Off (FO1) is the time when the subject's foot first leaves the force plate during the stepping down phase.

Second Foot Off (FO2) is the time when the subject has removed their second foot from either the ground when stepping up (SU-FO2) or from the force plate when stepping down (SD-FO2).

Total Duration (dTOTAL) is the time taken to perform the total movement, starting with the initiation of the stepping up phase, and ending with the stepping down phase (between t0 and FO2). The total duration of a particular phase can also be calculated, such as stepping up (SU-dTOTAL) or stepping down (SD-dTOTAL).

Anticipatory Postural Adjustment Duration (dAPA) is the duration of the movement called anticipatory postural adjustment (APA), which occurs when a person starts to prepare for a coming movement, prior any intentional movement. The APA phase duration occurs prior to FO1.

Swing Phase Duration (dSW) is the duration of the movement called the swing, which occurs when the subject swings their foot not in contact with the ground in a walking process. The swing phase duration occurs between FO1 and FC1.

Weight Transfer Phase Duration (dWT) is the duration of the weight transfer phase which is the phase when the weight of the subject switches from one foot to the other when stepping up or when stepping. The weight transfer duration occurs between FC1 and FO2.

Time Zero (T0) is the time at the beginning of the recording.

Stepping Up Duration (dST) is the total duration of the stepping up phase.

Mean distance is the mean position of the centre of pressure relative to the origin. It was measured on the resultant direction (MDIST) and both AP and ML directions (MDISTAP and MDISTML).

Root Mean Square Distance is the square root of the arithmetic mean of the squares of the original values of the CoP signals. It was computed on the resultant (RDIST), and AP (RDISTAP) and the ML directions (RDISTML).

Total Excursion is the total distance (or trajectory length) travelled by the CoP. TOTEX is calculated for the resultant, TOTEXAP for AP, and TOTEXML for ML.

Mean Velocity is the distance travelled by the CoP trajectory divided by the time taken. MVELO is calculated for the resultant, MVELOAP for the AP direction and MVELOML for the ML direction.

Range is the maximal distance travelled for the CoP, between the maximum positive and negative values. RANGE is measured for the resultant, RANGEAP for the AP direction and RANGEML for the ML direction.

Area Confidence Circle (AREACC) is the surface of a circle including 95 % of the points of CoP displacement.

Area Confidence Ellipse (AREACE) is the surface of an ellipse including 95% of the points of CoP displacement.

Sway Area (AREASW) is the total area of the surface covered by the oscillation of the CoP.

Loading Rate (en) was calculated from the ground reaction force (GRF) and phase duration, during the weight transfer phase. It corresponds to the slope of the vertical GRF normalized by body weight, and was measured between FC1 and FO2. It describes the intensity with which force is developed at impact.

Impulse. The calculation of impulse was made at different times of the movement. Impulses can be calculated at tVP (90% of the weight of the subject on the force plate) for the three directions: anteroposterior (ImpXtVP), mediolateral (ImpYtVP) and vertical (ImpZtVP). Impulse can also be calculated at FC2 (contact of the second foot with the force plate), once again in three directions: anteroposterior (ImpXFC2), mediolateral (ImpYFC2) and vertical (ImpZFC2). The integration of the GRF data normalized by subject weight can be used to calculate the impulse.

Mean Frequency: the mean frequency of a spectrum is the mean value of the frequency spectrum. MFREQ is calculated for the resultant, MFREQAP for the AP and the MFREQML for the ML.

Fractal Dimension (FD), this parameter, which is set between one and two, describes the fractal nature of the signal observed. When the parameter approaches a value of one, the parameter describes a curvilinear displacement with no complexity, whereas when the value approaches two, it corresponds to a highly complex pathway between the two points. The method of Katz was used to calculate Fractal Dimension (Katz and George 1985).

Fractal Dimension Confidence Circle (FDCC) is the fractal dimension of the 95% confidence circle.

Fractal Dimension Confidence Ellipse (FDCE) is the fractal dimension of the 95% ellipse.

Acceleration of the Centre of Mass is the acceleration at FC1 in the X direction accXNFC1, the Y direction accYnFC1, and the Z direction accZnFC1.

CATEGORY 2 – SPATIOTEMPORAL PARAMETERS

Power is the total power of the spectrum of the signal, with POWERRD calculated for the resultant, POWERAP for the AP direction and POWERML for the ML direction.

Median Frequency is the median frequency, calculated as the frequency such that 50% of the total power is on the left of that frequency in the spectrum. uDELTAFRD is the median frequency for the resultant, uDELTAFAP for the AP direction and uDELTAFML for the ML direction.

95% Frequency is a frequency such that 95% of the total power is on the left of this frequency on the spectrum. vDELTAFRD is calculated for the resultant, vDELTAFAP for the AP direction, vDELTAFML for the ML direction.

Centroid Frequency corresponds to half of the number of zero crossings per second of the temporal series. CFREQRD is the calculation for the resultant, CFREQAP for the AP direction, and CFREQMD for the MD direction.

Frequency Dispersion is a measure of the variability of the frequency included in the density of spectral power. The value is close to zero with a sinusoid and goes towards one when the frequency band increases. FREQRD is measure for the resultant, the FREQAP is for AP and FREQML is for ML.

CATEGORY 3 – STOCHASTIC PARAMETERS

Hurst Exponent is a measure of long-term correlation and auto-similarity in the signal. It can be estimated using different methods including Stabilogram Diffusion Analysis (DSA), Rescaled Range Analysis (R/S) and Detrended Fluctuation Analysis (DFA).

Rescaled Range Analysis is a method to estimate the value of the Hurst exponent. RSRD is the calculation for the resultant, RSAP for AP direction and RSML for the ML direction.

Detrended Fluctuation Analysis is a method used to calculation the Hurst exponent H+1. DFARD is the calculation for the resultant, DFAAP is for the AP direction and DFAML is for the ML direction.

Stabilogramme Diffusion Analysis (SDA) is another method used to calculate the Hurst exponent. From this method two values can be extracted, corresponding to the short term component HS and the long term component HL.

- **Short Term**. HSRD is the parameter for the resultant, HSAP for the AP direction and HSML for the ML direction.
- **Long Term.** HLRD is the parameter for the resultant, HSAP for the AP direction and HSML for the ML direction.

From the linear and logarithmic scale, other parameters were also extracted:

- **The Critical Time** is the time when the transition occurs between the two phenomena, short and long term. TCRD is the parameter calculation on the resultant, TCAP for the AP direction and TCML for the ML direction.
- **Mean Quadratic Distance** for the critical time. XCRD was the parameter for the resultant, XCAP for the AP direction and XCML for the ML direction.
- **Diffusion Coefficient for the short term** in the linear scale. DSRD is the calculation for the resultant, DSAP for the AP direction and DSML for the ML direction.
- **Diffusion Coefficient for the long term** in the linear scale. DLRD is the calculation for the resultant, DLAP for the AP direction and DLML for the ML direction.

In addition to the Hurst exponent, the model of Ornstein Uhlenbeck can be applied to the CoP trajectory. The model is based on the relationship between the variance of the increment of the displacement and the increment of the time.

Diffusion Coefficient of Ornstein-Uhlenbeck on the antero-posterior mediolateral and resultant axis. (KSAP KSML KSRD).

Derived coefficient of Ornstein Uhlenbeck on the antero-posterior mediolateral and resultant axis (KLML KLRD KLAP)

Entropy is a measure of the regularity and complexity within a signal. Entropy is the measure of the randomness and regularity of a system.

Mode entropy is a method used to calculate entropy across different modes, with several techniques used to calculate entropy such as Approximate Entropy, Sample Entropy and Multiscale Entropy.

Approximate Entropy (ApEn) is a measure of the regularity of a time series. ApEn can be efficiently computed for short and noisy time series.

Sample Entropy (SampEn) is an improved version of the ApEn. The sample entropy of a time series is a refinement of ApEn, which measures the negative logarithm of the condition probability that two sequences that are similar for m points, remain similar at the next point, within a tolerance. SampEn is widely used for nonlinear discrimination between sets, as it is assumed to distinguish data sets according to the regularity or complexity of their underlying dynamics.

Multiscale Entropy (MSE) is based on the sample entropy but several scales are taking into account.

Empirical Mode Decomposition (EMD) is a method used to decompose a signal. The principle of the EMD technique is to decompose a signal automatically into a set of band-limited functions called intrinsic mode function (IMFs) representing the oscillation of the entire signal.

Intrinsic Mode Entropy (IMEn) is a recent method for the estimation of entropy that removes errors sometimes contained in other method by calculating entropy after having applied EMD.

IMEn enables the signal dynamics and complexity to be calculated. This method yields a multiscale measure, meaning that selecting a relevant scale may improve the signal analysis method.

The IMEn method consists of computing SampEn of the cumulative sums of the IMFs obtained by the EMD decomposition. In fact, the cumulative sums of the IMFs beginning with the first IMF, yield a multilevel filtering of the signal starting from the finest scales and ending with the whole signal.

Since there are several scales for the measurement of the Intrinsic Mode Entropy, several parameters were computed on the two axes, AP and ML: IMEnAP1, IMEnAP2, IMEnAP3, IMEnML1, IMEnML2 and IMEnML3.

Reconstructed Phase Space (RPS) can be used to extract the nonlinear dynamics of the stabilogramme signal from the empirical modes. It is a time delay method and is used to characterize postural steadiness. The dynamics of the system can be characterized by studying the dynamics of the corresponding phase space points. The RPS method requires the estimation of the delay time and the embedding dimension. The RPS is calculated after EMD, once again resulting in several parameters for AP and ML displacement directions: RPSAP1, RPSAP2, RPSAP3, RPSAP4, RPSAP5, RPSAP6, RPSAP7 and RPSAML1, RPSAML2, RPSAML3, RPSAML4, RPSAML5, RPSAML6 and RPSAML7.

The Central Tendency Measure (CTM) quantifies the variability seen in the second order plot. It is computed by selecting a circular region of a given radius around the origin, then counting the number of points that fall within this radius. This number is then divided by the total number of points to give the fraction of the total number of points that fall within the specific radius. The CTM is a fast method for summarizing the visual information in the graphs.

The CTM was calculated on AP (CTMAP) and ML directions (CTMML). Measures were also made with the summation of IMF on the two axes (CTMEDAP) for the AP and ML (CTMEDML) directions.

1.6 TEMPORARY DEGRADATION OF INTRINSIC FACTOR

As mentioned earlier in the chapter, the impaired condition to analyse with the model, will be condition provoke by the temporary impairment of the intrinsic factors investigated. The main reason for choosing temporary degradation of the intrinsic factor is to allow the analysis of the impairment on its own. If we had chosen elderly population, they are known to cumulate several impairments, it would have been impossible to link the effect of impairment alone to any loss of balance. In order to analyse the direct effect of each impairment on balance they need to be isolated.

It is therefore necessary t investigated which degradation of the intrinsic factor can be used to attempts matching the elderly condition.

1.6.1 VISION DEGRADATION

Several studies have reported techniques that can be used to temporarily degrade vision and thus modify postural sway. Paulus et al. (1989) degraded vision with bifocal and multifocal lenses and found a trend for postural sway to increase. Straube et al. (1990) used plastic foils and lenses to blur vision, reporting an increase in postural sway. Elliott et al. (1996) degraded vision by scattering light, finding a decrease in visual quality, especially in contrast sensitivity and accuracy. Anand et al. (2002) used blurred lenses to decrease vision, noting an increase of CoP displacement. Anand et al. (2003a) used blurred lenses and light-scattering goggles to decrease vision and simulate cataracts, reporting that both blurred and diffuse-blurred vision produced a substantial decrease in postural stability. Buckley et al. (2005b) used scattering lenses to decrease vision, and found a decrease in postural stability during stepping up and down. Desphande et al. (2007) degraded vision with sand-treated goggles that created uniform blurring, then examined visual and vestibular interaction. Uchiyama et al. (2007) used contact lenses to rectify acuity problems before measuring displacement of the CoP in different condition including eyes closed and tunnel vision, finding greater CoP sway. Finally, Helbostad et al. (2009) used blurred foils attached to glasses to create blurred vision, dual vision, and tunnel vision, finding that decreased vision lead to instability during gait.

1.6.2 VESTIBULAR DEGRADATION

The techniques available to perturb the vestibular system are similar to the techniques used to test the vestibular system, which were described earlier in section 2.4.2.3. The main techniques include the application of cold air or cold water in the ear, vibration, and whole body rotation (Fife, et al. 2000). For instance, Anand et al (2003b) and Hansson et al. (2010) used head rotation to perturb the vestibular system and looked at the effect on body sway. Ivanenko et al. (1999) and Karlberg et al. (2002) used vibrations of the neck muscles and looked at body sway and subjective visual horizon, respectively. Another technique for the perturbation of the vestibular system is the use of galvanic vestibular stimulation (GVS),

which consists of the application of a small current to the mastoid bones in order to stimulate the vestibular nerve. This technique has been used by Scinicariello et al. (2002), Fransson et al. (2003), Fitzpatrick et al. (2004), and Iles et al. (2007), with all studies finding disturbance of postural sway while GVS was applied. Similarly, Desphandes and Patla (2007) found an effect of GVS on gait.

1.6.3 Joint Range of Motion Degradation

Restriction of joint of motion is usually performed by applying tape or braces to the joint in question, often after injury or to prevent further injuries. Purcell et al. (2009) tested three different tapes on the ankle joint, all of which reduced the range of motion

1.6.4 Joints and Muscles Proprioception Degradation

Cryotherapy is a technique that is often used clinically to reduce joint proprioception to decrease inflammation and pain when injury occurs as a result of physical activity. Hopper et al. (1997) showed that icing the ankle for 15 minutes lead to a reduction of proprioception in the angle at which the ankle was maintained during icing. Wassinger et al. (2007) reported that cryotherapy of a shoulder lowered the precision of throwing the ball in American football and the proprioception of the iced shoulder. Kernozek et al. (2008) showed that immersion of the ankle into iced water reduced postural stability as measured on a force plate. Muscular fatigue is also a good technique to reduce proprioception (Voight 1996, Lattenzio et al. 1997, Bjorklund et al. 2000, Robert et al. 2003, Pinsault & Vuillerme 2010). In one study both cryotherapy and muscle fatigue were combined, with a resulting reduction in muscle power (Schmid, et al. 2010). Given that the present study aimed at reducing one musculoskeletal intrinsic factor at a time, the degradation of muscle and joint proprioception should reduce proprioception only, and not reduce muscle power, meaning that another degradation method must be used.

A third method used to reduce proprioception is to apply vibration to muscles and tendons. These vibrations induce an illusion of movement by disturbing joint and muscle proprioception. For instance, Elklund (1972) and Goodwin and Wheat (2004) observed that vibration on muscles and tendons reduced joint proprioception. Goey et al. (2000) and Allen and Proske (2006) vibrated the arms of the subjects and examined the ability of subjects to perform a repositioning test and any disturbances in speed-movement perception. Finally, Michel Pelegrino et al. (2006) applied vibration on the Achilles' tendon of the subjects and looked at the effect on posture through the analysis of postural sway parameters, with more than half of the parameters modified following vibration.

1.6.5 Muscle Strength Degradation

Degradation of both muscle strength and muscle power was performed by getting the subjects to undergo fatiguing exercises. Such a technique can be used for all lower-limb muscles, with many different exercises available. Vuillerme et al. (2002) fatigued the calf muscles by requiring subjects to stand on their tiptoes until exhaustion. Corbeil et al. (2003) used a standard plantar-flexor training device, and proposed a block design training programme (pyramid) to fatigue the ankle plantar flexors. Noda et al. (2007) fatigued the calf muscles with repetitions of plantar flexion. Vuillerme et al. (2007) required subjects to cycle on an ergometer for 15 min with an ascending pedalling rate to induce fatigue. However, although exercises with movement (plyometric) are effective in reducing muscle strength, they have also been found to reduce joint proprioception (Allen and Proske 2006; Bjorklund, et al. 2000; Lattanzio, et al. 1997; Voight, et al. 1996). Robert et al. (2003) reported that after a cycling exercise, joint proprioception of the knee is affected only for flexion, which corresponds to the repeated movement of cycling. Cycling did not have any effect on knee extension proprioception. It follows that it would be possible to fatigue muscles without reducing joint proprioception if training did not involve joint movement. Such training, known as isometric contraction has also been used previously. Toumi et al. (2006), Babault (2006), as well as James (2010), described fatigue protocols using isometric contraction for lower limbs, respectively using the leg press, electro stimulation and isometric squat, each of which lead to a reduction in muscle power.

It seems that isometric fatigue exercise targeting the muscles of interest would be the most efficient technique to decrease strength without decreasing any other intrinsic factors such as joints proprioception.

1.6.6 Foot Cutaneous Proprioception Degradation

Anaesthesia and cooling of the feet are two of the most widely used methods to decrease the sensation of the foot sole. The review of Kars et al. (2009) described the use of both methods in several different studies. An example of anaesthesia is the study of Meyer et al. (2004), in which anaesthesia of the metatarsal head of both feet was produced by means of alternating-pulse iontophoretic delivery of an anaesthetic solution which targeted the cutaneous receptors, but which had no effect on the muscle and joint afferents. The procedure was effective, as attested by the results for the Semmes Weinstein filament test, which were much higher after the anaesthesia in comparison to the control condition. Similarly, McDonnell et al. (2000) reduced plantar sole sensation using a eutectic mixture of local anaesthetics (EMLA) and showed the decreased of gait velocity.

There are several examples of studies using a system to cool the feet, such as the study of Eils et al. (2002), who reduced plantar sensation using ice immersion for 10 min. Only the plantar aspect of the foot was submerged. Similarly, McKinnon et al. (2007b) immersed subjects' feet for 10 min in an ice bath to induce hypoesthesia. The success of the reduction of foot sensation was confirmed by both a two-point discrimination test and a pressure algometry test.

Another way of reducing foot sensation is described in the study of Wang et al. (2008), who disrupted of blood flow in order to affect the afferent fibres of somatosensory inputs. They placed a sphygmomanometer cuff directly above the lateral malleolus of the ankle joint to

interrupt the blood flow and disrupt the conduction of inputs from the deep and superficial mechanoreceptors of the feet and ankles. The technique was effective in decreasing proprioception, as verified by the Semmes Weinstein test performed before and after the blood-flow reduction.
Finally, standing on a piece of foam has also been widely used to reduce foot proprioception. Anand et al. (2003b) and Raymakers et al. (2005) carried out two studies that used foam to reduce foot proprioception. Hansson et al. (2010) also used this method and found an increase in the amount of postural sway. However, according to Patel et al. (2008) there are several problems with this method. It is difficult to measure the elasticity and thickness of the foam that is used, while the effect of the foam depends on the weight of the subject standing on it. For instance, a heavier subject would decrease the effect of the foam, meaning that sway measurement would then rely on the thickness of the foam instead of the lack of proprioception.
It seems that anaesthesia or hypothermia are the best methods to reduce foot proprioception.

1.7 Classification Models, potential & innovation

1.7.1 Model in medicine

Models come from the statistical and machine learning field, they are widely used in medicine/health research for prognostic, diagnosis, survival analysis and knowledge based decision support system (Dreiseitl and Ohno-Machado 2002; Futschik, et al. 2003; Lisboa 2002; Ohno-Machado and Rowland 1999).
The use of conventional model such as linear regression model is limited. To use linear regression model, the dependent variable has to be dichotomous (binary), complex non-linear relationship among independent and dependent variable cannot be modelled using linear methods (Khashei, et al. 2012; Ohno-Machado and Rowland 1999).
However in real life, the data are rarely linear and sometimes in medicine it not easy to check whether the data are linear or non-linear. Therefore non-linear methods are required and the artificial neural network appears as an interesting solution. Artificial Neural Network (ANN) covers both linear and non-linear data, ANN is a self-adaptive methods (flexible) and can generalize to new data. ANNs are often used for classification or pattern recognition and generally involved large dataset (Khashei, et al. 2012; Ohno-Machado and Rowland 1999).

The literature showed that recent studies use several models, for comparison, or hybrid models combining linear and non-linear algorithms. The most cited models are the logistic regression, k nearest neighbour, decision tree, support vector machine and artificial neural network (Dreiseitl and Ohno-Machado 2002; Khashei, et al. 2012).
The review of Lisboa (2002) extensively described the use of the neural network model in the field of medicine. They concluded their study saying that pattern recognition in medicine is not specific to neural network and could be achieved by simpler model correctly optimized. It is not necessary to complexity model with neural network when model easier to use and interpret are as efficient as ANN for pattern recognition.

1.7.2 MODEL CLASSIFIERS

The two most used classifiers in medicine seem to be the Logistic regression and the artificial neural network.

LOGISTIC REGRESSION:

In respect to logistic regression, the method has been widely used for prediction models in various fields, but has been found to be effective for prediction and diagnosis in biomedical studies (Nehme, et al. 2013). For instance, logistic regression has been used for fall risk assessment in elderly (Aizen and Zlotver 2013). Such fall risk models were built from health status questionnaires and clinical evaluations (Shumway-Cook, et al. 1997), from clinical and demographic factors related to health costs (Rizzo, et al. 1998), as well as from the results of different clinical tests (Stalenhoef, et al. 2002). Logistic regression has also been used to predict limb function, as well as the risk of falls from self-rated visual quality, although the model was not able to discriminate between conditions (Steinman, et al. 2009).

ARTIFICIAL NEURAL NETWORK:

The extent of the application of neural networks in physical medicine, rehabilitation and other medical specialties has been reviewed by Ohno Machado et al. (1999). Such methods have been used to predict survival in elderly (Song, et al. 2004) and mortality after hip fracture (Lin, et al. 2010). The neural network are also used for pattern recognition (Kasabov, et al. 2013). In respect to the analysis of movement in standing posture, Salveberg et al. (1999) used a neural network model to map the relationship between insole pressure patterns and the component of the ground reaction force. In another study, Chau et al. (2001) described the large application of neural networks in the field of gait analysis, a finding that was confirmed by other authors such as Hahn et al. (2005), Begg et al. (2006), and Lai et al. (2012), all of whom accurately predicted gait parameters from neural network models.

1.7.3 MODEL ACCURACY

1.7.3.1 PERCENTAGE ACCURACY

Percentage accuracy is the most widely used method to evaluate the performance of a model‘s classification (Baldi, et al. 2000; Stehman 1997; Valverde-Albacete and Peláez-Moreno 2014). However there are no normative score for success of failure of a model. Modelling studies in the medical field seem to agree upon a minimum accuracy of 60% as the threshold to characterise a model as acceptable. Indeed, few models used in the health field and investigating sway or intrinsic factors are cited below to compare the accuracy chosen to validate a model.

Models for gait analysis showed accuracy of 75-95% (Chau 2001). A model predicting mortality in older people produced accuracy of 82% (Song, et al. 2004), while a model to predict the age of people practising Tai Chi had an accuracy of 65% (Gongbing, et al. 2004). A model that predicted displacement of the CoP during gait had an accuracy of 57-89% (Hahn, et al. 2005), while models for the diagnosis of vestibular pathology from postural sway showed and accuracy of 73-98% (Krafczyk, et al. 2006). Finally, a model to recognise gait pattern had an accuracy of 83% (Begg and Kamruzzaman 2006), with a model predicting mortality after hip surgery accurate from 95-98% (Lin, et al. 2010). Those study range accuracy between57% and 98% and all models were concluded as efficient.

1.7.3.2 KAPPA COEFFICIENT

The Kappa coefficient is a measure of magnitude that was originally used as a measure of agreement. It can be defined as the proportion of agreement after the chance agreement has been removed from the equation (Cohen 1960; Kraemer 1980; Sim and Wright 2005; Viera and Garrett 2005). The Kappa coefficient falls between -1 and 1, whereby a Kappa of 1 indicates perfect agreement, a Kappa of 0 is what would be expected by chance, while a value of -1 indicates a perfect disagreement (Viera and Garrett 2005). The Kappa coefficient has a single way for calculation but seems to be interpreted in various ways. Sim et al. (2005) described a different use of the Kappa coefficient, not for agreement but as a measure of reliability or the magnitude of an effect. A range of studies propose different used of the Kappa coefficient such as a measurement of reliability, validity, and probability (Berry and Mielke 1988; Feinstein and Cicchetti 1990; Kraemer 1980; Stehman 1997; Thompson and Walter 1988).
Similarly, Maclure et al. (1987) reviewed studies of the Kappa coefficient and described the different uses, including, what is of interest for our study, the assessment of validity for multi category classification.

1.7.4 MODEL VALIDITY

INTERNAL VALIDITY

The construction of a model, otherwise known as the training or development of a model, need to be validated with new data to ensure that the model can be generalised (Aizen and Zlotver 2013; Altman and Royston 2000; Harrell, et al. 1996; Steyerberg, et al. 2001). There are several ways of testing the model using both internal and external testing. Internal validity involves training and testing the data with cases from the data set used to construct the model. In contrast, an external validity test involves testing the model with completely different data from that used to train of the model (Altman and Royston 2000; Harrell, et al. 1996; Picard and Berk 1990; Steyerberg, et al. 2001). Three well-known methods commonly used for internal validity are data split, bootstrapping (also called leave-one-out), and cross validation (Altman and Royston 2000; Picard and Berk 1990; Steyerberg, et al. 2001).

Data splitting involves the selection of a random sub-set of the data, which is then used to train the model, while the remaining sub-set of data is used to test the model. In this case, the testing data are new to the model and thus enable the model to be validated (Altman and Royston 2000; Harrell, et al. 1996; Picard and Berk 1990; Steyerberg, et al. 2001). Data-split methods randomly attribute the number of cases to each portion of data set, however if the model-training sub-set is too small, the performance of the model will be low. Any bias in the model can be reduced by splitting the data roughly into thirds, with one third attributed to testing and two thirds to training (Steyerberg, et al. 2001).

EXTERNAL VALIDITY

The use of internal validity has been considered as an approximation of the external validity (Steyerberg, et al., 2001). It should be noted, however, that external validation is more relevant than internal validity for the application of the models in clinical setting, as there is often a large variable across a population and multiple different health outcomes (Altman and Royston 2000; Nehme, et al. 2013; Steyerberg, et al. 2001). External validity is performed by testing the model with a complete different set of data, either from a totally different population with the same disease or impairments, or the same population tested elsewhere

(Aizen and Zlotver 2013; Altman and Royston 2000; Harrell, et al. 1996; Steyerberg, et al. 2001)

1.7.5 MODEL & SWAY PARAMETERS

Studies have investigated the use of predictive models with variables collected on force plates. Savelberg and De Lange (1999) used neural network to map the relationship between foot sole pressure and the anteroposterior component of ground reaction forces, reporting that the model was able to generalized to new cases. Gongbing and colleagues (2004) identified with ANN model, the relationship between the age of subjects tested and their level of Tai chi experience. They reported that the Tai Chi group had significantly less CoP displacement. Hahn and colleagues (2005) used ANN for mapping gait measurement onto CoP motion, and were able to identify elderly with balance impairment, who had significantly greater ML displacement and peak velocities. They created a mapping tool to estimate balance control during locomotion. Rocchi et al. (2006) used multiple regression analysis to detect the largest source of variability in COP sway in a data set of healthy and Parkinson subjects. Krafczyk and colleagues (2006) were able to differentiate between normal subjects and those with vestibular disorders using a neural network constructed with sway parameters.
Piirtola et al.(2006) and Krafczyk et al.(2006) both concluded that it seems possible to diagnose balance disorder using models based on sway parameters. The studies exposed in this section confirm this idea.

1.8 OBJECTIVE OF THE STUDY

1.8.1 PHD PART OF A LARGER PROJECT

This PhD thesis form part of a large body of work conducted in the University of Technology of Troyes (UTT), in France. The UTT has an E-health research laboratory that has developed a range of different tools to identify physical frailty in the elderly population. These tools have been designed with the user in mind, as well as to facilitate the task of healthcare professionals by providing quick, easy, and accurate measurements without requiring the presence of a trained evaluator, or in some cases any evaluator.

One of the tools developed by UTT is a bathroom scale known as the Balance Quality Tester (BQT) that has been modified in order to provide similar measures of balance quality to those obtained from a force plate (Duchene, et al. 2012). The BQT, which has been patented (Duchene, et al. 2012), is able to wirelessly transmit signals corresponding to AP, ML, and vertical force measurements to a remote server using a telephone or broadband to relay the data after an initial BlueTooth transfer. The BQT has been used in several studies to measure balance, to assess the elderly at home, and to follow them up with a view to reducing falls (Duchêne and Hewson 2011; Hewson, et al. 2013; Michel-Pellegrino, et al. 2009).

Even though the bathroom scale is able to measure the sway and to identify any degradation in balance that might occur prior to a fall, information about the causes of the balance dysfunction or the intrinsic factor associated with falls cannot be determined from this tool just yet. The work contained in this thesis provides a step towards the identification of the factors underlying decreases in balance quality. The idea was to identify those intrinsic risk factors associated with reductions in balance quality using measures of postural sway, thus

providing a tool able to quickly and inexpensively assess intrinsic factors of falls in elderly in standing posture.

1.8.2 AIMS

The general aim of the thesis is to develop a tool able to detect impairments of intrinsic factors in elderly adults. The detection of these impairments would allow the health practitioners to obtain valuable information about the balance state of the patient and therefore possibly propose preventive intervention targeted to the patient needs.

As described in this chapter, a tool to assess balance disorder quickly and accurately would be a valuable asset for healthcare professional. Given that postural sway parameters are sensitive to subtle changes, it might be possible to differentiate between different balance problems (Brauer, et al. 2000; Freitas, et al. 2005; Horak, et al. 1997; Piirtola and Era 2006). The large existing numbers of sway parameters could enable appropriate patterns of degradation in postural sway parameters to be related to specific musculoskeletal or sensory conditions (Michel-Pellegrino, et al. 2009). Efficient and precise screening is essential in order to focus any intervention programme on the deficit specific to the person tested (Brauer, et al. 2000; Freitas, et al. 2005; Horak, et al. 1997; Melzer, et al. 2004; Piirtola and Era 2006).

1.8.3 LIMITATIONS OF THE STUDY

The study is limited to the six musculoskeletal and sensorial intrinsic factors chosen.
The study was mainly performed with "healthy young adult" subjects, meaning the adults tested with this model are adults with very few ageing consequences, and with no chronic disease or degenerative disease.

1.8.4 RESEARCH QUESTIONS

The current thesis aims to test the research questions cited below.

- Do the experimental degradation of intrinsic risk factor of fall match the condition of impaired elderly
- What sway parameters can be used to characterize balance?
- Is it possible to build a model based on the sway parameters, able to differentiate healthy participant from impaired participant
- Is it possible to build a model based on the sway parameters, able to differentiate different impairment among a selection of intrinsic risk factor of fall
- Do such models built are effective in classifying real impaired elderly with real impairment.

1.8.5 OUTCOMES OF THE WORK

The results of this thesis will be included in the larger UTT project. The model built during this thesis will be applied to the BQT built by UTT, meaning that future studies could evaluate balance at home and screen the population for specific intrinsic factor deficits. Prior to such a step, any model would need to be validated with a clinical trial.

2 CHAPTER 2: PROTOCOL

2.1 ORGANIZATION OF THE EXPERIMENT

This thesis is a collaborative project between the Auckland University of Technology (AUT) of Auckland, New Zealand and the University of Technology of Troyes (UTT), Troyes, France. The PhD is part of a larger project which is in collaboration with the Indian Institute of Technology Jodhpur (IITJ), Rajasthan, India. The project India/France into which this PhD is included aims to adapt the physical frailty devices built in UTT for an Indian population. Accordingly, it was decided to carry out the first study in ITTJ, India, using the facilities of the movement analysis laboratory, in collaboration with physiotherapy department of the Jodhpur Hospital.
Therefore, the experiment were conducted in several place, in India first then in Auckland. The experiment could not be conducted in one country only since the agreement at the beginning of the thesis required time repartition between the involved countries, initially France and New Zealand, but we had to fit some time in India also.
Similar experiment was conducted in the two countries and this section describes the protocol for the experiments and details the small differences due to the location of the two experiments.

2.2 ETHIC APPROVAL

JODHPUR, INDIA
Ethical approval was granted by the Ethical Review Committee of the SN Medical College of Jodhpur, Rajasthan, India, on the 15th of December 2011. The registration number for the ethic approval is 1262/6419 (RMC). The letter of approval is in Appendix 1.

AUCKLAND, NEW ZEALAND
Ethical approval was granted by the Auckland University of Technology (AUT) Ethics Committee on the 10th of January 2013. The registration number of the ethical approval is 12/301: "Construction of a physiological model of balance in older adults based on measures of sway". The letter of approval from the AUT Ethics Committee is presented in Appendix 2.

2.3 LOCATION

JODHPUR, INDIA
The Jodhpur experimentation was divided into two parts, with the first tests using younger adult subjects, followed by a second set of testing on elderly subjects. Two locations were chosen for the experiments:

- All testing with the control subjects was performed in the movement analysis laboratory of IITJ, Old Residency road, Ratanada, PWD Colony, Jodhpur, Rajasthan, India.
- All testing with the elderly subjects was performed in the Physiotherapy Department of the Jodhpur Hospital, MDM Hospital of Jodhpur, Shastri Nagar, Jodhpur, Rajasthan, 34003, India.

AUCKLAND, NEW ZEALAND

The Auckland experimentation was undertaken in the Health and Rehabilitation Research Centre (HRRC) on the Akoranga campus of the AUT, which is located in Auckland, New Zealand.

Health & Rehabilitation Research Centre HRRC
School of Rehabilitation and Occupation Studies (A11)
Faculty of Health and Environmental Sciences
AUT University
90 Akoranga drive. Northcote
New Zealand

2.4 POPULATION

2.4.1 SUBJECT NUMBERS

The current study aims to build models which usually required a large number of subjects. The Table 1showed the studies using investigating balance using models.

Studies reference	Participants	Objective of the study
(Savelberg and De Lange 1999)	5 adults	Determine the horizontal ground reaction force from insole pressure pattern
(Gongbing, et al. 2004)	96 Chinese adults	investigate the effect of Tai Chi on age
(Hahn, et al. 2005)	11 healthy young adults 19 healthy elderly 10 balance-impaired elderly	investigate gait pattern
(Krafczyk, et al. 2006)	676 patients	diagnose vestibular impairment

TABLE 1: STUDIES BUILDING MODELS INVESTIGATING BALANCE

Those studies showed various numbers of subjects, from very little to really large data set. Apart from Krafcyk et al. (2006) who investigated the vestibular system, none of the other studies investigate any of the intrinsic factors used in this present study. The Table 2 showed twenty-one relevant studies with a design similar to that described in the current experimental protocol, have examined the influence of a sensory degradation on the quality of intrinsic factors and on the control of balance while standing or while walking.

Studies reference	Participants	Objective of the study
(Yagi, et al. 2000)	59 healthy 12 vestibular impaired	Influence of muscle vibration on balance
(Michel-Pellegrino, et al. 2006)	17 healthy adults	Effect of vibration applied on the Tibialis anterior
(Vuillerme, et al. 2002)	9 healthy young adults	Effect of calf muscle fatigue on sway
(Corbeil, et al. 2003)	11 healthy adults	Effect of muscle fatigue on sway
(Vuillerme and Hintzy 2007)	24 healthy adults	Effect of cycling on postural control
(McDonnell and Warden-Flood 2000)	20 healthy young adults	Effect of foot anaesthesia on normal gait
(Eils, et al. 2002)	9 healthy young adults	diminished plantar sensation and observed the effects on plantar pressure during gait
(McKeon and Hertel 2007a)	32 healthy adults	effect of hypoesthesia on the sway in a population
(Kernozek, et al. 2008)	15 healthy young adults	effect of cryotherapy of the ankle on postural sway
(Elliott, et al. 1996)	30 healthy young adults	the effect of cataracts on vision quality
(Anand, et al. 2003b)	15 elderly	influence of blurred vision on postural stability
(Buckley, et al. 2005b)	12 elderly	effect of blurred vision on stepping
(Uchiyama and Demura 2007)	15 young adults	influence of visual changes on the CoP sway
(Deshpande and Patla 2007)	9 healthy young adults 9 elderly	the effect on locomotion caused by blurred vision
(Helbostad, et al. 2009)	24 elderly	Effect of vision on gait
(Hansson, et al. 2010)	30 healthy young adults	effects of both visual and vestibular degradations on the postural sway
(Ivanenko, et al. 1999)	13 healthy young adults	effect of neck and vestibular simulation on postural response
(Scinicariello, et al. 2002)	10 healthy adults	effect of galvanic stimulation on postural sway
(Fransson, et al. 2003)	34 young adults	effect of galvanic stimulation on postural sway
(Iles, et al. 2007)	13 healthy adults	examined postural sway and gait
(Raymakers, et al. 2005)	45 healthy young adults 38 elderly	examine relevant body sway parameters

TABLE 2: STUDIES INVESTIGATING INTRINSIC FACTORS OF FALLS

The average of young subjects used in these studies is 21.4 and the average of elderly tested is 19.6.

It seems that the construction of models required a large number of subjects however the complexity of experimentation of the intrinsic factors limits to a smaller number of subjects. Therefore, since this current study experiment the intrinsic factors and aim to build a model it requires large number of subject but small enough to be manageable.

The current study included 50 healthy adults and 25 elderly.

2.4.2 RECRUITMENT

JODHPUR, INDIA

The young subjects were recruited among student volunteers of the Indian Institute of Technology of Jodhpur. An email was send to all students advertising the study. The volunteer were then recruited.

The elderly subjects were recruited among Jodhpur volunteers. The study was advertised in the local newspapers. A social group of former engineers was involved in activities in the physiotherapist department where the experiment was performed, curious and interested, a large range of the member of the group were volunteers for the study.

AUCKLAND; NEW ZEALAND

All participants in the Auckland study were recruited amongst students and staff on the AUT Akoranga campus. Subjects were recruited by means of advertisements placed on notice boards across the campus.

2.4.3 INCLUSION AND EXCLUSION CRITERIA

The young group was recruited according to the following inclusion criteria:

- Healthy adults with no known neurological and musculoskeletal impairments
- Ages between eighteen and forty-five years old.

Note: Although people are considered to be elderly at 65 y according to most studies (Banez, et al. 2008; Services 2008; Society 2001b), the ageing process starts earlier depending on the subject and their lifestyle. In order to ensure that control subjects had undergone as little ageing as possible, the age limit was placed at 45 y.

The elderly group was recruited according to the following inclusion criteria:

- Age sixty years and older.

Note: The age at which a person is considered to be elderly is usually set at 65 y western countries, partly due to the increase in diseases and impairments with increasing age from 65 y and onwards (Satariano, et al. 2012). However, life expectancy and health status in India is lower than in western countries. For this reason, the Indian government use 60 y as the age at which someone is considered to be elderly. In a study performed in India and China, it was reported that there is a marked increase in disease rate due to age that starts at 45 y in India (Chatterji, et al. 2008; Kumar 2003)

2.5 STUDY DESIGN

2.5.1 DESCRIPTION

The aim of the experimentation was to examine the effect of intrinsic musculoskeletal and sensory factors on the displacement of the centre of pressure (sway) of control, impaired and elderly subjects during a task that required them to step up onto a force plate, stand quietly, then step down backwards off the force plate.

For the control subjects, the experimental design was a pre-test/post-test protocol for each of the six intrinsic musculoskeletal and sensory factors. The pre-test consisted on a measure of postural sway and an evaluation of one of the intrinsic musculoskeletal and sensory factors. The treatment between pre-test and post-test was a temporary degradation of the factor previously measured, followed by a second evaluation of the intrinsic factor degraded and post-test measurement of the sway. Each intrinsic factor was analysed separately to avoid interactions of their effect on the sway. The order in which the intrinsic factors were assessed and degraded was semi-randomised. The Figure 2 showed the design of the experiment for the control subjects.

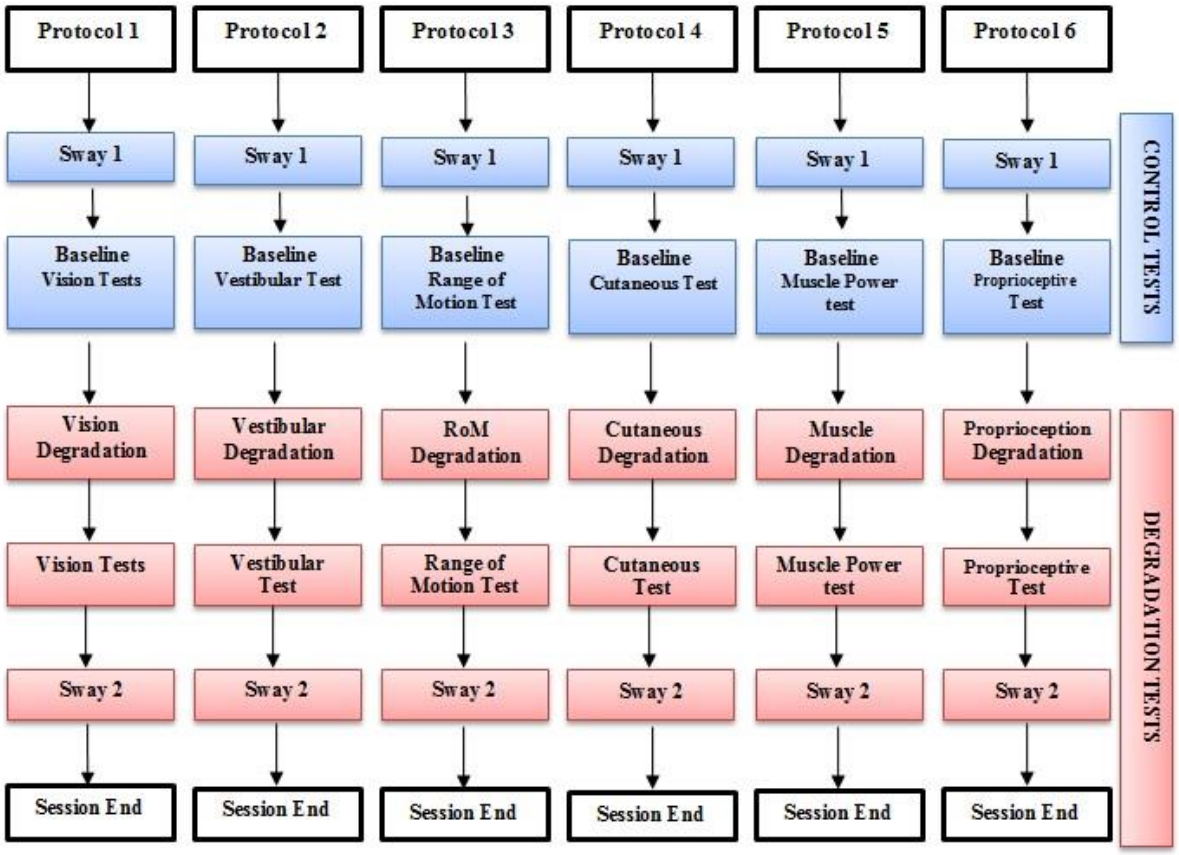


FIGURE 2 : DESIGN OF THE STUDY FOR THE CONTROL GROUP

For the elderly subjects, the study was a test design. The elderly subjects performed the same tests as the control subjects, except for the muscle power test (an appropriate and safe test was proposed for each population). The elderly were not submitted to the degradation since their musculoskeletal intrinsic factors were already considered as degraded, due to the ageing process. The difference with the control subjects is that the elderly usually have more than

one musculoskeletal intrinsic factor degraded due to age, while control subjects were degraded one musculoskeletal intrinsic factor at a time. . The order in which the intrinsic factors were assessed was semi-randomised. The diagram presented in Figure 2 shows the design of the study for healthy people and the Figure 3 shows the design of the study for elderly.

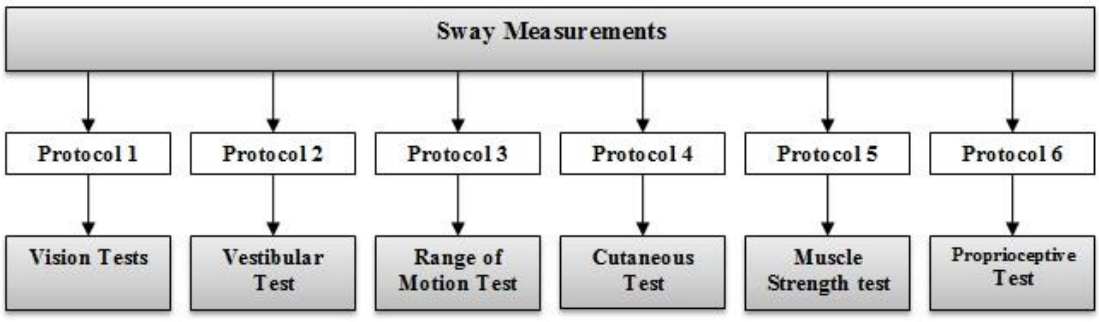


FIGURE 3: DESIGN OF THE STUDY FOR THE ELDERLY

2.5.2 ORDER OF TESTING

For the elderly group, the order of the testing was randomised, with the exception of the muscle test, which was always performed at the end of the session to avoid the fatigue induced by this test influencing the results of other tests.
For the control group, the order of the testing of the musculoskeletal intrinsic factors was semi-randomised with the Excel randomization function.
Two of the degradations of the musculoskeletal intrinsic factors required a lengthy recovery before subsequent testing. The muscle testing requiring at least 48h to recover, while the cutaneous degradation required one hour to recover their previous ability. The control subjects had two sessions with three sensory degradations per session. Thus, one session finished with the muscle fatigue degradation, while the other session finished with the cutaneous degradation. An appropriate interval (one hour to 48 hours) was left between the two sessions to avoid the effect of one of the degradations influencing the other tests.
Within the testing, the order of testing was also randomised. The vision testing had 4 components, performed in a random order. Range of motion testing was performed on three joints, with a randomised order used. Joint proprioception testing was also performed on three joints, again with a randomised order. For the replacement test, angles for the test were randomised for each joint.

2.5.3 BLINDED ASSESSMENT

Participants were informed about the general objective of the study but the details or the data that were collected were not fully explained in order to avoid the subject trying to influence the results. Two examiners performed the tests; one person performed the sensory test while another performed the sway test. The examiners who collected the data were blind to the questionnaire results/responses of the participants (data concerning previous injuries, physical activity, diseases and medication).

2.6 MATERIALS

2.6.1 SUBJECT INFORMATION

2.6.1.1 INFORMATION SHEET

JODHPUR, INDIA

Subject information sheets were in English, with a translator provided to explain the procedure to the elderly subjects who did not speak English. Subjects were free to ask questions at any time throughout the experiment. Phone numbers and emails of the experimenters were provided for further contacts in English and in Hindi.

AUCKLAND, NEW ZEALAND

The information sheet for the Auckland experimentation was only in English. The version was similar to the Jodhpur experiment and is presented in Appendix 3.

2.6.1.2 CONSENT FORMS

JODHPUR, INDIA

Consent forms were read and signed by every subject. Three forms were signed, one for the subject, one for the researcher and one that was held by the university that was hosting the experiments (IITJ, India).

For the elderly subjects, a Hindi version was available in order to make sure they fully understood the study protocol, and that they had the right to withdraw from the study at any time without having to give a reason. The English version of the consent forms is presented in Appendix 4, and the Hindi version in Appendix 5.

AUCKLAND, NEW ZEALAND

The consents forms were written in English. Two copies were read and signed by the subjects, with one copy kept by the subject, and one kept by the examiner. A copy of the consent from is presented in Appendix 6.

2.6.1.3 QUESTIONNAIRE

Information was collected from all subjects via a questionnaire. An example of the questionnaire is presented in Appendix 7.

The questions of the questionnaire were related to:

- Identity of the subject
- Age (date of birth)
- Contact details
- Physical activity history
- Main occupation and/or job before retirement
- Injuries and illness
- Presence of chronic diseases
- Medication

Elderly people were also required to complete a fall history

2.6.1.4 SUBJECT HEIGHT AND WEIGHT

The height of each subject was measured using a classic wall tape, with height reported in meters and centimetres. Subject weight was using data recorded from force plate.

2.6.1.5 ELDERLY MOBILITY

A complete health assessment of the elderly was not possible, in term of time and staff required. It is however necessary to obtain information about the mobility to comment or explained the results. The Timed Up and Go test described in the review of literature was performed here for the elderly participant only.

- The elderly sat on a bench
- They stand to walk 3m
- Turn around a mark on the ground
- Return to the bench
- Sit down
- The performance was timed with a stop watch by the examiner
- A second examiner was walking aside of the elderly in case of a loss of equilibrium

2.6.2 BASELINE ASSESSMENT

2.6.2.1 SWAY MEASUREMENT

As explained earlier, the PhD is part of a larger project and the results are meant to be use with the Balance Quality Tester (BQT) mentioned in the review of literature.
Therefore the settings of the force plate match the setting of the BQT.
The force plate was set with a height of 30mm and a width of 400 mm. The subjects were required to look down at the force plate while standing.
The measurement was for a total duration of 30 seconds and they repeated the measurement from 1 to 3 times.

JODHPUR INDIA

In the Jodhpur experiment, 3 measurements of the sway were performed for the healthy control subject. However, only one sway measurement was performed for the impaired subjects. At that time, it was thought that the temporary degradation would not last long enough to record three sway measurement and also it was thought that three measurements would significantly increase the duration of the experiments, duration that was already an obstacle for participant to enrol.
The elderly did recorded three sway measurements.
The force plate (Figure 4) used in the present study was a Bertec 4060-80 (Bertec Corporation Colombus, OH USA). There is no safety concern in relation to the use of the force plate in any population.

FIGURE 4 : FORCE PLATE FOR THE JODHPUR STUDY.

AUCKLAND NEW ZEALAND

The measurement of sway was repeated 3 times for the healthy as well as the impaired condition.

The equipment available in the AUT laboratory differed from that used in Jodhpur, meaning that different force plates were used. The force plate (Figure 5) used for the Auckland study was a Kistler 5695A (Kistler Instrument Corporation, 75 John Glenn DR, Amherst, NY 14228, USA) which was located in the HRRC of AUT.

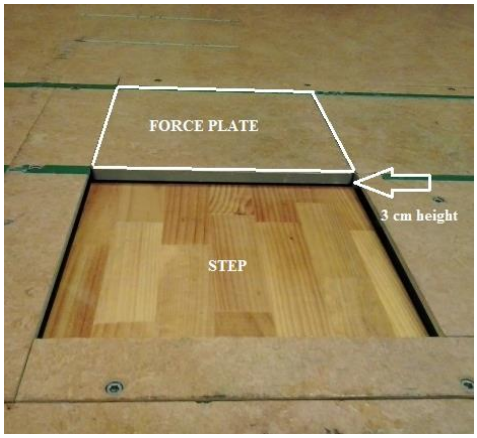


FIGURE 5: SETTING OF THE FORCE PLATE FOR THE AUCKLAND STUDY.

2.6.2.2 VISION ASSESSMENT

2.6.2.2.1 VISION ACUITY

A Snellen wall chart (Figure 6) was used (Distrimed, Le Galaxie B-2793 Ch. St Claude, 06600 Antibes, France). The chart has 11 lines with the size of the letters decreasing with each line. The subject stands 20 feet (6.1 m) from the chart. The test is a logMAR chart with a logarithmic progression in the size of letters, with equal graduations between letters and lines.

The Snellen chart was fixed on the wall, with subjects standing 20 feet from the chart. Subjects were required to read the letter starting from the top, reading down as long as they were able to see the letters. The examiner asked the subject to repeat the letters that were wrong. If the subject was unable to completely read a line without mistakes then their score was taken as the previous line correctly completed. The Snellen test has several different scoring systems. For the present study, the most basic system was used, with one point scored for each line read. The test contains 11 lines, giving a maximum score of 11 points.

FIGURE 6: ILLUSTRATION OF THE ACUITY TESTING FOR THE JODHPUR AND AUCKLAND STUDY.

2.6.2.2.2 VISION CONTRAST

The Mars Letter Contrast Sensitivity test (Figure 7) was used (Mars Perceptrix Corporation, 49 Valley View Road, Chappaqua, NY 10514-2523, USA). The Mars Contrast Sensitivity test is a printed contrast test with 48 different contrast levels declining gradually in 0.04 log unit steps. Only the contrast declines throughout the test not the letters.

Visual contrast: the Mars Perceptrix test has three plates, each with different letters but with the same contrast for each plate. The use of multiple plates ensures that there is no learning effect. The test begins with the subject seated before the plates are presented. The subject is required to read the line starting at the top right going across the line, down to the bottom left. The subject should not move their head during the test. The subject and the plate are kept in the same positions for the duration of the test. The examiner terminates the test after two consecutive errors of reading.

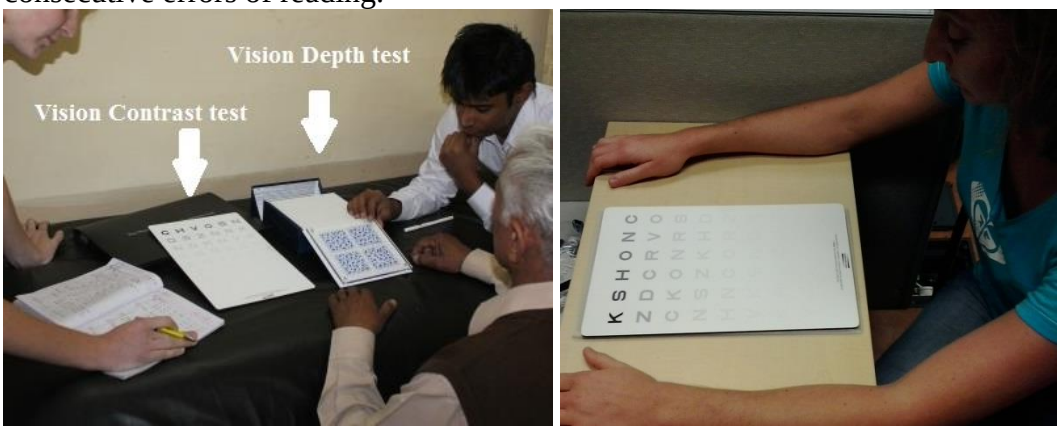


FIGURE 7: ILLUSTRATION OF VISION CONTRAST TESTING FOR THE JODHPUR AND AUCKLAND STUDY

2.6.2.2.3 VISION DEPTH

The Frisby test (Figure 8) was used (Distrimed, Le Galaxie B-2793 Ch. St Claude, 06600 Antibes, France). The Frisby test consists of thee transparent plates of different thickness, with each plate having four quadrants. Each quadrant is printed with a random texture pattern and in one of the quadrants there is a hidden circle shade (circle rising or in depth). The participant has to designate which quadrant is different from the three others

The Frisby test is furnished in a box with indication for the test and the evaluation. It is recommend testing the three plates one after the other starting with the thickest one, the plate is tested three time to avoid random response. The vision depth test for the Jodhpur study is presented Figure 8 and in figure for the Auckland study.

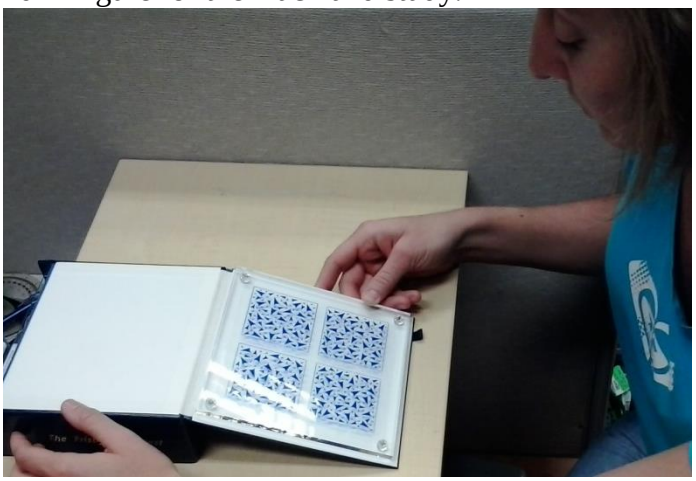


FIGURE 8 : VISION DEPTH TEST FOR THE AUCKLAND EXPERIMENT.

2.6.2.2.4 VISION PERIPHERY

It was not possible to have an automated system to test vision field. Therefore an own designed test was build (Figure 9). A perimeter was drawn on the ground around the participant. The participant fixed is gaze in front of her/him. The examiner arrives from the side of the participant with a pen. The subject tells the investigator when they can see the pen while looking forward. The position where the participant could see the pen was reported on the perimeter. The test is made on each side. The angle produced on the perimeter was measured with a manual goniometer. There is no reliability or repeatability data for this test.

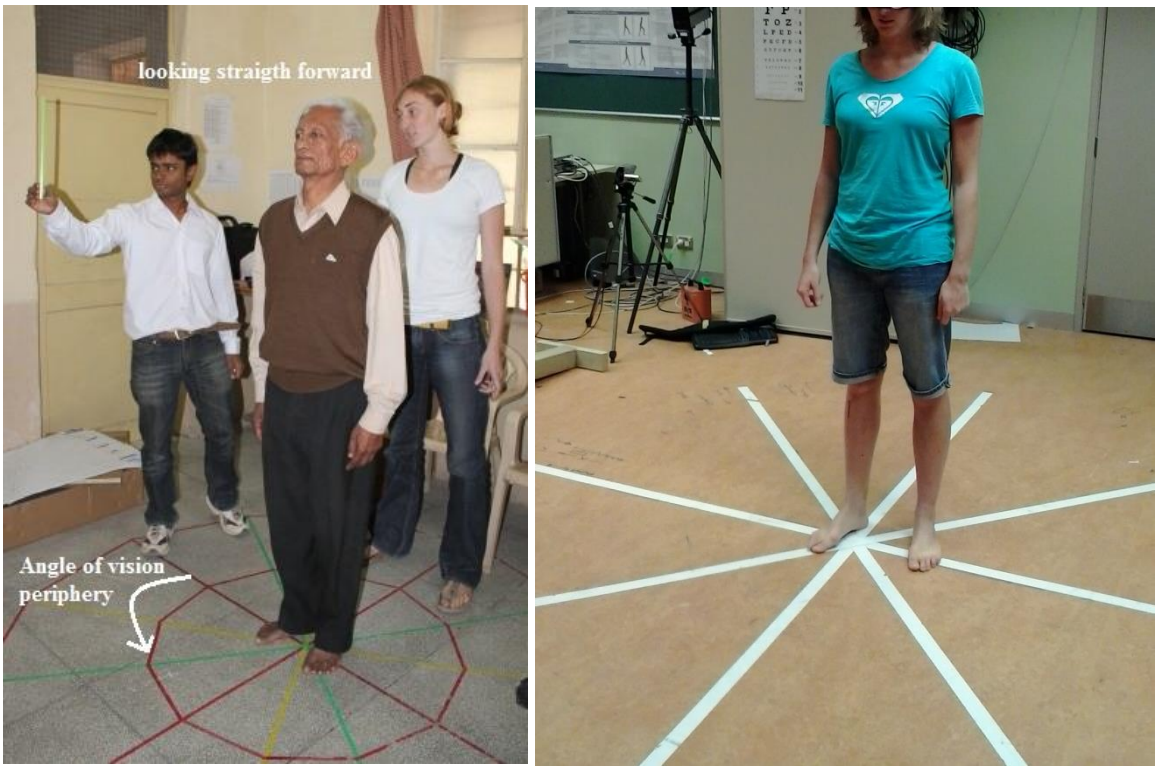


FIGURE 9: ILLUSTRATION OF THE MEASUREMENT OF THE VISION PERIPHERY FOR JODHPUR AND AUCKLAND STUDY.

For all vision tests, the participants were assessed binocularly, with both eyes open in order to correspond to a real life situation. The order of tests was randomised.

2.6.2.3 VESTIBULAR ASSESSMENT

The test used to assess the vestibular system in both studies Jodhpur and Auckland was the Fukuda stepping test (Figure 10).
The protocol for the Fukuda test requires concentric circles with a radius of 0.5m and 1m to be drawn on the ground. It is also possible to use four circles with a radius of 0.5m, 1m 2m, and 3m. The circles are divided into sections by lines passing through the centre of the circles at 15° angles. The subject stands in the middle of the two circles, blindfolded, in a quiet room, with their feet together. Subjects are then instructed to step in place at a normal walking speed (about 110 steps/min) for a total of 50 steps. At the end of the test, the examiner determines the angle of the body rotation, around the vertical axis.

FIGURE 10: ILLUSTRATION OF THE FUKUDA STEPPING TEST FOR THE VESTIBULAR ASSESSMENT.

2.6.2.4 JOINT RANGE OF MOTION ASSESSMENT

The range of motion tests (Figure 11) in the present study were performed using a two-armed plastic goniometer for the Jodhpur study and electric goniometer for Auckland study (Biometrics ltd sensors, SG twin axis goniometers, Biometric Ltd PO Box 340, Ladysmidth VA 22501, USA).

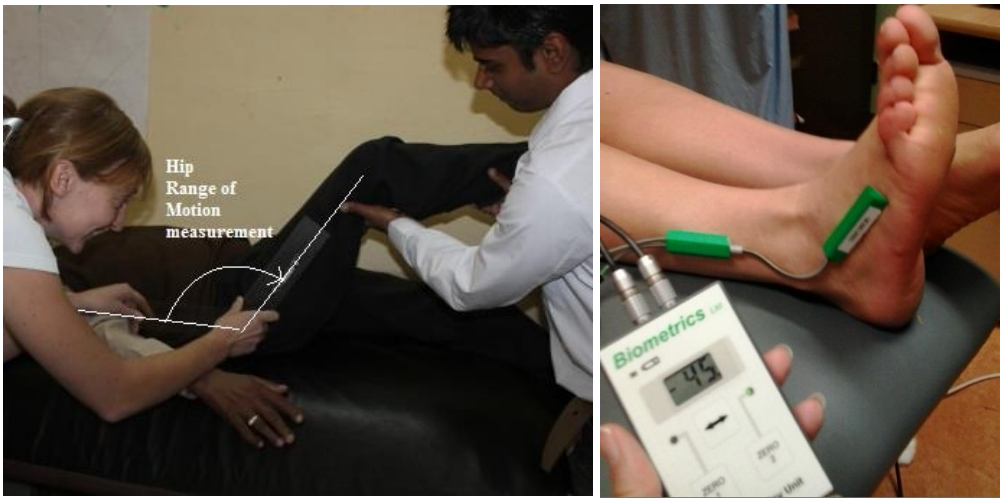


FIGURE 11: ILLUSTRATION OF THE MEASUREMENT OF THE HIP RANGE OF MOTION IN THE JODHPUR STUDY AND ANKLE ROM IN THE AUCKLAND STUDY

JODHPUR, INDIA

Range of motion (RoM) was measured at the hip, knee and ankle joints on the right-hand side only. Maximum passive flexion and maximum passive extension were measured. Subjects lay on their back on an examination table, with two examiners required. The first examiner moved the limbs of the subject while the second examiner measured joint angles. The examiners kept the same roles throughout the measurement protocol for all subjects.

Hip RoM was measured by placing the centre of the goniometer on the greater trochanter, with one of the goniometer's arms following the axis of the femur, with the other arm following the axis of the trunk. This measurement technique was reported in the study of Holm et al. (2000). Passive flexion was performed by bringing the right leg towards the torso, with flexion completed when the pelvis began to lift off from the table. Extension was measured with the subject lying prone, with the right leg raised until the pelvis was about to lift off from the table.

Knee RoM was measured by placing the centre of the goniometer on the lateral epicondyle of the knee, with the fixed arm following the axis toward the greater trochanter and the second arm following the axis toward the lateral malleolus. The same goniometer positioning was used by Unver et al. (2009). Knee flexion was performed by bringing the ankle towards the buttock, while knee extension was performed by completely extending the leg. In order to avoid any effect of muscle flexibility on the test results, the hip was kept at around 60 degrees of flexion during the test.

Ankle RoM was measured by placing the centre of the goniometer set on the lateral malleolus, with the static arm of the goniometer following the axis towards the lateral condyle of the knee and the second axis following the axis towards the big toe. The same technique was used in the study of Croxford and al. (1998). Ankle flexion was performed by bringing the toes toward the tibialis anterior, while ankle extension was performed by bringing the heel toward the calf.

The axes followed by the goniometer's arms were drawn on the subjects' limbs in order to accurately repeat the measurements.

AUCKLAND, NEW ZEALAND

Only the ankle joint was tested. The results of the Jodhpur study exposed in later chapters showed no significant result with the knee and hip, it was therefore decide to be dropped for the Auckland study.

The same measurements were performed at the ankle joints. The difference was that with electronic goniometer, a single examiner was required to fix the arms of the goniometers, move the joint and records the angle.

2.6.2.5 MUSCLE AND JOINT PROPRIOCEPTION ASSESSMENT

JODHPUR, INDIA

Recording devices required to perform joint position sense test were not available in the location of the Jodhpur experiments. Therefore, the protocol of Robert et al. (2003) was used. In this protocol an angle scale was directly printed onto a board, on which the angle in which the participant positioned their limb was marked. In the current study, the angle scale was drawn on large paper sheet, which could be easily adjusted to the position of the participant's limb. Three joints of the right leg of each subject were tested, the ankle the knee, and the hip. The order of the joint tests was randomised, as were the target angles.

The test starts with the joint in a neutral position. It is then moved to a targeted (random) angle passively by the examiner. The joint is held in position for three seconds at the target position while the subject is asked to memorize the position. The joint is then returned to the initial position with subjects required to move the joint back to match the target position, actively. The error between the target angle and the angle in which the subject places the joint is interpreted as the accuracy of joint position sense. The targeted angle and the matched angle were reported on the sheet fixed on the board next to the subject's limb. (See Figure 12 and Figure 13)

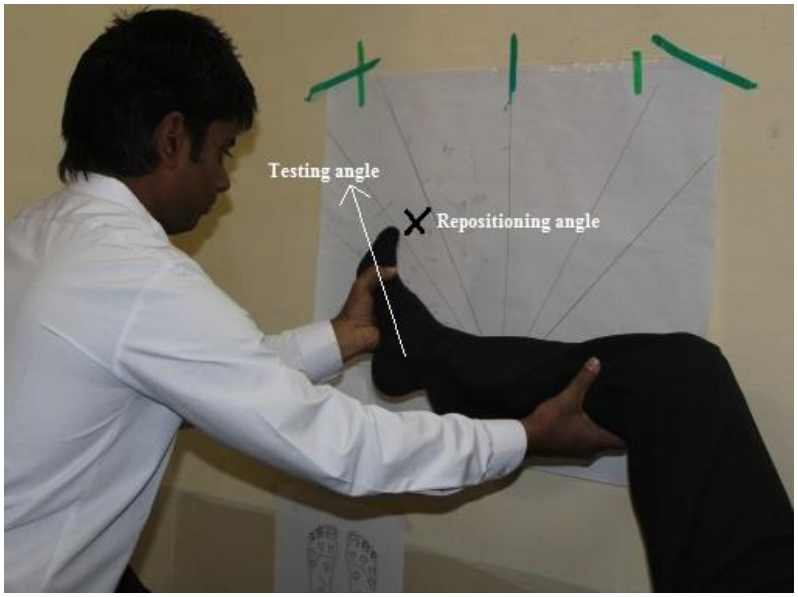


Figure 12: Illustration of the repositioning test for the ankle joint proprioception

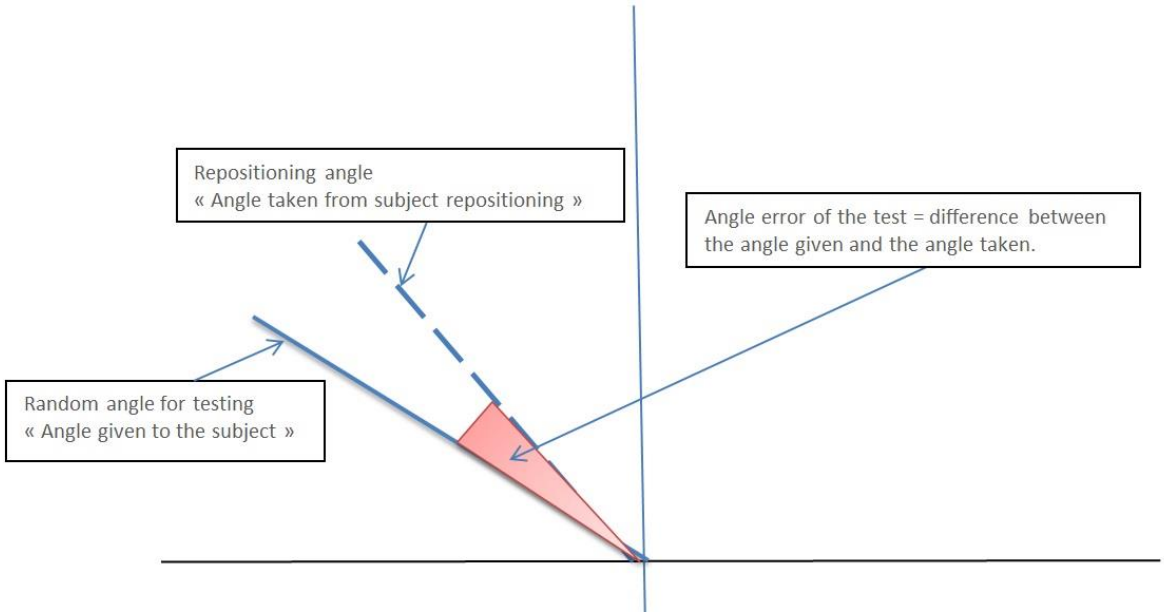


Figure 13: Angle error measurement of the joint repositioning tests

Ankle position sense test: the angle was determined by the angle formed between two lines drawn on the subject's skin. One line was drawn from the centre of the medial malleolus toward the big toe, while the second line was drawn from the centre of the malleolus toward the medial femoral epicondyle of the knee. The subject lay on their back on the examination table, with the leg maintained parallel to the table and the malleolus aligned with the centre of the angle scale. The target angles were randomised between 5 and 75 degrees from the plantarflexion toward the dorsiflexion.

Knee position sense test: the angle was determined by the angle formed by two lines drawn on the participant's skin. One line was drawn from the centre of the medial femoral condyle) toward the femoral head and the other line was drawn from the centre of lateral tibial epicondyle toward the malleolus. The subject lay on their back, with the thigh set at a comfortable position and the centre of angle scale was aligned with the centre of the knee. The target angles were randomised between 5 and 75 degrees.

Hip position sense test: the angle was determined by the angle formed between two lines drawn on the subject's skin. One line was drawn from the greater trochanter toward the lateral epicondyle. The subject lay on their back on the examination table. The centre of the angle scale sheet was aligned with the greater trochanter. The target angles were randomised between 5 and 45 degrees.

AUCKLAND, NEW ZEALAND

The very same protocol was performed to the exception of the device used and the joints tested. In Auckland, electric goniometers were available (Biometrics ltd sensors, SG twin axis goniometers, Biometric Ltd PO Box 340, Ladysmidth VA 22501, USA). Therefore the targeted angle and the match angle were tracked using the electric goniometer. In addition, only the hip and the ankle were tested, since the knee appears not relevant according to the test performed in India and described in later chapters. (See the picture on the right in Figure 11).

2.6.2.6 LEG MUSCLE STRENGTH ASSESSMENT

The review of literature in chapter one mentioned the importance of leg muscle strength but also leg muscle power. Therefore the testing included both tests: strength and power, only for the control subject of the Jodhpur study. It was not possible to perform the same power test on the elderly for obvious security reason. For the Auckland study it was found after the Jodhpur study that the power test was useless so it was drop, the results and discussion about the Jodhpur study will be found in later chapter.

JODHPUR INDIA

The control subjects were tested for leg muscle strength with the sited position maximal voluntary test and the leg muscle power with the counter movement jump.

- Countermovement jump: A short warm up was performed, which consisted of sit to stand and up on toes movements. Subjects stood on the force plate with their legs hip width apart. Subjects' hands were kept on their hips for duration of the test. Subjects flexed their knees at 90 degrees before immediately performing a fast upward vertical jump as high as possible without any stopping or hesitation at the transition from knee flexion to extension. The protocol is similar to that used by Slinde et al. (2008). Three jumps were performed by each subject.
- Chair maximal isometric voluntary contraction test: Each subject was then required to take the chair position against the wall, with the examiner adjusting the position of the subject until they were at ninety degrees of flexion. The chair position is shown in Figure 14, with subjects' backs leaning against the wall, with their feet apart at hips width. Subjects were then required to hold the position for one minute in order to fully warm up the leg muscles and to become familiarised with the position. A maximum voluntary isometric contraction (MVC) was then performed, in which weights were placed on the subjects' thighs and held for 15 seconds. Several repetitions were needed to reach the maximal weight, with the weight progressively increased until the subject failed twice to hold a weight for 15 seconds. The last weight was considered to be the MVC for the subject.

FIGURE 14: ILLUSTRATION OF THE SITED MVC TEST

The elderly subjects were tested with the sit-to-stand test and heels-raise five times as fast as possible while remaining balanced.

Both tests, the five sit to stand and the five heels raised are timed, the tests involved the strength of the leg muscle necessary to perform the movement required but also the speed of the muscle contraction to perform the test quickly. It could be assumed that the test provides an indication of muscle power. However with no reliability or validity of the tests, the results will simply be interpret as indication of the leg muscle strength of the elderly and especially used to compare the elderly between each other. The control subject also performed those test in order to have normative data to compare to.

A warm up was performed before taking the tests, with subjects required to walk up and down the corridor for three minutes prior to performing several sit to stand down and up on toes repetitions (Figure 15).

- Sit to stand test: The test requires the subject to sit down and stand up five times as fast as possible without using the armrests, and while keeping the movement under control. The test starts in a sitting position and finishes when the subject returns to the sitting position at the end of the five repetitions. The time to perform these five movements is recorded with a time watch. The protocol was similar to that used in the study of Whitney et al. (Whitney, et al. 2005)

- Heels-raise / Up on toes: The test requires the subjects to stand up on their toes five times consecutively. Subjects start standing on flat feet, before going up on their toes five times, with the test ending when the subject is back on flat feet. The duration of the test is timed with a stopwatch.

Figure 15: Illustration of the sit to stand test and heel up test.

AUCKLAND, NEW ZEALAND

The countermovement jump was not performed in the Auckland study. The isometric strength test was performed but using the strength training machine provided in the facilities. The clinical tests were not performed during this Auckland study.

The maximum isometric voluntary contraction was performed on a horizontal leg press. The same protocol was follow to assess the maximum weight lifted (see Figure 16).

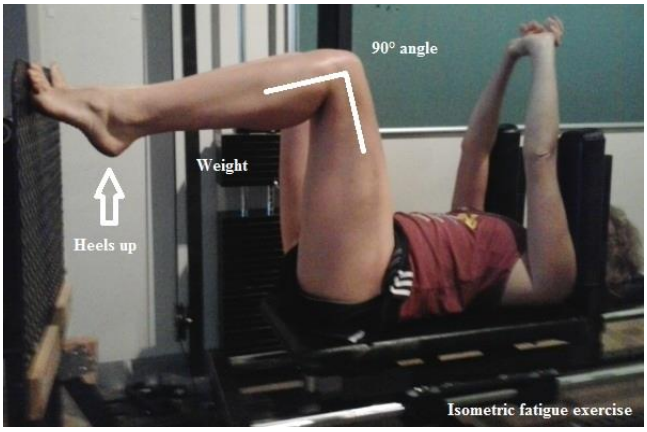


FIGURE 16: ILLUSTRATION OF THE HORIZONTAL LEG PRESS USED FOR THE DEGRADATION OF MUSCLE POWER.

2.6.2.7 CUTANEOUS PROPRIOCEPTION ASSESSMENT

The test chosen for the present study was the touch sensation threshold, using the Monofilament Touch test.

The filaments used for the test are calibrated such that each filament bends when the specific pressure is reached. The test requires the filament to be applied until the filament bends. The participants are asked to say "YES" if they felt the stimulus. If the subject answered correctly, the next smallest size of filament is used and the test repeated. If the subject could not correctly identify the stimulus, the next largest size of filament is used (Alfuth and

Rosenbaum 2011; Meyer, et al. 2004; Wang and Lin 2008). Subjects are evaluated in a supine position on an examination table with their eyes closed.

JODHPUR, INDIA

The test was performed with a filament size of 5.07 (Rehaforum Medical GmbH, Daimlerstrabe 12a, 25337 Elmshorn, North Coast Medical Inc. Morgan Hill, CA. USA). The 5.7 filament was chosen since it is normally indicative of peripheral sensory neuropathy (Meyer, et al. 2004).
No other mono-filaments were available.

The foot is divided into zones (Figure 17), with the test performed on each zone. The nine-zone division reported in previous studies was used in the present study (Alfuth and Rosenbaum 2011; Eils, et al. 2002; Gopalakrishna Prabhu, et al. 2001; Perry 2006). The areas where the mono-filament was applied are represented on figure 17 and listed below:

- Big toe
- Third toe
- Fifth toe
- First metatarsal
- Third metatarsal
- Fifth metatarsal
- Arch of the medial part of the foot
- External side of the medial part of the foot
- Centre of the heel.

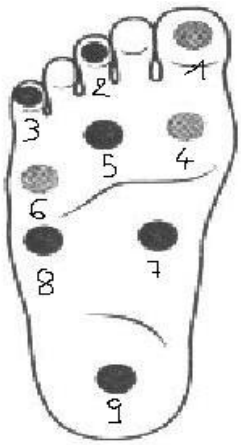


Figure 17: Illustration of the zones of the foot that were tested.

The filament was applied on the 18 zones in a random order (Figure 18). If the answer from a touch was not clear or was spoken with a substantial delay, the zone was tested again. The score sheet was filled up as the test was performed in order to ensure all the zones were tested. Only one filament, of size 5.07, was used in the pilot study.

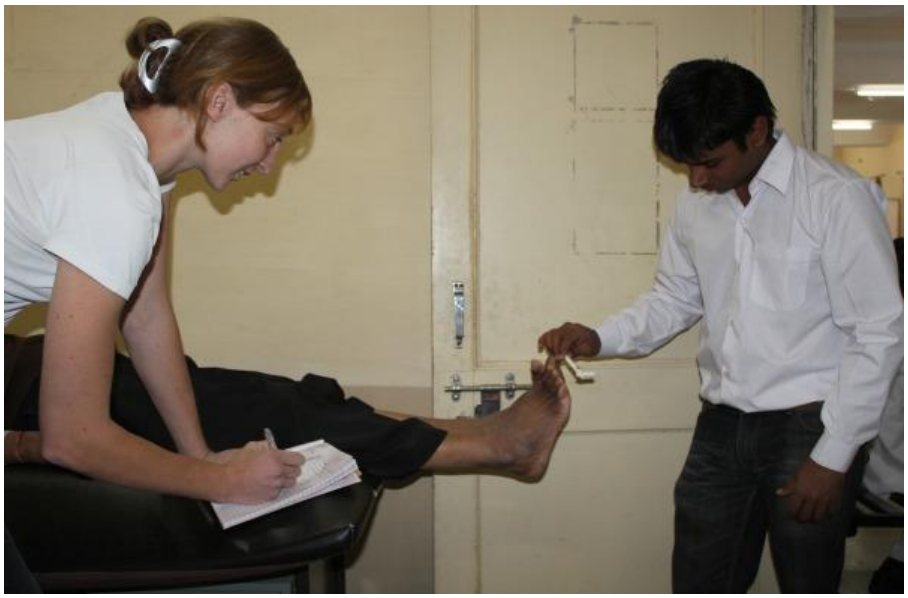


FIGURE 18: ILLUSTRATION OF THE CUTANEOUS TEST WITH THE MONO FILAMENT.

AUCKLAND, NEW ZEALAND

Unlike in Jodhpur where only one mono-filament was used, multiple mono-filaments of different thickness were used in the Auckland study (Figure 19). The difference between the Jodhpur and Auckland experiments was that, rather than of counting the number of zones on which the monofilament was felt (Jodhpur), the index (size) of the monofilament that could be felt on the foot was recorded (Auckland).

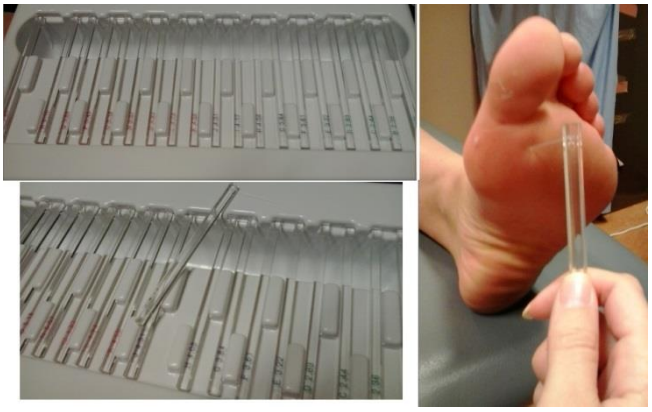


FIGURE 19: ILLUSTRATION OF THE LARGE RANGE OF MONO-FILAMENT USED IN THE STUDY IN AUCKLAND.

2.6.3 DEGRADATION OF THE INTRINSIC FACTORS

The previous section has exposed the baseline test for the measurement of the sway and the intrinsic factors. This section exposes the temporary degradation performed to simulate impairment of the intrinsic factors investigated.

2.6.3.1 VISION DEGRADATION

The vision degradation was performed by wearing modified goggles. The degradation was similar for the two studies.
Four different goggles were built in order to degrade the four components of vision. The goggles were purchased in a French DIY store BricoDepot®, and were chosen as they completely covered the eyes. Subjects were required to put on the goggles immediately prior to testing, and to remove them at the end of the experimentation. Subjects wore the goggles throughout the visual tests and the postural sway tests.
The modifications made to the goggles were as follows:

- Visual Acuity: a thin piece of blurred transparent paper covered the surface of the mask (Figure 20).

FIGURE 20: ILLUSTRATION OF THE BLUR GOGGLES FOR VISUAL ACUITY DEGRADATION.

- Visual Contrast: white dots of paint were spread across the visor of the mask. During the testing a strong light was directed toward the goggle, with the high luminosity combined with the white dots decreasing the contrast (Figure 21).

FIGURE 21: ILLUSTRATION OF THE CONTRAST DEGRADATION GOGGLES.

- Visual depth perception: depth perception was suppressed by covering one side of the goggles with black paper (Figure 22).

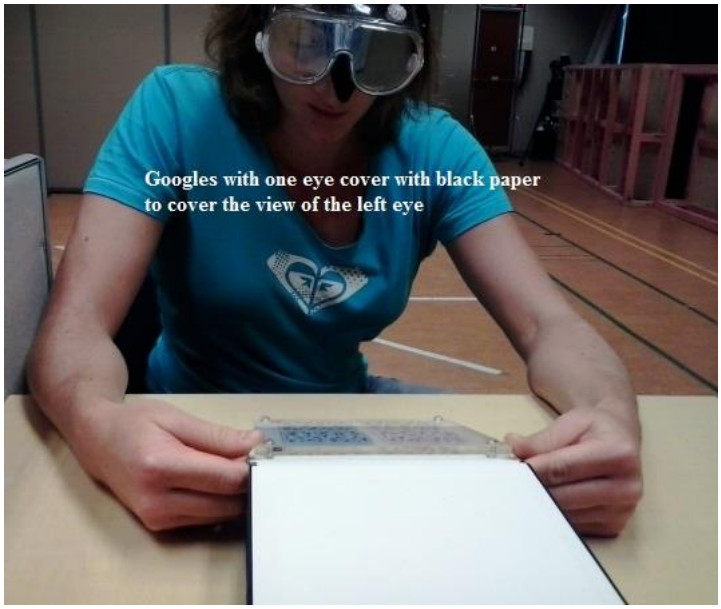


FIGURE 22: ILLUSTRATION OF THE DEPTH VISION DEGRADATION.

- Peripheral vision: tunnel vision was created on the goggle by occluding the entire surface of the mask with black paper except for two holes in front of the eyes (Figure 23).

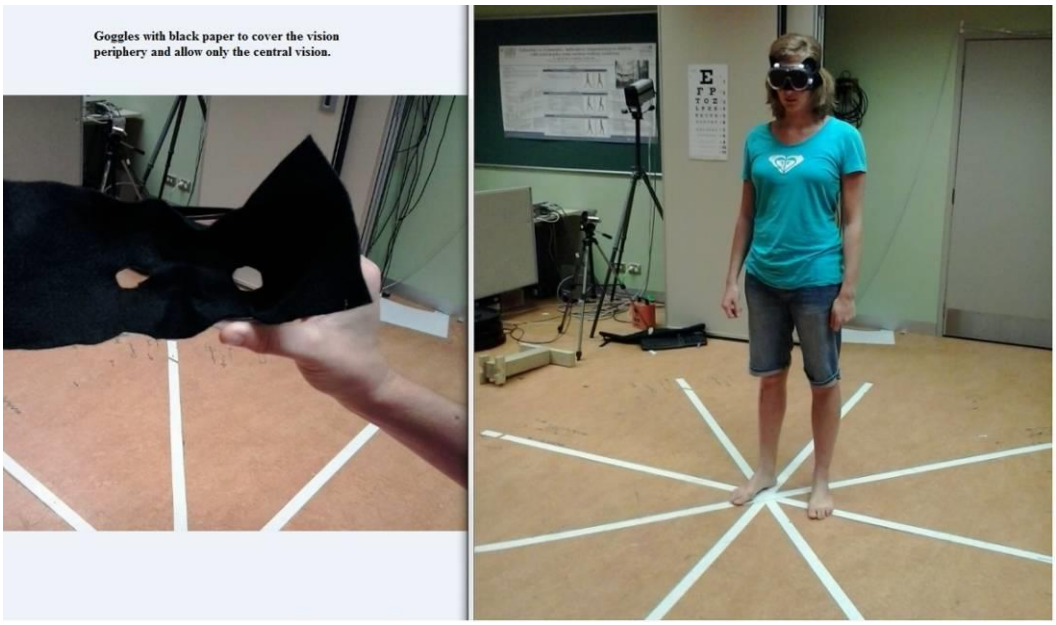


FIGURE 23: ILLUSTRATION OF THE VISION PERIPHERY DEGRADATION.

2.6.3.2 VESTIBULAR DEGRADATION

The vestibular degradation was performed using galvanic vestibular stimulation. The degradation was similar in both studies (Figure 24).
The degradation used in this study was GVS. The device used was the Galvanic Current Generator GALVADYN 2 (Kinessonne France, 200 avenue des Gresillons, 92601 Asniere cedex France).

Fitzpatrick et al. (2004), in a review of the literature on GVS, described the process as simple and without risks for the subject's health. Similarly, Utz et al. (2010), reported that no study has shown any counter indications for using GVS. Utz et al. (2010) also reported that stimulations of 0,6 to 0,8 mA for a duration of 20 min had no negative effects on subjects. This is in accordance with Day (1999), who suggested GVS with an intensity of around 1mA. The stimulation duration of this study was intermittent, with the degradation was applied only during the testing part, which takes less than five minutes in total.

The GVS device was used with two stimulating electrodes. The electrodes were embedded in a foam pocket, with the foam dampened before the electrodes were inserted. The electrodes were placed on the mastoid bones of the subjects, and secured using an elastic band. The device was then turned on, with the current progressively increased to 1mA. The subject then performed the vestibular assessment test and the postural sway test. After completion of the two tests the current was turned off and the electrode removed.

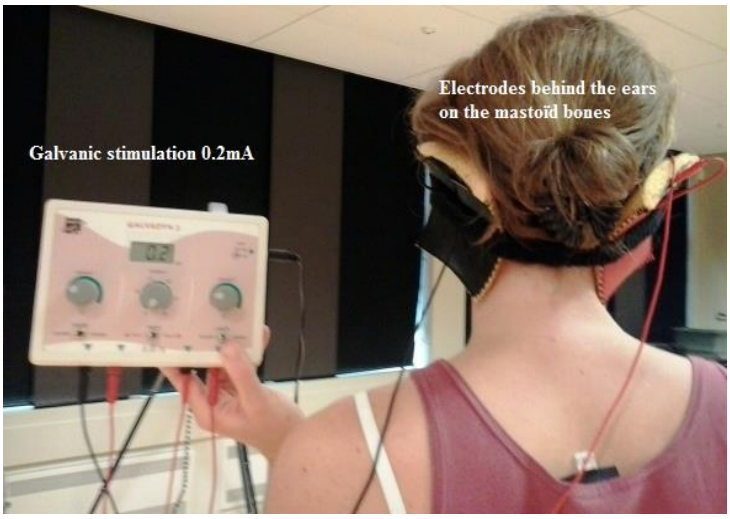


FIGURE 24: ILLUSTRATION OF THE GALVANIC STIMULATION SYSTEM.

2.6.3.3 JOINT RANGE OF MOTION DEGRADATION

The degradation of joint range of motion was performed using brace of the joints tested. Different brace and joints were tested in Jodhpur and Auckland.

JODHPUR, INDIA

The devices used to restrict joint movement were all custom-made for the project (Figure 25). Hip range of motion was decreased by using a piece of cloth wrapped around the hips and the thigh of the subjects with additional straps to keep it tight around the hips. The brace reduced the hip range of motion, which did not exceed 10 degrees.

Knee braces were designed using cloth, pieces of wood and leather straps. The wooden struts were strapped to the shanks and thighs with cloth, thus preventing the participant from flexing or extending their knees. Knee range of motion was limited to 60 degrees.

Ankle braces were also designed using wooden struts, cloth, and leather straps. The wooden struts were placed at an angle of 90 degrees before being fixed to the ankle with the straps. Ankle range of motion was limited to 4 degrees.

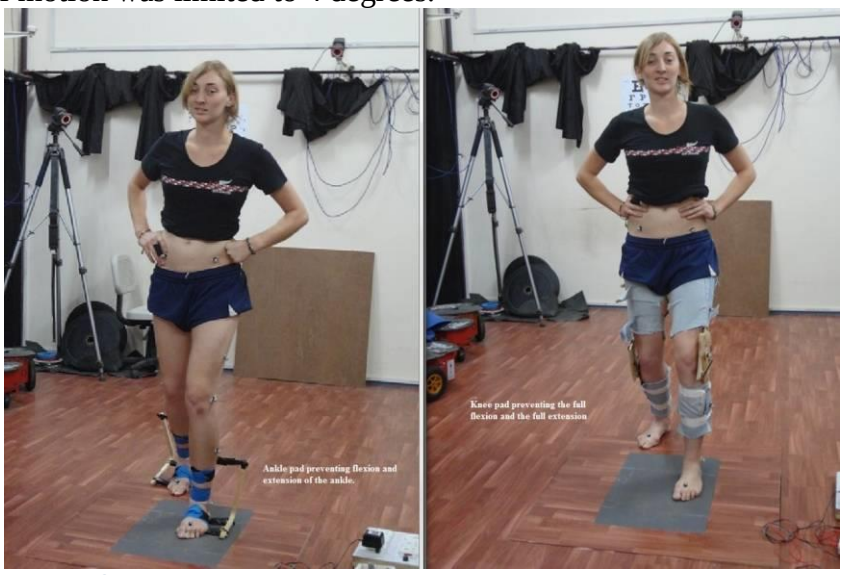


FIGURE 25: ILLUSTRATION OF THE JOINT RANGE OF MOTION DEGRADATION.

The braces were placed bilaterally on the participants. The joints (hips, knees and ankles) were all tested separately, with the order of testing randomised. First, the braces were fixed on the participants, before the limitation of motion was checked and the subject was required to perform the sway test. The braces were then taken off and the next joint was tested.

AUCKLAND, NEW ZEALAND

The ankle braces used in Auckland were different (Figure 26). In the Auckland study, Moon Boot Walkers (classic orthopaedic ankle braces for rehabilitation) were used to bilaterally reduce the range of motion at the ankle. The ankles were strapped tight in the moon boot walker to avoid any ankle movement. A compensatory sole was added to the boots to make them flat and thus stop the rocking movement initially present and enable subjects to walk.

FIGURE 26: ILLUSTRATION OF THE ANKLE BRACE FOR THE AUCKLAND STUDY.

2.6.3.4 MUSCLES AND JOINTS PROPRIOCEPTION DEGRADATION

The degradation of the muscle and joint proprioception was performed using vibration of the tendons. The same degradation was used in both studies (Figure 27).

The vibration was generated with a VB 115 device (Techno Concept, ZA Pitaugier, 04300 Mane, France).

The vibrators were placed bilaterally on the subjects. Each joint was tested separately, with a randomised order of testing. The vibrators were maintained on the tendon by the examiner for 30 seconds at 115 Hz. The duration of 30 seconds and the frequency of 115HZ are the maximum parameters of the vibrators. Previous study performed in UTT have shown that 10 seconds at 90Hz vibration of the tibialis anterior was sufficient to present perturbation of postural sway (Michel-Pellegrino, et al. 2006).

In Jodhpur the three joints were tested while in Auckland only hip and ankle were tested.

For the hips, the vibrators were placed on the iliopsoas muscles. For the knee the vibrators were placed on the vastus lateralis tendon. For the ankle, the vibrators were placed on the Achilles tendon.

FIGURE 27: ILLUSTRATION OF THE VIBRATORS USED FOR DEGRADATION OF JOINT PROPRIOCEPTION.

The repositioning test was performed while the vibrations were on, with the examiner waiting 15 s after the beginning of the vibration before moving the limb to ensure the vibration had an effect before the test. For the sway measurement, it was impossible to keep the vibrators on during the measurement since the force plate would have picked up the vibration, resulting in a noisy signal. Therefore, each joint was vibrated for 30 s, before the vibrators were removed and the sway measurement was performed as close as possible to the end of the vibrations. The same technique was used for all three joints.

2.6.3.5 MUSCLE STRENGTH DEGRADATION

The degradation of the leg muscle strength was performed using fatigue isometric protocol. The same protocol was followed in both studies, only the position of the test changed. In the Jodhpur Study, the participant performed the sited isometric test. In Auckland, horizontal leg press was available and therefor used for the testing.

A custom-designed fatigue inducing exercise program inspired from the various protocol presented in the literature, was developed to fit to our settings.
All subjects warmed up before the training using the five times sit-to-stand test. Subjects were asked to stand up and sit down five times as fast as possible. Although repetitions of joint movements can cause fatigue thus reducing joint proprioception, it was assumed that five repetitions were not enough to create fatigue in young healthy adults.

JODHPUR, INDIA

The equipment used was standard weight training weights of 2.5 kg, 5kg, 10kg, 15kg, 20kg and 25kg. A timer was used to control the training duration.
Each subject was required to take the chair position against the wall, with the examiner adjusting the position of the subject until they were at ninety degrees of flexion. The chair position is shown in Figure 14, with subjects' backs leaning against the wall, with their feet apart at hips width. Subjects were then required to hold the position for one minute in order to fully warm up the leg muscles and to become familiarised with the position. The maximum voluntary isometric contraction (MVC) was then performed (described in previous section 2.6.2.6 as baseline assessment). Seventy percent of the MVC was then calculated and the subject was required to repeat a set of 15-s chair positions with the weight on their thighs,

with a 30-s rest between sets. The set continued until the subject could not hold the weight for at least 8 s. The fatiguing exercise continued with the load decreased to 70 % of the last load maintained for 15 s, before repetitions started again until exhaustion. Weight was reduced until the subject could not hold 50% of their initial MVC for more than 8 s. The maximal duration of the exercise was limited to 45 min. After the fatigue exercise and the different tests, subjects were advised to walk or jog for 5-10 min in order to fasten the recovery and decrease delayed-onset muscle soreness. Illustration of the test has been previously presented in Figure 14.

AUCKLAND, NEW ZEALAND

The isometric fatigue exercise bout was performed on a horizontal leg press (see Figure 28). Other than the change in equipment the same protocol was followed.

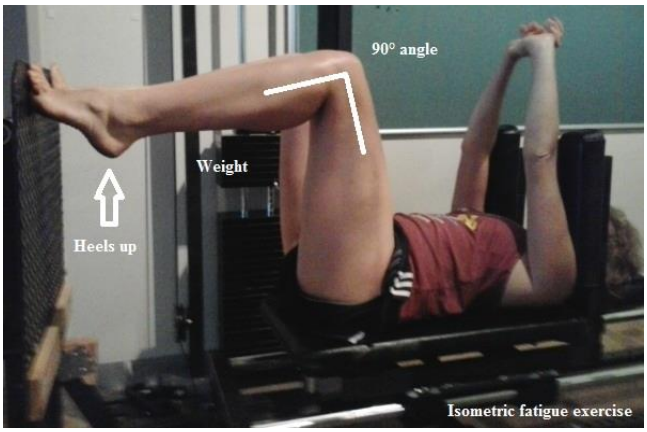


FIGURE 28: ILLUSTRATION OF THE HORIZONTAL LEG PRESS USED FOR THE DEGRADATION OF MUSCLE POWER.

2.6.3.6 CUTANEOUS PROPRIOCEPTION DEGRADATION

The method used in the present study cooling of subjects' feet (Figure 29). Iced water was used to reduce the proprioception of the foot, as follows. Buckets of ice were frozen at -20°C, with the bucket large enough to enable subjects to put both feet side by side on top of the ice. Several buckets were used in order to ensure that the temperature remained at -20°C throughout the trial.

The process of icing was performed for 15 min, with some subjects reporting initial discomfort. However, no studies have shown the technique to be dangerous to health. In the study of Galvan et al. (2006), pain during ice bath immersion was evaluated using the Borg scale (Galvan, et al. 2006; Muyor 2013), with participants rating the discomfort as an average on one (very weak) for a temperature of 15°C and an average of four (somewhat strong) for a temperature of 1°C. The authors explained that the most significant pain was felt during the first four minutes, before slowly decreasing or remaining constant until the end of the 20-min experiment. They concluded that if the participant can resist the cold temperature for four minutes then they would be able to last until the end of the trial. All subjects completely recovered proprioception in their feet within one hour of the test.

The buckets of ice were kept in the freezer until the beginning of the cutaneous degradation. The subject was required to put both their feet on the ice in the bucket. The subject was allowed five minutes to become familiar with the sensation experienced,, then the feet were

iced for a further 10 minutes. If the subject removed their feet from the ice the timer was stopped, and started again when both feet were back on the ice. Each subject had at least 10 minutes of icing. The 10-min minimum duration was chosen based on the results of Eils et al. (2002), who reported that sensation, as measured by Semmes Weinstein monofilaments did not change after an initial 10 minutes of cooling, regardless of the site tested.

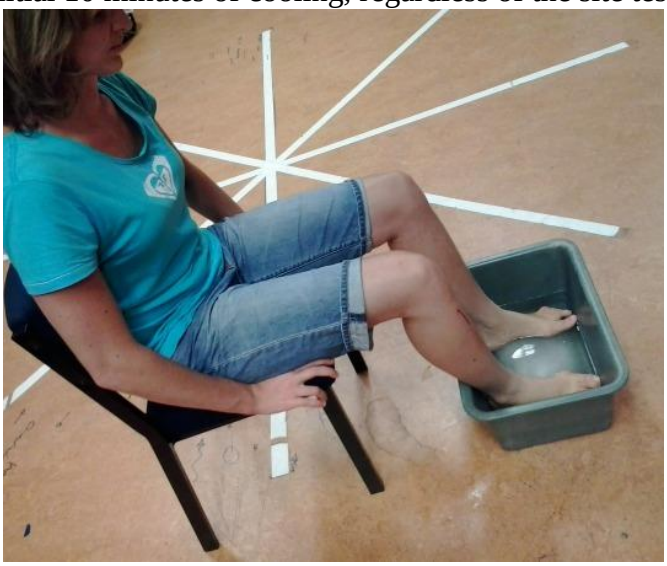


FIGURE 29: ILLUSTRATION OF THE ICING OF THE FEET FOR THE FOOT CUTANEOUS PROPRIOCEPTION.

2.7 GENERAL ORGANIZATION OF THE EXPERIMENTS

The protocol followed is described step by step, for maximum clarity.

2.7.1 ORGANISATION FOR THE CONTROL SUBJECT

Two sessions were required for the control subjects, as follows:

- Session 1
    - Information sheet
    - Consent form in two copies (one for the subject, one for the examiner)
    - Interview to complete the questionnaire
    - Pre-test measurement of postural sway:
        - 3 x 30s quiet standing
    - Intrinsic factor (1)
        - Pre-tests (Vision charts)
        - Degradation
            - Goggles are put on
        - Post-tests (Vision charts)
        - Post-test measurement of postural sway:
            - 4 x 30s quiet standing (1 x visual contrast, 1 visual acuity, 1 peripheral vision, 1 depth vision) *(x3 for Auckland Study)*
        - End of degradation (goggles off)
    - Intrinsic factor (2)

        - Pre-tests (Vestibular)
        - Degradation start (GVS on)
        - Post-test (Vestibular)
        - Post-test measurement of postural sway
            - 30 s quiet standing *(x3 for Auckland Study)*
        - End of degradation end (GVS off)
    - Intrinsic factor (3)
        - Pre-tests (Muscle power)
        - Degradation starts (Muscle fatigue exercises)
        - Post-test (Muscle power)
        - Post-test measurement of postural sway
            - 30 s quiet standing *(x3 for Auckland Study)*
        - End of degradation (active recovery/rest)
- <u>Session 2</u>
    - Pre-test measurement of postural sway
        - 30 s quiet standing *(x3 for Auckland Study)*
    - Intrinsic factor (4)
        - Pre-tests (Joint range of motion)
        - Degradation start (Joint braces on)
        - Post-tests (Joint range of motion)
        - Post-test measurement of postural sway
            - 3 x 30 s quiet standing (RoM for ankle, knee, and hip) *(only 3x ankle ROM impaired measurement for Auckland)*
        - End of degradation (Joint braces off)
    - Intrinsic factor (5)
        - Pre-tests (Muscle and joint proprioception)
        - Degradation start (Vibration on)
        - Post-tests (Muscle and joint proprioception)
        - Post-test measurement of postural sway
            - 3 x 30 s quiet standing (proprioception for ankle, knee, and hip) *(3x ankle and 3 x hip proprioception measurement for Auckland)*
        - End of degradation (Vibration off)
    - Intrinsic factor (6)
        - Pre-tests (Foot sole proprioception)
        - Degradation start (Icing of the feet)
        - Post-tests (Foot sole proprioception)
        - Post-test measurement of postural sway
            - 30 s quiet standing *(x3 for Auckland Study)*
        - End of degradation (Warm up feet).

Note: For the Jodhpur study, 3 control sway measurements were performed then 1 sway measurement for each impaired condition. In Auckland study, 3 measurements of sway were performed for the control but also 3 measurements of sway were performed for each impaired condition. In addition for the Auckland study only the ankle ROM was tested and only the ankle and hip proprioception was tested compared to the Jodhpur where the all three joints; ankle, knee and hip were tested for both range of motion and proprioception.

2.7.2 ORGANISATION FOR THE ELDERLY SUBJECT

The elderly testing was performed in the Jodhpur study only.
The elderly subjects testing session lasted for approximately one hour. It included the following:

- Information sheet and oral explanation
- Consent form in three copies (1 in Hindi for the participant, 1 in English for the examiner, 1 in English for the university)
- Interview to complete the questionnaire
- Measurement of postural sway
  - 3 x 30 s quiet standing
- Timed up and go test
- Intrinsic factor (1)
  - Vision tests
- Intrinsic factor (2)
  - Vestibular tests
- Intrinsic factor (3) test
  - Joint range of motion tests
- Intrinsic factor (4)
  - Muscle and joint proprioception tests
- Intrinsic factor (5)
  - Foot sole proprioception test
- Intrinsic factor (6)
  - Muscle power test

3 CHAPTER 3: DATA COLLECTION AND ANALYSIS

3.1 SUBJECT'S INFORMATION DATA

3.1.1 INFORMATION DATA COLLECTION

PARTICIPANTS

The population tested were analysed under 5 different groups:

- Young control Jodhpur
- Young Control Auckland
- Degraded control Jodhpur
- Degraded control Auckland
- Elderly (Jodhpur)

QUESTIONNAIRE

The questionnaire was an electronic version, with all data entered directly into a computer and saved as an individual files with the assigned subject number. While completing the questionnaire, the examiner tried to make the subject talk about themselves, their life habits, and their medical condition to make them feel comfortable first, before gather information about eventual falls or diseases. The questionnaire was conducted in more of an interview format than as a simple questionnaire. Additional questions were asked depending on the answers of the subjects to the initial questions. Details or explanation of diseases, medication or impairments were often required.

Physical Activity

The time duration and intensity of the physical activity was extracted from the questionnaire. Duration and frequency were provided by the participant. Exercise intensity was quantified by the participants using an arbitrary scale, with a choice between low (for example walking), medium (for example volleyball or cricket), or high (for example running or athletics). In order to compute mean values for exercise intensity, a number was attributed to each intensity level as follows:

- 0 - no activity
- 1 – low-intensity activity
- 2 – medium-intensity activity
- 3 - high-intensity activity

Timed up and Go

The examiner time the TUG using a hand-held stopwatch, with the time recorded on the participant experimentation sheet.

Elderly Impairment

Elderly people were scored based on the impairments they presented, as measured by the clinical intrinsic factors tests.

3.1.2 INFORMATION DATA ANALYSIS

The age, height and weight of the subjects were imported in Excel sheet for average, standard deviation, minimum and maximum calculation.

For the physical activity, the duration, frequency and intensity was imported in Excel sheet for average, standard deviation, minimum and maximum value calculation.

A score table was designed to classify the elderly according to their major impairment.

3.2 Intrinsic Factors tests Data

3.2.1 Intrinsic test Data Collection

Each intrinsic factor result was recorded on each subject's experimentation sheet. Each test has a specific scoring system that was provided with the testing tools. The details of the measurements are reported in this section. An excel sheet was used to record the scores for all tests for each participant. Average, standard deviation, minimum and maximum value were computed for all population for each test.
The score for each participant is reported Appendix 8

3.2.1.1 Vision Tests Data Collection

- The Snellen chart, measuring visual acuity, has fraction and number scoring system. The fractions are easier to interpret in terms of the quality of visual acuity. The subject stands 20 feet from the chart, meaning that line with the fraction 20/20 is the standard value for normal visual acuity. When the fraction decreases, the vision is considered to be better, while if the fraction increases, vision is considered to be worse. Subjects are considered to have normal vision if they were able to read the line of the fractions 20/20, 20/15, 20/13 and 20/10. If the value was higher, such as for fractions 20/25, 20/30, 20/40, 20/50, 20/70, 20/100, 20/200, visual acuity was considered to be impaired

To calculate average values and to compare the score among subjects or among trials, each vision fraction was given a numerical value, as shown in Table 3.

Table 3 : Visual acuity scoring system based on the fraction obtained from the Snellen chart.

Fraction	20/20	20/100	20/70	20/50	20/40	20/30	20/25	20/20	20/15	20/10
Score	1	2	3	4	5	6	7	8	9	10

- The score for contrast sensitivity is a log value given by the Mars Perceptrix chart scoring system.
- The score for the depth perception is zero, one, two, or three, depending of the number of plates that can be read. Zero being the lowest score and three the maximum.
- The score for peripheral vision is the total angle of vision of each subject expressed in degrees.

3.2.1.2 Vestibular test Data Collection

The Fukuda stepping test has three values to measure performance: angle of rotation, angle of displacement, and the distance of displacement (see Figure 30). According to the review of Grommes and Conways (2011), the Fukuda test for normal subjects should give no more than 50 cm of forward movement after 50 steps, and a rotation of between 30 and 45 degrees. When values exceed these limits, subjects can be considered to be impaired. Nyabenda et al.

(2004) proposed that a rotation of more than 48.5 degrees should be considered as pathological.

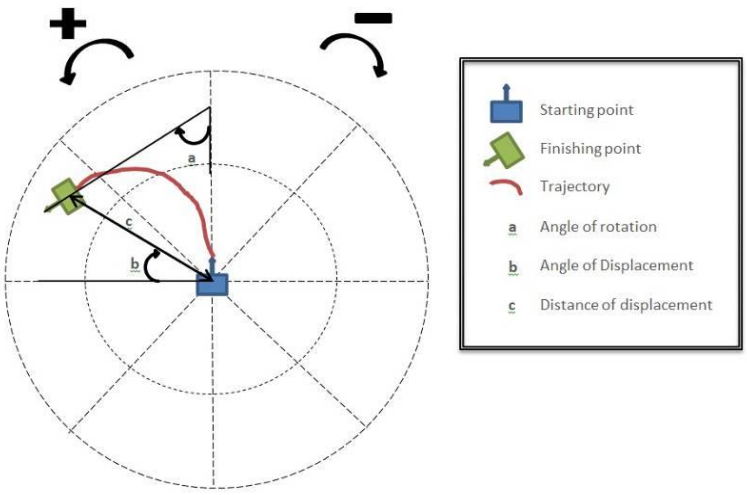


FIGURE 30: DIAGRAM EXPLAINING THE MEASUREMENT OF THE VESTIBULAR FUKUDA STEPPING TEST.

3.2.1.3 MUSCLE AND JOINT PROPRIOCEPTION TEST DATA COLLECTION

The test used to assess muscle and joint proprioception was the repositioning test. Subjects were given a joint position by the experimenter, with the joint angle measured. This was taken to be the "testing" angle. Subjects were then required to reposition their limbs in the same position, with the joint angle measured. This angle was taken to be the "repositioning angle". The difference in degree between those two angles was calculated and called the "error angle".

3.2.1.4 JOINTS RANGE OF MOTION DATA COLLECTION

The total angle of range of motion measured by the goniometer was reported on the experiment sheet.

3.2.1.5 MUSCLE STRENGTH TEST DATA COLLECTION

The Maximum voluntary isometric contraction was reported on the experiment sheet.
It has to be noted that for the Jodhpur experiment, the chair position required the subject to carry their own weight. In the Auckland experiment, the subjects were lying supine and therefore did not have to carry their weight. Therefore, to calculate the isometric maximal voluntary contraction (IMVC) of the Jodhpur experiment, the weight of the subject was added to the maximum weight lifted. In that way, the performance between Jodhpur and Auckland experiment could be compared.

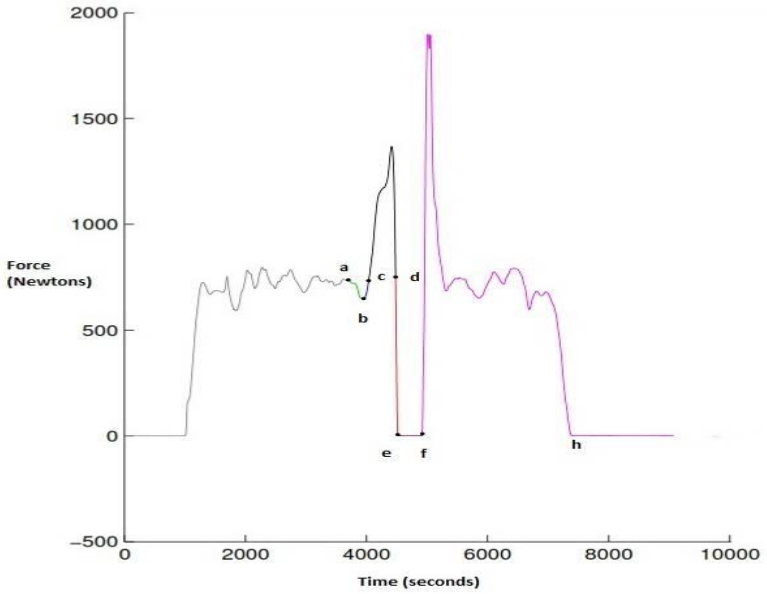
The timed recorded for the sit to stand and heel raise tests were reported on the experiment sheet.
For the Jodhpur experiment, the countermovement jump was recorded through the force plate with the Bertec software and exported to Excel format.

3.2.1.6 CUTANEOUS PROPRIOCEPTION TEST DATA COLLECTION

For the Jodhpur experiment, the number of zones on which the filaments could be felt was reported for each foot on the experiment sheet
For the Auckland experiment, the index of the last monofilament felt was reported on the experimentation sheet.

3.2.2 INTRINSIC TEST DATA ANALYSIS

Mean, standard deviation, maximum and minimum value of the results of the intrinsic factor tests were computed in Excel sheet for each population.
The countermovement jump required a specific analysis. The data from the force plate during the CMJ were analysed with Matlab (version 7.12, R2011a, Mathworks Inc.) using the variables described in the Figure 31.



a-> starting position knee at 90 degrees hand on the hips
b-> maximum flexion before the jump
c-> instant before the jump equal to the intial position
d-> instant after the impulsion when the force is equal to the initial force
e-> instant when there is no contact with the force plate (participant in the air)
f -> instant when the participant land on the force plate (touch the ground after jumping)
h-> end of the recording

FIGURE 31 : COUNTERMOVEMENT JUMP TIMES CALCULATION

The intrinsic tests for the elderly were supposed to provide information about the impairment of the elderly. It was not so easy to distinguish which impairment was predominant in the elderly population. Therefore Table 4 showed the score scale that was built for each test. A

five-point scale was created for each test, with zero being a normal result, through to five, which was considered to be a major impairment

TABLE 4 : SCORES OF INTRINSIC FACTORS FOR ELDERLY

	Score	Acuity	Contrast	Depth	Periphery
VISION	1	< 8	1,72 - 1,92	3 mil	180 and more
	2	7 & 8	1,48-1,68	3 mil	160<x<180
	3	6 a 3	1,00 - 1,44	6 mil	100<x<160
	4	2 & 1	0,52 - 0,96	9 mil	60<x<100
	5	cannot see	0,04 - 0,48	No score	< 60
VESTIBULAR	Score	A	B	C	
	1	0	0	0	
	2	0<x< 30	0<x<30	0<x<50cm	
	3	30<x<90	30<x<60	50cm<x< 1m	
	4	90 <	60<x<90	1m<x<1m50	
	5	no score	no score	no score	
JOINT PROP	Score	HIP	KNEE	ANKLE	
	1	0	0	0	
	2	0 10	0 10	0 10	
	3	10 20	10 20	10 20	
	4	20 more	20 more	20 more	
	5	no score	no score	no score	
JOINT ROM	Score	HIP	KNEE	ANKLE	
	1	130 +	150 +	80 +	
	2	90-129	130-149	60-79	
	3	70-89	110-129	50-59	
	4	50-69	89-109	30-49	
	5	less	less	less	
MUSCLE	Score	QUAD	CALF		
	1	less	less		
	2	10s 15s	5s 10s		
	3	16s 20s	11s 15s		
	4	over 20s	over 15s		
	5	no score	no score		
CUTANEOUS	Score	2 FEET			
	1	18			
	2	16 to 18			
	3	11 to 15			
	4	5 to 10			
	5	less 5			

3.3 POSTURAL SWAY DATA

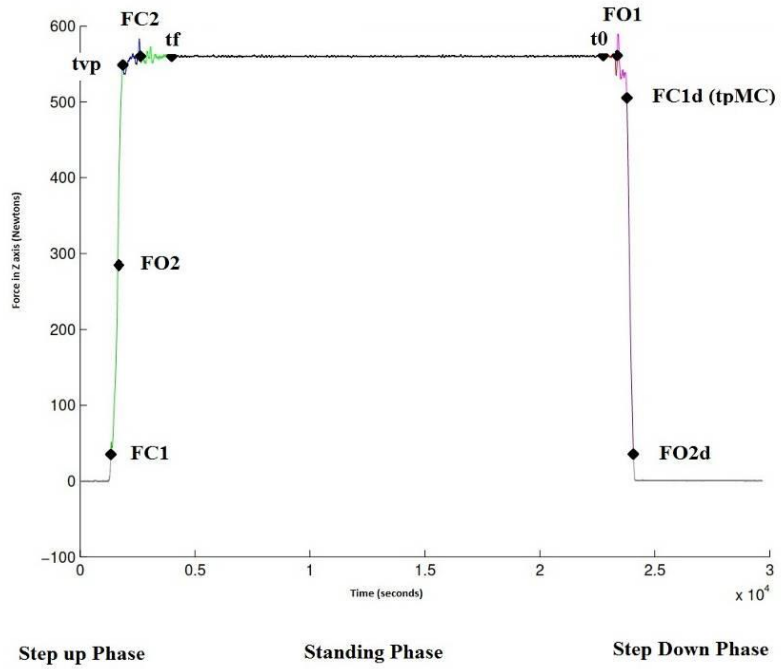
3.3.1 POSTURAL SWAY DATA COLLECTION

The collection of postural sway data started on the instruction of the examiner. The examiner requested the subject to step onto the force plate, then to stand still and finally to step off the force plate once the appropriate time had passed. Data collection ended when both feet of the subjects were off the force plate. The total duration was 30 seconds.
For the India experiment, the data were recorded using the Bertec software, with data saved on the laptop. The data from the force plate were stored as ".xls" or ".txt" files, and included the force in x, y and z directions, and moments in x y and z directions, as well as the time and the centre of pressure.
For the Auckland experiment, the data were recorded via the Qualysis software (Qualisys AB, Packhusgatan 6, 411 13 Gothenburg, Sweden) supplied the Kistler force plate. This software program provided time, force in x, y and z, moment in x, y and z, and the position of the centre of pressure (x,y coordinates).Files extracted in ".xls" and in the original Qualisys format.

3.3.2 POSTURAL SWAY DATA ANALYSIS

In a previous PhD thesis in the UTT E-Health research laboratory, all of the parameters related to static balance were identified in the literature, as well as several new parameters that were developed, in particular a group resulting from a decomposition of the CoP signals (Amoud 2006; Amoud, et al. 2007a; Amoud, et al. 2007b; Amoud, et al. 2008). In other work in the UTT E-Health team, a range of parameters from the stepping up and stepping down from the force plate were developed based on biomechanical methods of gait analysis (Michel-Pellegrino, et al. 2008a; Michel-Pellegrino, et al. 2008b). Matlab programmes for all of the parameters identified above were available for use in this thesis. However, all of the programmes used in the PhD were reviewed and extensively worked on with an associate specialist in Matlab programming, Doctor Paul Renaud-Goud (PhD at Ecole Normal Suppérieure, Lyon, France).

The programmes were built with the determination of temporal markers exposed in the Figure 32.



FC1 *-> Foot Contact 1: first foot in contact with the force plate*
FO2 *-> Foot Off 2: second foot of the ground*
tVP *->time when 90% of the weight is on the force plate*
FC2 *-> Foot Contact 2: second foot in contact with the force plate*
tf*-> Time final: time of the end of the stepping-up, the standing phase starts*
t0 *-> Time Zero: time of the end of the standing phase the stepping-down starts*
FO1 *-> Foot Off 1: the first foot is removed from the force plate*
FC1d/ tpMC *-> Foot contact 1 down: the first foot is in contact with the ground*
FO2d *-> Foot Off 2 down: the second foot leaves the force plate.*
The ***step-up*** *phase is defined from FC1 to tf.*
The ***standing phase*** *is defined from tf to t0.*
The ***step-down*** *phase is defined from t0 to FO2d.*

FIGURE 32 : TEMPORAL MARKER OF THE SWAY MEASUREMENT

FC1 (Foot Contact 1)

This is the instant when the first foot touches the force plate for the first time. FC1 is taken as the instant when the Fz exceeds 35 N. This value was chosen based on the recommendations of the force plate manual.

FO2 (Foot Off 2)

This marker occurs when the second foot leaves the ground, meaning that the subject only has contact with the force plate. FO2 is taken as the instant when the Fz is greater than half of the subject's weight.

FC2 (Foot Contact 2)

This marker occurs when the second foot comes in contact with the force plate. FC2 is identified as the time when the CoP shifts being under the first foot the centre of the force plate. It is calculated using the mediolateral CoP signal.

tvp (90% of weight transferred)

This is taken as the time when the Fz reaches 90% of the total weight of the subject.

tf: time final (end of the stepping up phase)

It is the instant where mediolateral and antero-posterior oscillation became stable, with only small oscillations present. "tf" is considered to be the time where the subject is stabilized on the force plate.

t0: time zero (the start of stepping down)
The t0 parameter is taken to be the time when the oscillations of antero-posterior and mediolateral CoP displacement signals exceed five times the standard deviation of the average oscillation of the standing phase. It is considered to be the beginning of the anticipatory postural adjustment.

FO1 (Foot Off 1)
The F01 parameter occurs when the subjects remove a foot from the force plate in order to step down. It is calculated using the change in mediolateral CoP.

FC1d (tPMC)
Foot Contact 1 down is the instant when the first foot removed from the force plate comes into contact with the ground. FC1d is taken to be the time when Fz decreases to 90% of the subject's total weight.

FO2d (Foot Off 2 down)
FO2d is considered to the instant when the subject removed their second foot from the force plate during the stepping down phase. The subject is thereby standing on the ground and is no longer on the force plate. In keeping with FC1, the force plate manual considers the foot to be off the plate when the Fz is less than 35 N. This is the end of the recording.

When the temporal markers of the recording were calculated, a large range of parameters where then computed. The parameters were cited in the review and a full list of the parameters with the unit and the phase they belong to can be found in Appendix 9. A total of 198 parameters were calculated for each recording.

3.3.3 Postural Sway Data Statistic: Models

In light of the 198 parameters available for balance quality, it was decided to use a neural network for the analysis and pattern recognition. In addition to neural networks, a range of other models and classifiers were also evaluated. The next section is entirely dedicated to the explanation of the analysis with models

3.4 Details of the use of Models

The objective was to create a model from the control subject data that could then be used to test the elderly subjects and detect their impairment.
In order to create and manipulate models, a considerable help was provided by the Knowledge Engineering and Discovery Research Institute of Auckland, New Zealand (KEDRI). Doctor Ammar Mohemmed (software engineer in Machine Learning) was the engineer providing formation and advice on the use of machine learning. The explanations provided and choices made were in accordance to his advices.

3.4.1 Terminology

INSTANCE/ CASE:

The one instance or case in this study is a single subject balance quality measurement. The balance measurements are calculated using Matlab, with 198 parameters obtained. In this study one instance/case is a line of 198 parameters from one subject in one condition.

CONDITIONS:
The condition is the context within which the measurements have been recorded. In this study subjects were exposed to six conditions, three of which included sub-conditions. Therefore, the total number of conditions is 13:

- range of motion (ankle, knee, and hip)
- proprioception (ankle, knee, and hip)
- cutaneous proprioception in the foot
- vision (acuity, contrast, depth, peripheral)
- vestibular
- fatigue

PATTERN:
The pattern is a combination of parameters that is specific to a condition. The analysis aims to detect a pattern of balance for each condition tested.

INPUTS:
The inputs are the data given to the model for training or testing. The inputs are the instances given to the model with information about the condition tested.

OUTPUTS:
The outputs are the results given by the model. In this study the output is a class. The model analyses the pattern of the instance given and classifies it into classes.

THE CLASSES:
The model classifies the instance/case into classes. Inputs are sent to the model telling the condition of testing of each instance/case; the model determines a balance pattern specific to a condition. Then, when testing the model, the pattern of sway is recognized and classified into classes, which correspond to the conditions. There are 13 classes in total. The conditions and the classes are similar except that the conditions are the context of the balance testing, while the classes are the groups with similar balance patterns. An instance/case can be entered into the model under one condition, yet classified into another condition, meaning that the balance sway pattern is closer to the second group condition than to the original condition, meaning that the model fails to recognize the pattern.

SET OF DATA:
A set of data is the data presented to the model for analysis. Various sets of data are successively made for the different analyses. One set of data includes all the subjects tested in two or more conditions. At least two conditions were included in all data sets since the data set are provided to the model to be classified into different classes, therefore, at least two conditions are needed to classify the instance into the first or the second class. Twenty five subjects were tested in each condition, therefore a data set included at least 50 instances; 25 subjects forming one condition and 25 subjects forming a second condition. Later in the analysis, the data sets provided to the model included three or more conditions.

ATTRIBUTES / FEATURES:

Attributes, also known as features, are the variables used to build the model. In this model the attributes are the balance parameters calculated in Matlab and described earlier. The total number of parameters is 198. For all the testing undertaken, the number of attributes was therefore 198 (+1, for the condition).

3.4.2 CHOICE OF THE SOFTWARE

Specialist software was chosen for the Neural Network analysis. The open source WEKA data mining software in Java was chosen (University of Waikato, Hamilton, New Zealand). The versions used were Weka 3.6, Weka 3.7.7 and Weka 3.7.8. The WEKA suite consists of a collection of machine learning algorithms for data mining task, with tools for data pre-processing, classification, regression, clustering, association rules and visualization. It is also well suited for developing new machine learning schemes (Hall, et al. 2009).

3.4.3 CONSTRUCTION OF A MODEL

DATA SET

The data set was composed of all the experiments performed. The experiment of Jodhpur and Auckland were regrouped in a single data set. The population were therefore as below:

- 50 young control subjects (Jodhpur + Auckland)
- 50 young vision acuity degraded subject (Jodhpur + Auckland)
- 50 young vision depth degraded subject (Jodhpur + Auckland)
- 50 young vision field degraded subject (Jodhpur + Auckland)
- 50 young vision contrast degraded subject (Jodhpur + Auckland)
- 50 young vestibular degraded subject (Jodhpur + Auckland)
- 50 young ankle proprioception degraded subject (Jodhpur + Auckland)
- 50 young hip proprioception degraded subject (Jodhpur + Auckland)
- 50 young ankle range of motion degraded subject (Jodhpur + Auckland)
- 50 young muscle strength degraded subject (Jodhpur + Auckland)
- 50 young foot cutaneous degraded subject (Jodhpur + Auckland)
- 25 elderly (Jodhpur)

CLASSIFIERS

WEKA offers a large variety of classifier and neural network analysers (Hall, et al. 2009). Four classifiers were selected being the most appropriate for the field and the data set available (according to the expert advising on the thesis): the Multilayer Perceptron, the Support Vector Machine (SVM) and a Tree Classifier.

The Multilayer Perceptron is a classifier that uses back-propagation to classify instances (Kou-Yuan 1994; Ruck, et al. 1990). Insight and full details for the construction of neural network can be found in the study of Kasabov al. (1997). In the present study the auto-build function was used, which adds and connects up hidden layers on the network.

The SVM is a classifier function that uses support vectors and a PolyKernel. This method implements John Platt's sequential minimal optimization algorithm for training a support vector classifier (Platt 1998). This implementation globally replaces all missing values and transforms nominal attributes into binary ones. It also normalizes all attributes by default. In

this case the coefficients in the output are based on the normalized data, not the original data. More information about the support vector machine can be found in the study of Chang et al. (Chang and Lin 2011).

The J48 is a simple recursive structure. Each leaf of a the tree denotes a class (Quinlan 1986).

The simple logistic classifier uses linear logistic regression models. The version used was LogitBoost, which uses simple regression functions as base learners to fit the logistic models. The optimal number of LogitBoost iterations to perform was cross-validated, which leads to an automatic attribute selection.

STEPS

Several steps are necessary in order to create a final model that answers the objectives of the study. It was necessary to create and test many different models to compare conditions and get valuable information about the data sets in order to examine the possibility of building a single model able to discriminate among the conditions tested.

Various models were created for the following purposes:

- Verify that the impaired conditions differed from the control condition
- Verify that the different impaired conditions differed from each other
- Examine the accuracy of the model depending of the number of classes included
- Find the combination of classes that gives the most accurate prediction
- Apply feature selection on the parameters to keep only the most significant sway parameters
- Examine the accuracy of the model with feature selection
- Build a final model with the selection of classes and feature that gives the most accurate predictions
- Test the model with real data from elderly subjects

3.4.4 CLASSIFICATION

There is a large range of model selection methods, Weka software propose several classification methods including cross validation and percentage split, which seems to be the most used and most appropriate for the construction of predictive models (Morisson et al. 2013, Zhang et al. 2015).
For the present study the cross validation method with 10 folds data split was used.
The results provide by the classification appears in term of accuracy, error value and coefficient.

3.4.5 ACCURACY OF THE MODEL

The accuracy of the model was taken to be the number of correctly classified cases. Weka software provides a summary of statistical analysis including:

- Correctly classified instances (%)
- Incorrectly classified instances (%)
- Kappa statistic
- Mean absolute error

- Root mean square error
- Relative absolute error
- Root relative square error
- Total number of instances
- The details of accuracy by classes
- The confusion matrix

In this thesis, the data used to evaluate the quality of the model are the percentage of correctly classified instances, and the Kappa coefficient as a measure to assess the validity of classification. These methods were chosen as they are the most commonly-used methods described in the literature (Baldi, et al. 2000; Stehman 1997).

SCALES/ BENCHMARK

There is no gold standard for the evaluation of the Kappa coefficient, or for the percentage accuracy for the classification of models. Meaning that no % of accuracy has been set as a minimum value to validate the efficiency of a model, similarly, no value of Kappa coefficient has been set as acceptable for the undergoing analysis. However, some scales have been proposed for the Kappa coefficient. Landis and Koch (1977) proposed a scale that, although defined as "arbitrary", did provide benchmark for discussion as well as proposing a consistent nomenclature. They considered a Kappa value of 0 as poor, between 0.0 and 0.20 as slight, between 021 and 0.4 as fair, between 0.41 and 0.60 as moderate, between 0.61 and 0.80 as substantial, and between 0.81 and 1.00 as almost perfect. Viera et al. (2005) confirmed the use of the scale of Landis and Koch (1977) for the interpretation of the Kappa coefficient, using and citing the same scale. In the field of statistics, Hopkins (2000) explained the interpretation of the magnitude of correlation coefficients and propose a scale linking the value of the coefficient to a descriptor. According to his table, 0.00 could be considered to be considered to be a trivial effect, 0.10 as small, 0.30 as moderate, 0.50 as large, 0.70 as very large, 0.90 as nearly perfect, and 1.00 as perfect. Since the Kappa coefficient has been previously used as a measured of Magnitude as stated in the previous section, it seems possible to use the table of Hopkins as a scale to describe and interpret the Kappa coefficient. This current thesis will therefore use a table for the interpretation of the Kappa coefficient similar to the tables provided by Landis and Koch (1977), Viera et al. (2005), and Hopkins (2000).

Several studies including that of Byrt et al. (1993) have concluded that the Kappa coefficient needs to be associated to other coefficients or indicators, and should not be used alone. Since the current study already used the % accuracy to assess the validity of the model, the percentage accuracy and the Kappa coefficient will be used conjointly when evaluating the models in this thesis. In order to make the discussion of the results clear, a table that resumes the kappa coefficient value, the percentage accuracy, and the nomenclature used in this thesis is presented in Table 5.

TABLE 5 : NOMENCLATURE FOR THE USE OF KAPPA COEFFICIENT AND % ACCURACY.

Nomenclature	Trivial	Small	Moderate	Large	Very Large	Nearly perfect	Perfect
Kappa coefficient	0.00	0.10	0.30	0.50	0.70	0.90	1.00
% Accuracy	/	/	60%	65 %	75%	85%	100%

In this thesis an acceptable value for the kappa coefficient was taken to be 0.50, with an acceptable accuracy of 65%.

3.4.6 IMPROVEMENT OF THE MODEL: FEATURE SELECTION

It is possible to improve the standard model by using feature selection. In this way, only those variables that are pertinent to the model are retained. The Weka software provides a function called Select Attributes designed for feature selection. This function selects the balance parameters that are highly associated with the classification of instances. For the present study, this meant choosing the pattern of balance parameters that contributed the most to the classification of data according to the testing condition.
For the feature selection, several attribute evaluators are available. According to our pre-testing and papers in the literature, the Wrapper SubSet Eval is typically the most efficient attribute evaluator (Blum and Langley 1997; Kohavi and John 1997).
The Wrapper Subset Eval evaluates attribute sets by using a learning scheme before cross validation is used to estimate the accuracy of the learning scheme for a given set of attributes. Such a method requires a classifier, with SVM classifier used for the present study. The decision tree classifier was not chosen as it has rarely been used in health field, while the multilayer perceptron classifier required much more time for processing, taking 10 times longer than the SVM classifier.

Weka software provides details and explanation about feature selection and selectors available.
The search methods available within the feature selection are Best First and Greedy Stepwise. The Best First method searches the space of attribute subsets by greedy hill climbing, augmented with a backtracking facility. Setting the number of consecutive non-improving nodes enables the level of backtracking to be controlled. Best First can start with an empty set of attributes and search forwards, or start with a full set of attributes and search backwards. It is also possible to start at any point and search in both directions by considering all possible single attribute additions and deletions at a given point.
The Greedy Stepwise method performs a greedy forwards or backwards search through the space of attribute subsets. This can start with none or all of the attributes, or from an arbitrary point in space. The method stops when the addition or deletion of any remaining attributes results in a decrease in accuracy. It is also possible to produce a ranked list of attributes by traversing the space from one side to the other and recording the order that attributes are selected.
There are also two different ways in which to use the feature selection search methods, using either the full training set or a cross validation approach. Both search methods in combination with the two testing sets were evaluated, with the full training set proving to be more efficient. Preliminary testing obtained the same feature irrespective of whether BeFirst or Greedy Stepwise methods were used. After feature selection was used to improve the model, only those parameters identified were kept in the model, with all other parameters removed. The resulting model was used to classify the instances, with results compared to the classification without feature selection.

In the present study, the models built were submitted to feature selection to improve the accuracy of the results. Only the model build with all the sway parameters and presenting 60% accuracy and over were selected to be further analysed with feature selection.

3.4.7 TESTING THE MODEL: INTERNAL VALIDITY

When a model is build, it need to be tested with data new to the model therefore data that have not been involved in the training of the model. Based on the recommendations of experts on machine learning in literature on modelling in the field of health, the data-split method was used to test the model. The data were randomly assigned to a training set or testing set. The data was split into 70% for training and 30% for testing. Similar proportions have been reported previously by Lin et al. (2010).
Only the models that obtained percentage accuracy over 65% during the learning phase, or a Kappa coefficient of at least 0.50 were included in the testing part of the construction of the models.
An additional method of cross validation was also used in this study. This technique is inherent in the Weka software used to develop the models, with several methods available including cross validation. The cross validation used included 10 folds for training each model built and for testing the models. In simple terms, cross validation is a repeated data splitting, with the data set split into folds, with each combination successively tested with each fold (Harrell, et al. 1996).

3.4.8 VALIDITY OF THE MODEL: EXTERNAL VALIDITY

At that point the models were fully built. The last step concern the use of the model on real data. In the current thesis, the external validity was performed using elderly data.
Only the models presenting over 65% accuracy or Kappa value over 0.50 were used for the test of the elderly.
The trained models were therefore provided with the elderly data. According to the table of score of the elderly, the models were provided with the elderly presenting the known impairment and the model was required to classify the elderly in one condition to define their impairment.
As the results will show, there were few elderly presenting a single major impairment, only those elderly were tested for the validation of the models.

4 CHAPTER 4: RESULTS

4.1 RESULTS INFORMATION DATA

POPULATION:

Three populations were tested:

- 25 healthy adults in Jodhpur
- 28 elderly population in Jodhpur
- 26 healthy adults in Auckland

CHARACTERISTICS:

The characteristics of the population are reported in following table and figure.
The Figure 33, Figure 34 and Figure 35 present the height weight and age of the participants

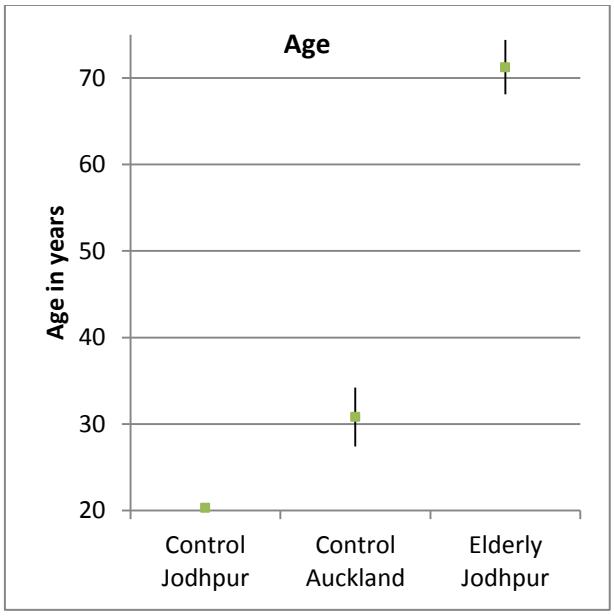


FIGURE 33: AVERAGE AND 95% CONFIDENCE INTERVAL FOR THE AGE OF THE POPULATIONS

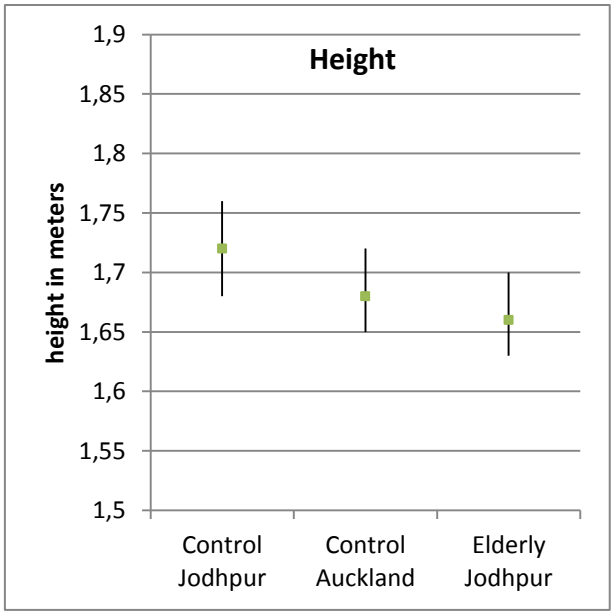


FIGURE 34: AVERAGE AND 95% CONFIDENCE INTERVAL FOR THE HEIGHT OF THE POPULATIONS

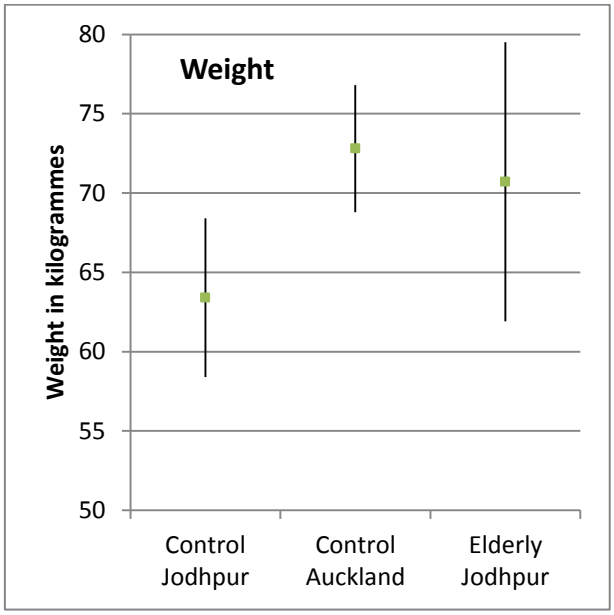


FIGURE 35: AVERAGE AND 95% CONFIDENCE INTERVAL FOR THE WEIGHT OF THE POPULATIONS

All three groups were of similar height and weight, although the age differed significantly between the groups. As expected, the elderly subjects were significantly older, with an average age greater than 70 years (SD: 6.3y), while the Auckland young controls averaged over 30 years (SD: 6.9y) and the Jodhpur young controls 20 years (SD: 1.0y).

PHYSICAL ACTIVITY:

The physical activity of the populations is reported in Figure 36, Figure 37 and Figure 38.

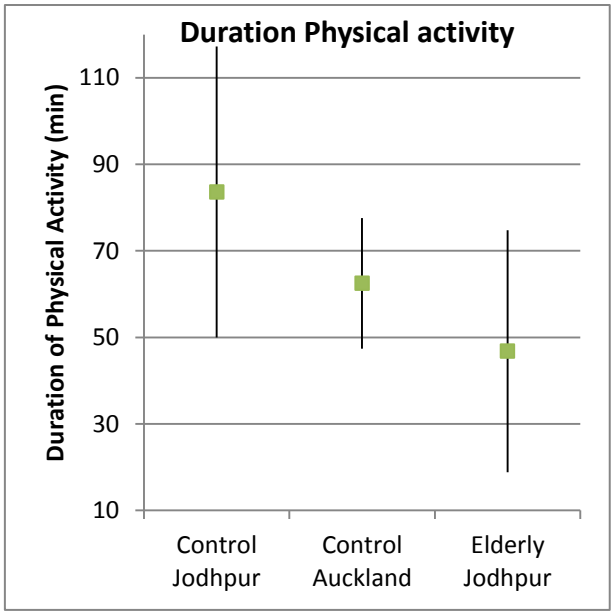


FIGURE 36: AVERAGE AND 95% CONFIDENCE INTERVAL FOR THE DURATION FOR PHYSICAL ACTIVITY

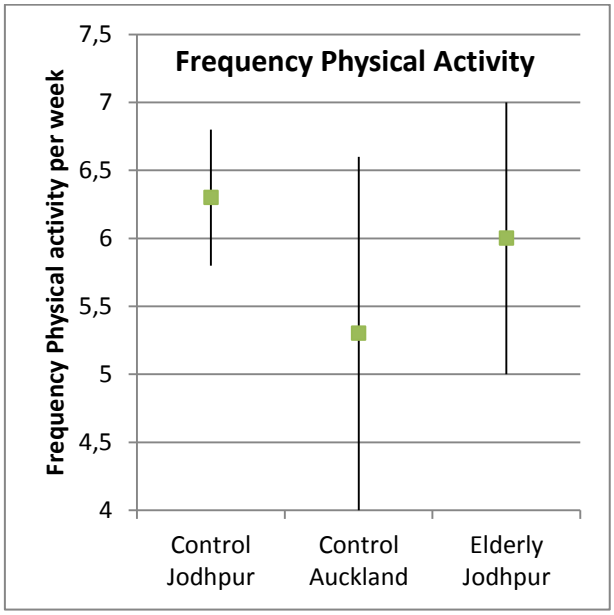


FIGURE 37: AVERAGE AND 95% CONFIDENCE INTERVAL FOR THE FREQUENCY FOR PHYSICAL ACTIVITY

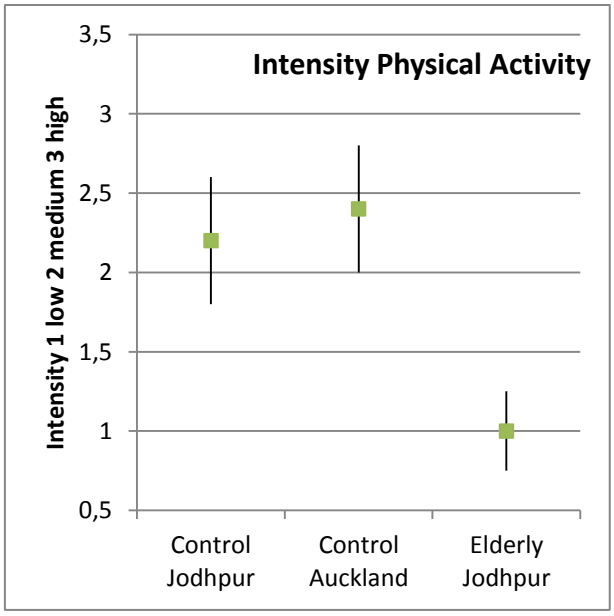


FIGURE 38: AVERAGE AND 95% CONFIDENCE INTERVAL FOR THE INTENSITY FOR PHYSICAL ACTIVITY

The physical activity levels of the three populations were similar in respect to duration (60 min average) and frequency (6 times per week). However, the average intensity of physical activity differed significantly between the populations. On a three-point scale, with three being the most intense activity and one being the lowest, the elderly population rated the intensity of their physical activity at 1 while the young control groups rated intensity at 2.2 and 2.4 for the Jodhpur and Auckland young control groups, respectively.

The times up and go test was performed in elderly only the results are shown in Table 6.

TABLE 6: RESULTS OF THE TIMED UP AND GO TEST FOR THE ELDERLY POPULATION.

	ELDERLY			
	Average	SD	Min	Max
TUG *(s)*	12.0	2.5	7.5	17.7

ELDERLY IMPAIREMENT:

The impairment of the elderly was scored to detect their major impairment.

The Table 7 presents the scoring of each intrinsic factor with the last column showing the intrinsic impairment with the highest score and therefore the "major impairment".

TABLE 7: SCORE OF THE ELDERLY FOR THE INTRINSIC FACTOR AND MAJOR IMPAIRMENT DETECTED

SCORE	Vestibular a	Vestibular b	Vestibular c	Vision acuity	Vision contrast	Vision depth	Vision field	Ankle proprioception	Knee proprioception	Hip prop	Ankle rom	Knee rom	Hip rom	Cutaneous proprioception	Quadriceps strength	Calf strength	"major impairment"
Elderly 1	2	2	3	3	2	2	2	2	2	2	4	2	2	3	3	1	**Ankle RoM**
Elderly 2	3	4	2	3	3	5	2	3	1	1	2	2	2	3	2	2	**Vestibular**
Elderly 3	1	3	2	3	3	2	2	3	2	2	4	2	3	3	1	2	**Ankle RoM**
Elderly 4	2	2	4	4	3	5	3	2	2	3	4	3	3	3	3	2	**multiple**
Elderly 5	2	2	3	3	3	4	3	2	2	2	4	3	4	4	3	2	**multiple**
Elderly 6	2	2	3	1	3	2	2	2	2	2	4	2	3	4	2	2	**multiple**
Elderly 7	3	3	2	3	2	3	3	5	2	3	3	3	3	4	2	2	**Ankle Proprioception**
Elderly 8	4	4	3	3	4	4	3	2	2	2	4	2	5	1	2	2	**Hip RoM**
Elderly 10	2	2	3	3	3	2	3	4	2	4	3	2	3	3	2	2	**multiple**
Elderly 12	3	2	3	3	3	3	3	1	1	2	2	3	2	3	1	2	**multiple**
Elderly 14	3	2	2	5	3	4	3	4	4	1	4	2	3	3	3	3	**Visual acuity**
Elderly 15	3	2	3	4	3	2	3	2	2	1	4	2	2	5	3	3	**multiple**
Elderly 16	3	2	4	4	4	3	3	1	1	2	4	1	2	3	2	2	**multiple**
Elderly 17	4	3	3	4	2	3	3	2	2	2	4	2	4	3	3	2	**multiple**
Elderly 18	3	2	3	4	3	3	3	2	2	3	3	1	2	3	2	2	**Visual acuity**
Elderly 19	1	1	3	5	4	5	4	2	2	1	3	2	3	4	3	5	**multiple**
Elderly 20	3	3	3	3	3	5	3	2	2	1	4	2	3	3	2	2	**Depth vision**
Elderly 21	5	5	5	3	3	4	4	2	2	2	3	2	5	5	4	2	**multiple**
Elderly 22	4	2	3	3	3	3	3	3	2	3	4	3	3	3	2	3	**multiple**
Elderly 23	4	3	3	3	3	3	3	1	2	1	2	2	3	2	1	2	**Vestibular**
Elderly 24	2	2	2	3	3	4	3	2	4	2	4	3	4	3	3	3	**multiple**
Elderly 25	3	2	3	3	3	2	3	3	1	1	5	2	2	4	3	2	**Ankle RoM**
Elderly 26	3	2	4	2	3	2	3	2	1	2	3	2	3	3	2	2	**Vestibular**
Elderly 27	2	2	4	3	3	3	3	1	1	2	1	1	3	2	1	2	**Vestibular**
Elderly 28	2	2	2	3	4	3	3	2	1	2	4	3	3	3	2	2	**Ankle RoM**

Most of the elderly present multiple impairments, however there are still few of them showing a major impairment: 4 elderly seem to have ankle ROM impairment, 4 elderly have vestibular impairment and 2 elderly show visual acuity impairment. There is also one elderly showing ankle proprioception impairment, one with vision depth impairment and one shows hip RoM impairment.

The
Table 8 presented the average, minimum, maximum score of each intrinsic factor tested.

TABLE 8: AVERAGE, MIN, MAX AND SD OF THE INTRINSIC FACTORS TESTS IN THE ELDERLY JODHPUR POPULATION

SCORE	Vestibular a	Vestibular b	Vestibular c	Vision acuity	Vision contrast	Vision depth	Vision field	Ankle proprioception	Knee proprioception	Hip prop	Ankle rom	Knee rom	Hip rom	Cutaneous proprioception	Quadriceps strength	Calf strength
Average	2.7	2.4	3.0	3.2	3.0	3.3	2.9	2.2	1.9	2.0	3.4	2.2	3.0	3.2	2.2	2.2
max	5	5	5	5	4	5	4	5	4	4	5	3	5	5	4	5
min	1	1	2	1	2	2	2	1	1	1	1	1	2	1	1	1
SD	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1

4.2 RESULTS INTRINSIC RISK FACTOR DATA

4.2.1 RESULTS OF THE VISION TESTS

The results of the visual acuity test are presented in the Figure 39.

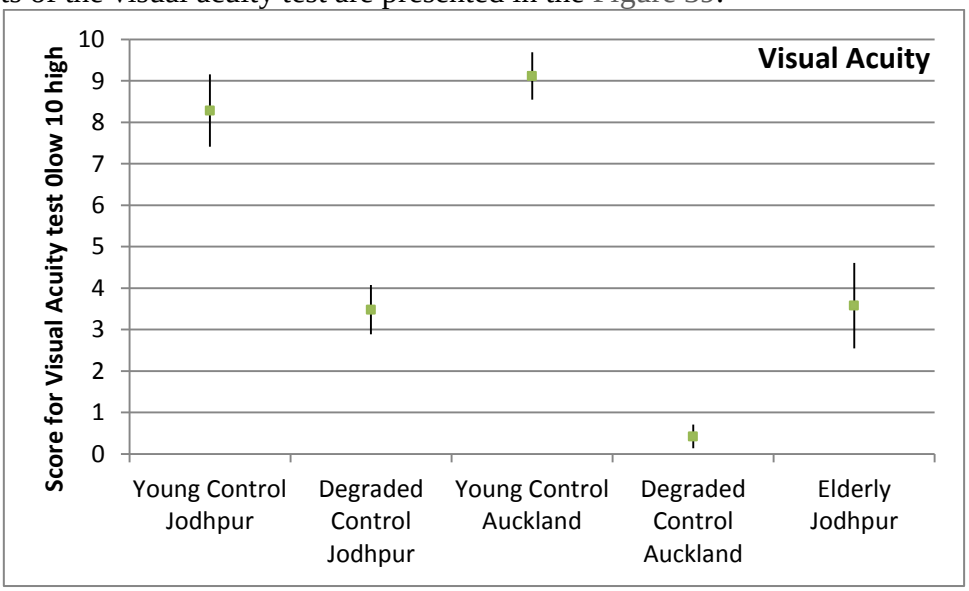


FIGURE 39: AVERAGE AND 95% CONFIDENCE INTERVAL FOR THE VISUAL ACUITY TEST

The results of the Visual contrast test are presented in the Figure 40.

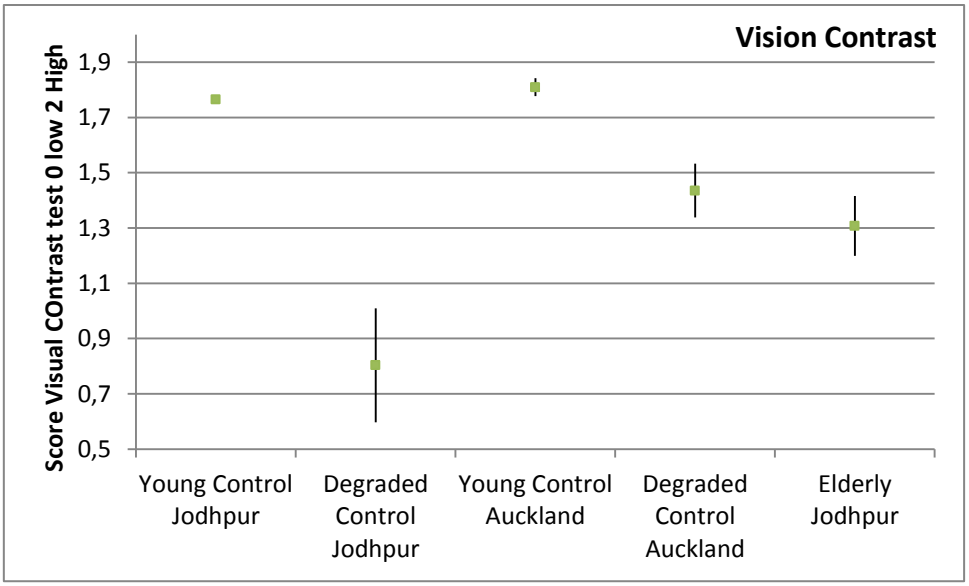


FIGURE 40: AVERAGE AND 95% CONFIDENCE INTERVAL FOR THE VISUAL CONTRAST TEST

The results of the Visual depth test are presented in the Figure 41.

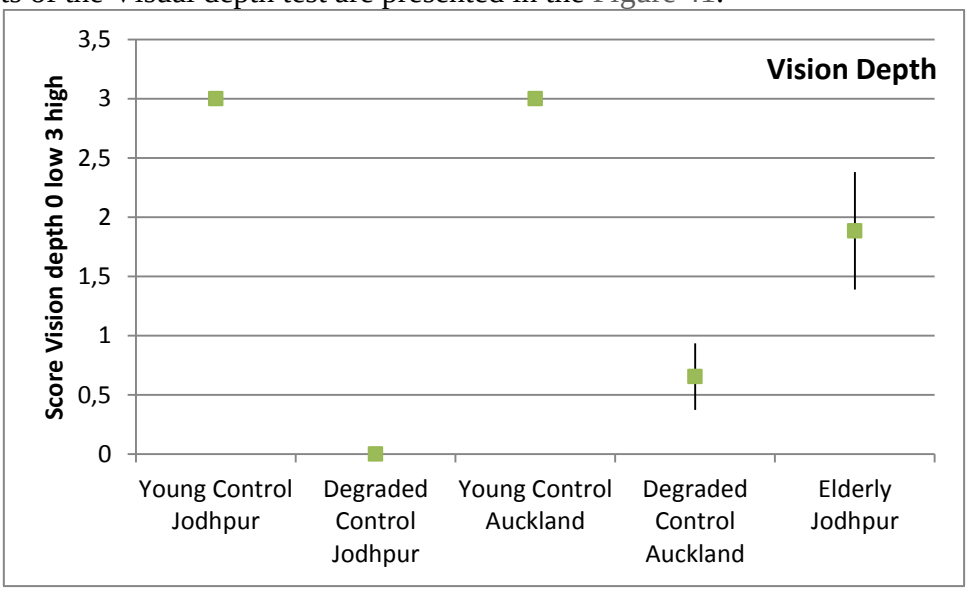


FIGURE 41: AVERAGE AND 95% CONFIDENCE INTERVAL FOR THE VISUAL DEPTH TEST

The results of the Visual field test are presented in the Figure 42.

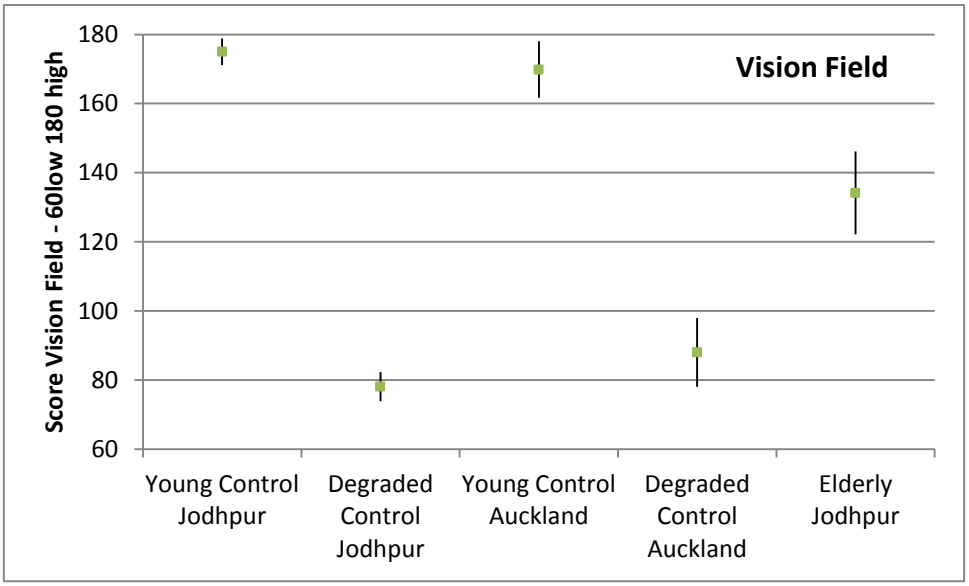


FIGURE 42: AVERAGE AND 95% CONFIDENCE INTERVAL FOR THE VISUAL FIELD TEST

The figures 40 to 43 showed that the degraded control population presented a lower score at each vision tests compare to young control. The elderly showed lower score than young control but higher score than degraded control for each vision tests.

4.2.2 RESULTS OF THE VESTIBULAR TEST

Three values were recorded for the vestibular test. The results for the angle of rotation are reported in the Figure 43, the results for the angle of displacement is reported in Figure 44 and the displacement is reported in Figure 45.

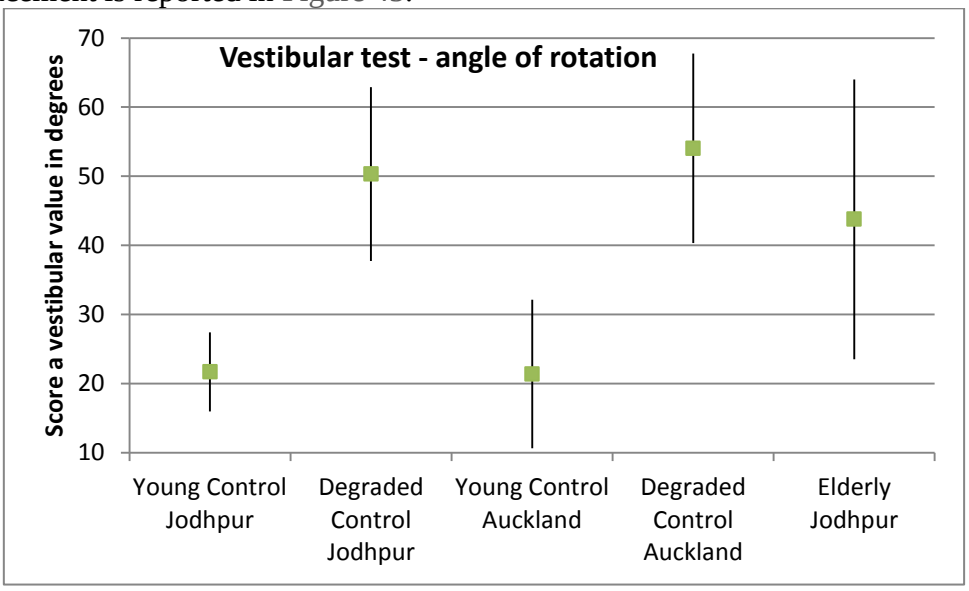


FIGURE 43 : AVERAGE AND 95% CONFIDENCE INTERVAL OF THE VESTIBULAR TEST- ANGLE OF ROTATION

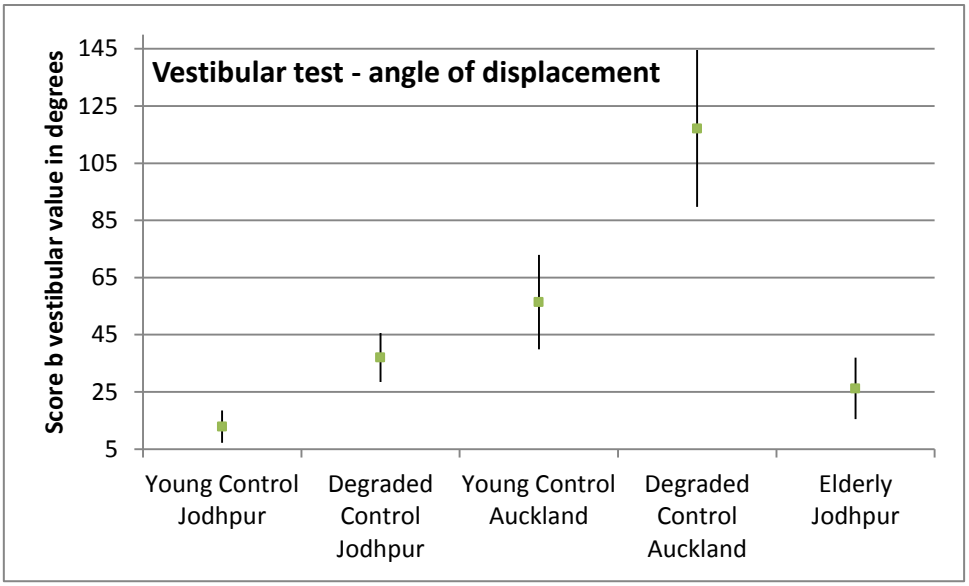


FIGURE 44 : AVERAGE AND 95% CONFIDENCE INTERVAL OF THE VESTIBULAR TEST- ANGLE OF DISPLACEMENT

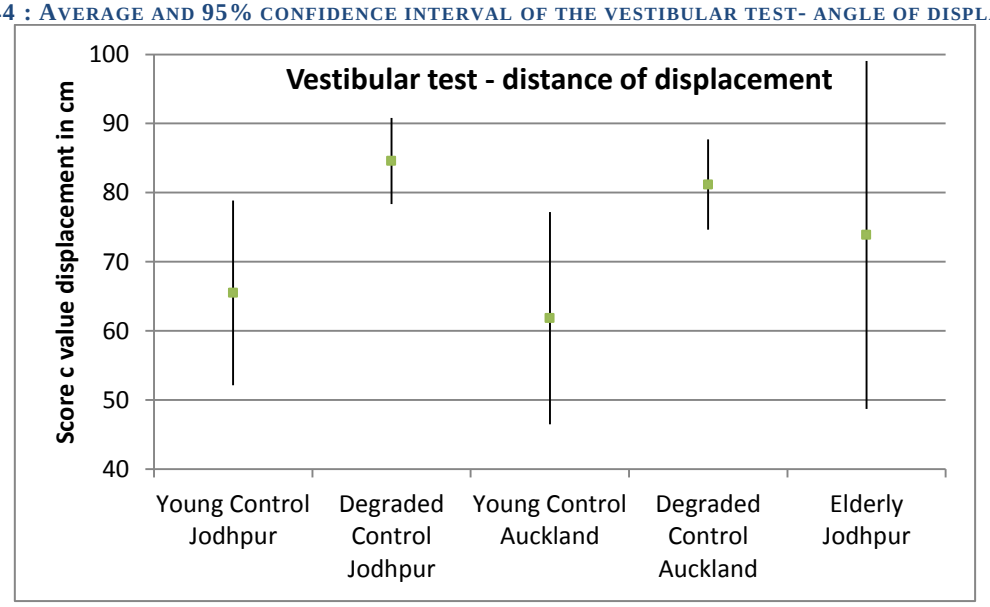


FIGURE 45 : AVERAGE AND 95% CONFIDENCE INTERVAL OF THE VESTIBULAR TEST- DISTANCE OF DISPLACEMENT

The figures 44, 45 and 46 show a tendency to higher score for degraded control compare to young control for the vestibular tests. No significant differences were found between the young control and the elderly, but the elderly showed large variation of scores for each of the three vestibular values.

4.2.3 RESULTS OF THE JOINT RANGE OF MOTION TESTS

Reminder: in the Jodhpur experiment the hip, knee and ankle were tested while only the ankle was tested in Auckland.

The Figure 46 presents the result of the hip range of motion test, the Figure 47 presents the results of the knee range of motion test and the Figure 48 presents the results of the ankle range of motion test.

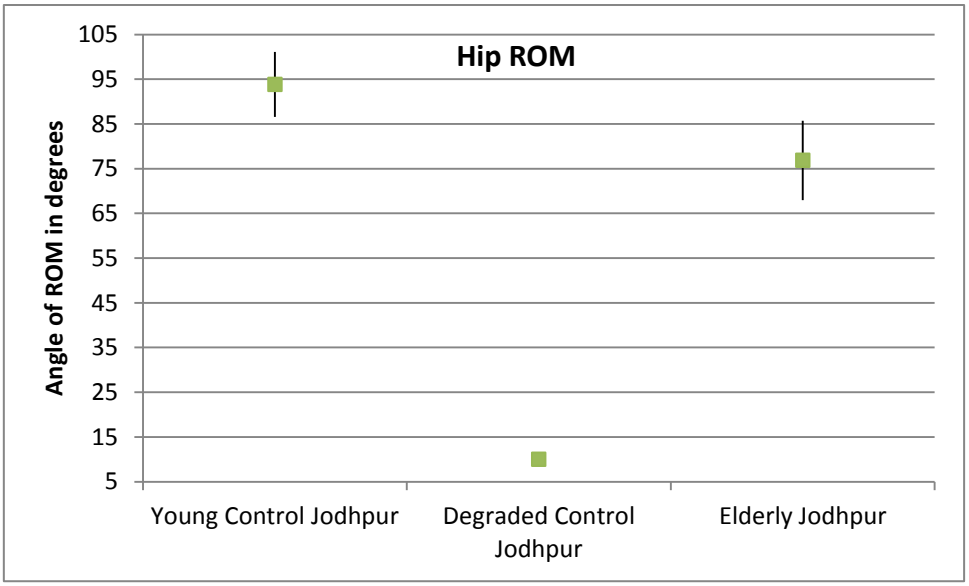


FIGURE 46 : AVERAGE AND 95% CONFIDENCE INTERVAL OF THE HIP RANGE OF MOTION TEST

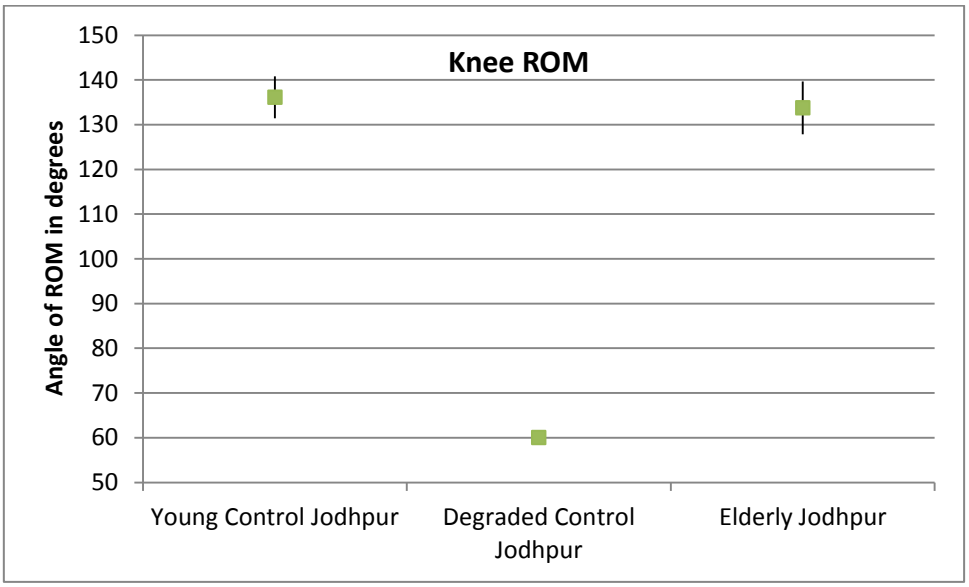


FIGURE 47 : AVERAGE AND 95% CONFIDENCE INTERVAL OF THE KNEE RANGE OF MOTION TEST

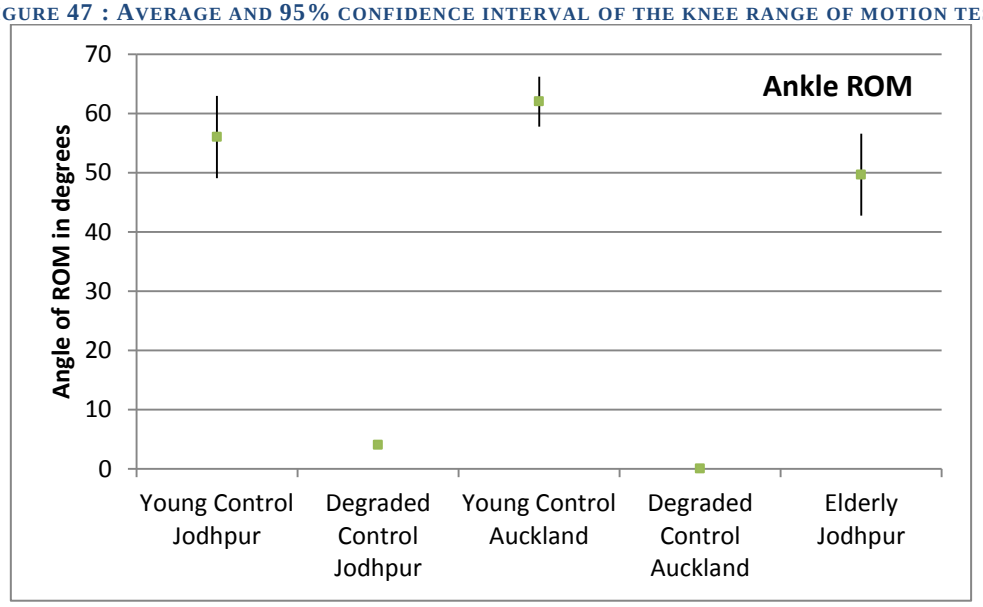


FIGURE 48 : AVERAGE AND 95% CONFIDENCE INTERVAL OF THE ANKLE RANGE OF MOTION TEST

The figures 47 to 49 show that the young control has higher score for ROM of the three joint compare to degraded control. Elderly present higher score at ROM than degraded control and similar score compare to young control.

4.2.4 RESULTS OF THE JOINT AND MUSCLE PROPRIOCEPTION TESTS

Reminder: The hip, knee and ankle proprioception were tested in Jodhpur and only the hip and ankle were tested in the Auckland experiment.
The Figure 49, Figure 50 and Figure 51 present results of the proprioception tests.

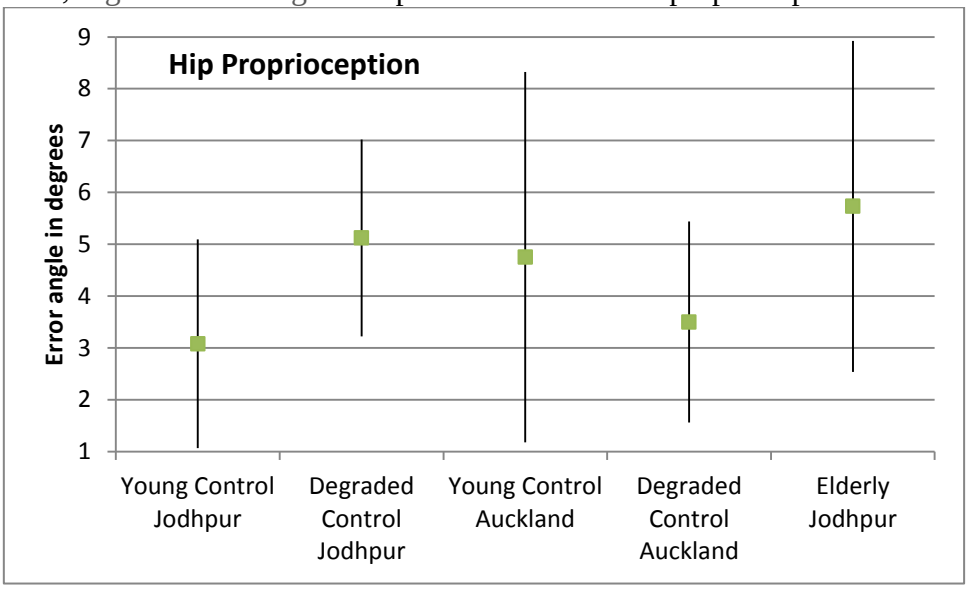


FIGURE 49 : AVERAGE AND 95% CONFIDENCE INTERVAL OF THE HIP PROPRIOCEPTION TEST

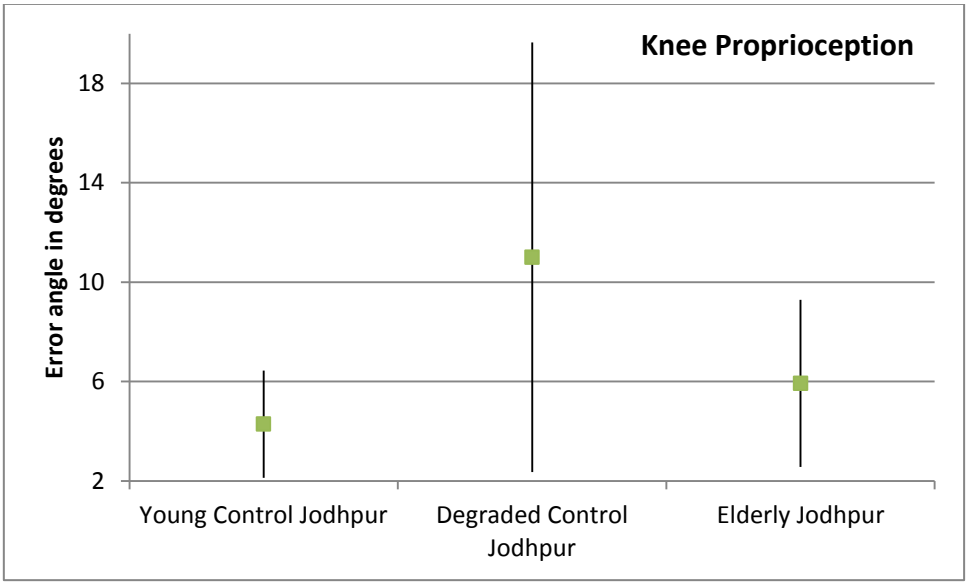


FIGURE 50 : AVERAGE AND 95% CONFIDENCE INTERVAL OF THE KNEE PROPRIOCEPTION TEST

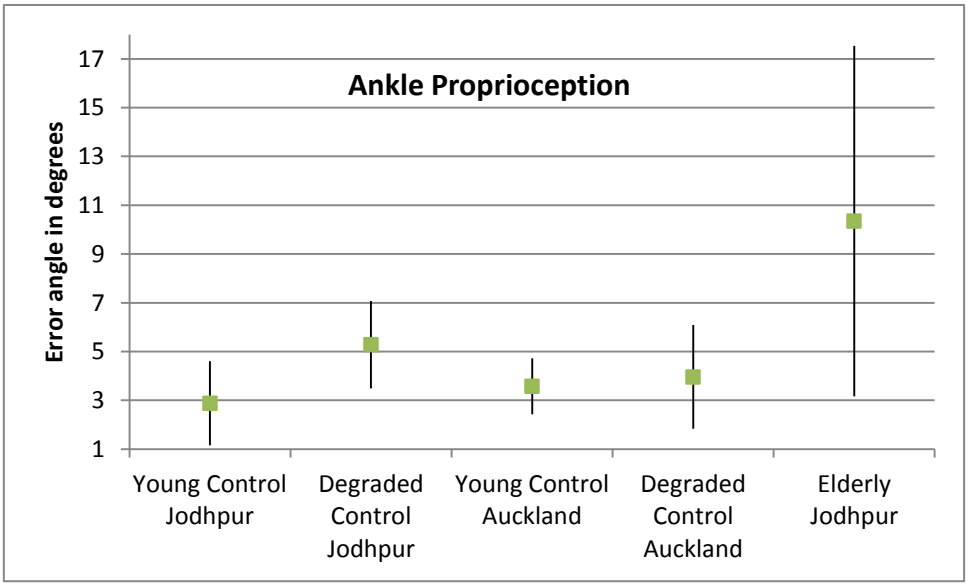


FIGURE 51 : AVERAGE AND 95% CONFIDENCE INTERVAL OF THE ANKLE PROPRIOCEPTION TEST

No difference can be seen between populations for the joint proprioception test.

4.2.5 RESULTS OF THE LEG MUSCLE STRENGTH TESTS

The results of the maximum isometric voluntary test are presented in the figure 52 to 56.

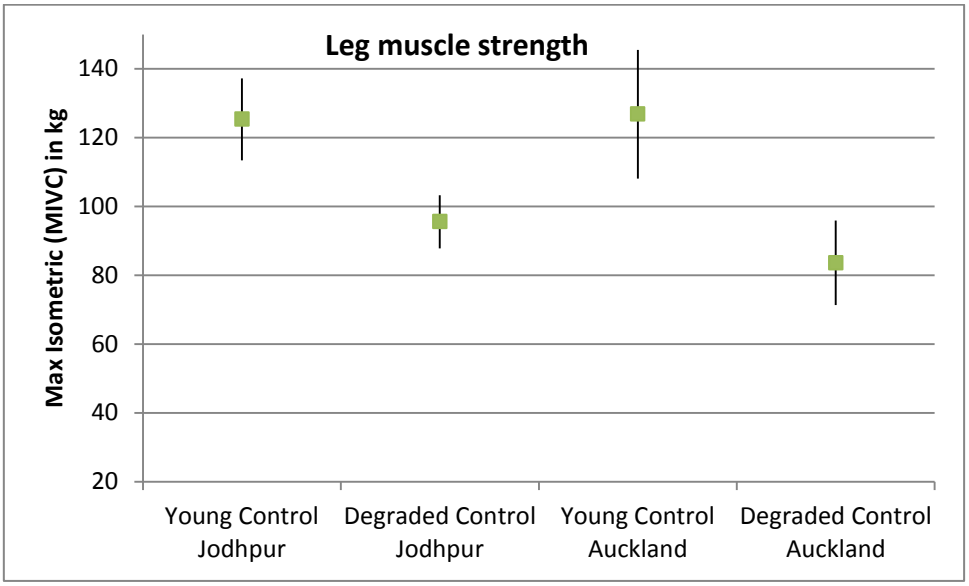


FIGURE 52 : AVERAGE AND 95% CONFIDENCE INTERVAL OF THE LEG MUSCLE STRENGTH (MIVC)

The young control had higher score at muscle strength test measured by IMVC compare to the degraded control.

Reminder: the young control Jodhpur subjects were also tested for the counter movement jump. The results of the height and impulse of the CMJ are exposed in Figure 53 and Figure 54.

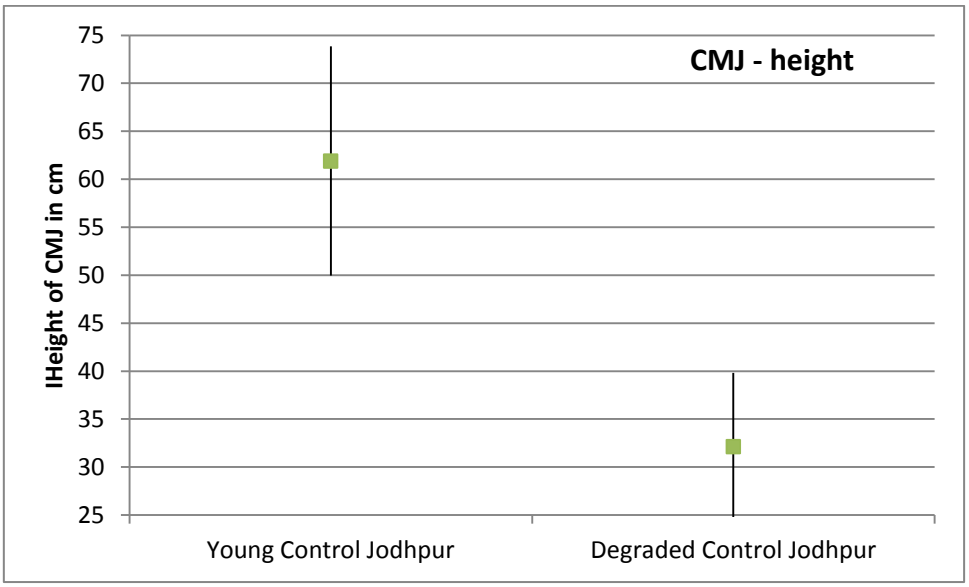


FIGURE 53 : AVERAGE AND 95% CONFIDENCE INTERVAL OF THE HEIGHT FOR THE CMJ TEST

The young control jump a greater height at the CMJ test compare to the degraded control.

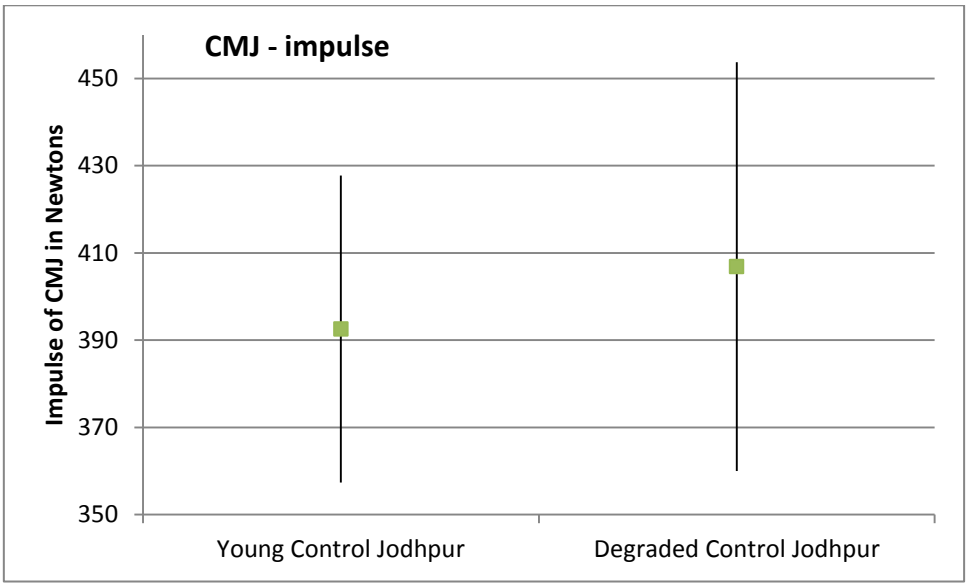


FIGURE 54 : AVERAGE AND 95% CONFIDENCE INTERVAL OF THE IMPULSE FOR THE CMJ TEST

Reminder: The elderly population was tested with the sit-to-stand test and the heels-raise test. The young control Jodhpur population was also tested for those tests but the young control Auckland population was not.

The results of the sit-to-stand test are presented in the Figure 55 and the results for the heels-raise test are presented in the Figure 56.

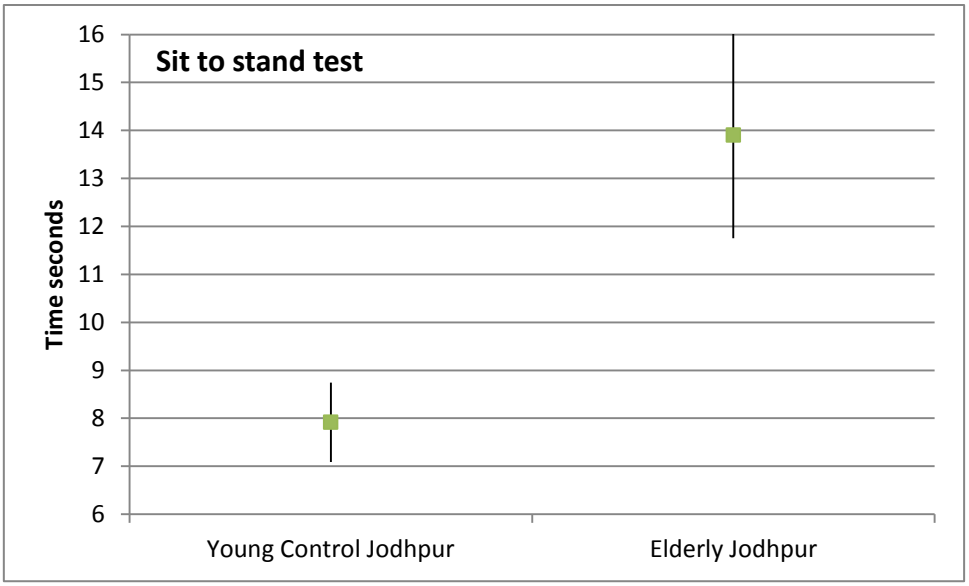


FIGURE 55 : AVERAGE AND 95% CONFIDENCE INTERVAL OF THE SIT TO STAND TEST

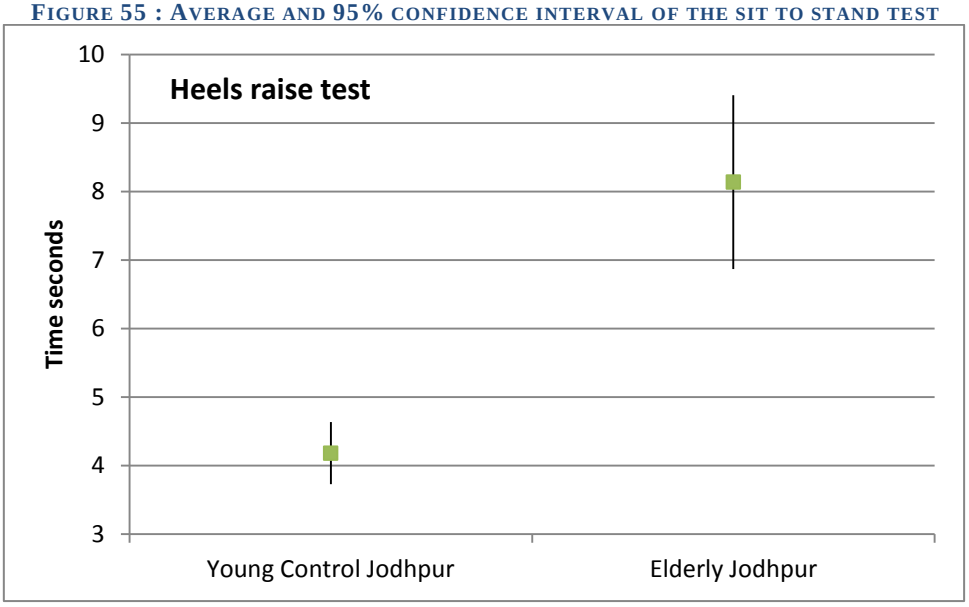


FIGURE 56 : AVERAGE AND 95% CONFIDENCE INTERVAL OF THE HEELS RAISE TEST

The elderly showed greater time score for the sit to stand and heels raise tests compare to young control of Jodhpur.

4.2.6 RESULTS OF THE FOOT CUTANEOUS PROPRIOCEPTION TESTS.

Reminder: The scoring of the foot cutaneous test for the Jodhpur and the India experiments were different.

The results of the test in the Jodhpur experiment are presented inFigure 57. The results of the experiment of Auckland are presented in Figure 58.

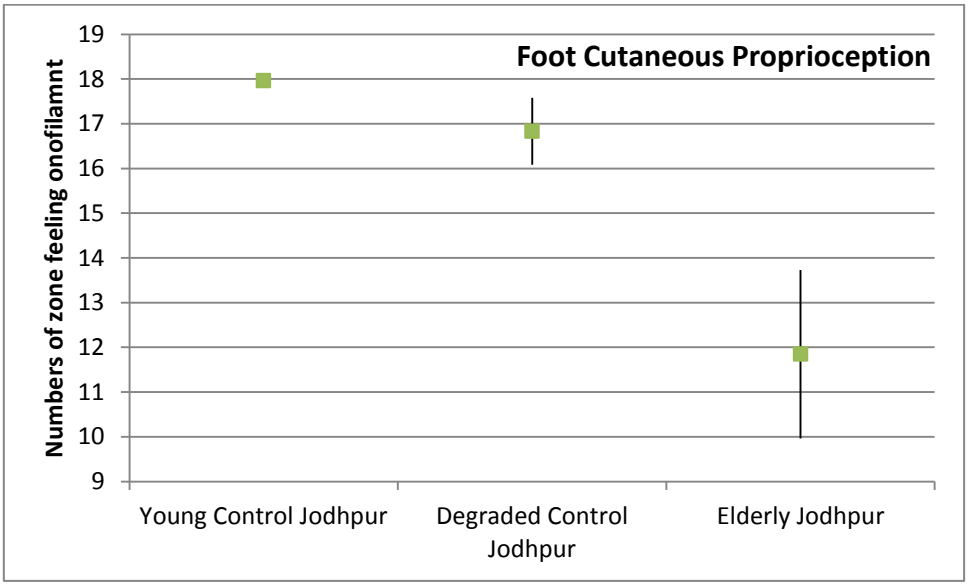


FIGURE 57 : AVERAGE AND 95% CONFIDENCE INTERVAL OF CUTANEOUS TEST IN JODHPUR

The young controls were able to feel the monofilament on the zones. The young degraded felt in average 16.8 zones and the elderly could feel only 11.8 zones.

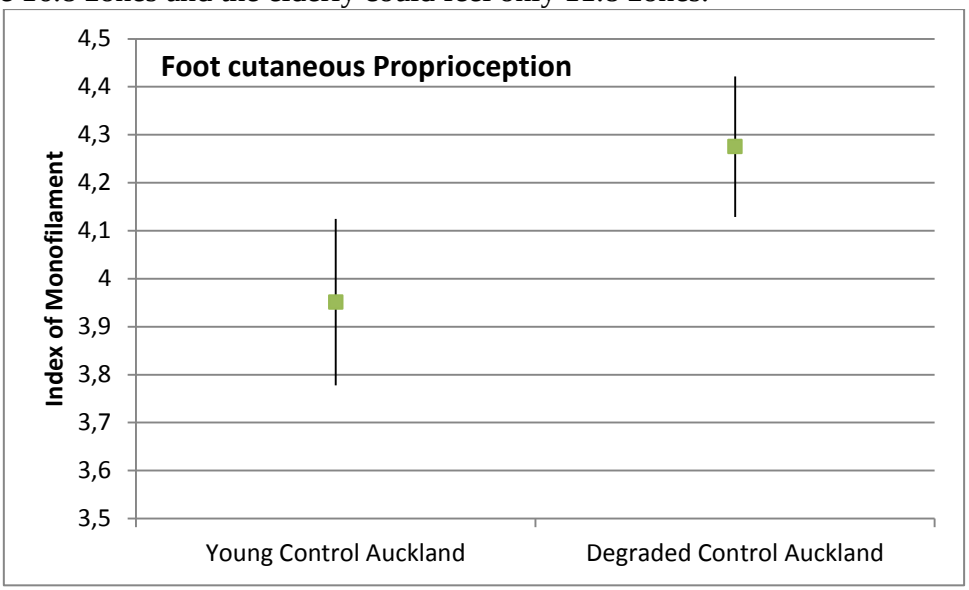


FIGURE 58 : AVERAGE AND 95% CONFIDENCE INTERVAL OF CUTANEOUS TEST IN AUCKLAND

The young control subject showed average of index 3.95 monofilament and the young degraded presented average index of 4.28.

The degraded control showed lower foot cutaneous proprioception compare to young control. The Elderly can only be compared to the Jodhpur groups and showed lower score at foot cutaneous proprioception test.

4.3 RESULTS SWAY PARAMETERS

4.3.1 TRAINING THE MODELS

4.3.1.1 CLASSIFICATION HEALTHY OR IMPAIRED

A model was build including the young control and the degraded control in order to verify whether the model would be able to discriminate healthy people from impaired people from the say parameters. The results are presented in Table 9.

TABLE 9: COMPARISON OF THE CONTROL AND DEGRADED CONDITIONS. DATA ARE PERCENT OF CASES CORRECTLY CLASSIFIED. THE TRAINING SET INCLUDED 300 IMPAIRED CASES AND 38 CONTROLS. THE TESTING SET INCLUDED 132 IMPAIRED CASES AND 13 CONTROLS.

Young control compare to young degraded					
Classifier	**SVM**	**ANN**	**J48**	**Simple logistic**	**Kappa**
Training	88.%	85 %	90 %	89 %	0.42
Testing	91 %	81 %	87 %	91 %	0.39

The classifier Simple Logistic shows the best result with 89% training and 91% testing for the classification of young control and degraded control.

4.3.1.2 CLASSIFICATION HEALTHY OR IMPAIRED, CONDITION ONE BY ONE

ANKLE RANGE OF MOTION

A model was made to differentiate between the ankle ROM impairment and the control condition. Results of this comparison can be seen in Table 10.

TABLE 10: COMPARISON OF THE IMPAIRED ANKLE RANGE OF MOTION CONDITION TO CONTROL CONDITION. DATA ARE PERCENT OF CASES CORRECTLY CLASSIFIED. THE TRAINING SET INCLUDED 33 IMPAIRED CASES AND 36 CONTROLS. THE TESTING SET INCLUDED 18 IMPAIRED CASES AND 18 CONTROLS

Young control compare to ankle ROM young degraded					
Classifier	**SVM**	**ANN**	**J48**	**Simple logistic**	**Kappa**
Training	79%	**83 %**	77 %	76%	**0.66**
Testing	90 %	**80 %**	97 %	87 %	**0.60**

ANKLE PROPRIOCEPTION

A model was made to differentiate between the ankle proprioception impairment and the control condition. Results of this comparison can be seen in Table 11.

TABLE 11: COMPARISON OF THE IMPAIRED ANKLE PROPRIOCEPTION CONDITION TO CONTROL CONDITION. DATA ARE PERCENT OF CASES CORRECTLY CLASSIFIED. THE TRAINING SET INCLUDED 30 IMPAIRED CASES AND 39 CONTROLS. THE TESTING SET INCLUDED 18 IMPAIRED CASES AND 12 CONTROLS..

Young Control compare to ankle proprioception young degraded					
Classifier	**SVM**	**ANN**	**J48**	**Simple logistic**	**Kappa**
Training	61 %	61 %	**67 %**	51 %	**0.31**
Testing	73 %	63 %	**73 %**	67 %	**0.50**

VESTIBULAR

A model was made to differentiate between the vestibular system impairment and the control condition. Results of this comparison can be seen in Table 12.

TABLE 12: COMPARISON OF THE IMPAIRED VESTIBULAR SYSTEM TO THE CONTROL CONDITION. DATA ARE PERCENT OF CASES CORRECTLY CLASSIFIED. THE TRAINING SET INCLUDED 31 IMPAIRED CASES AND 36 CONTROLS. THE TESTING SET INCLUDED 15 IMPAIRED CASES AND 15 CONTROLS.

Young Control compare to vestibular young degraded					
Classifier	**SVM**	**ANN**	**J48**	**Simple logistic**	**Kappa**
Training	**73 %**	70 %	70 %	69 %	**0.45**
Testing	**70 %**	70 %	70 %	77 %	**0.40**

LEG MUSCLE STRENGTH

A model was made to differentiate between the leg muscle strength impairment and the control condition. Results of this comparison can be seen in Table 13.

TABLE 13: COMPARISON OF THE FATIGUE CONDITION TO THE CONTROL CONDITION. DATA ARE PERCENT OF CASES CORRECTLY CLASSIFIED. THE TRAINING SET INCLUDED 35 IMPAIRED CASES AND 33 CONTROLS. THE TESTING SET INCLUDED 12 IMPAIRED CASES AND 18 CONTROLS.

Young Control compare to leg muscle strength young degraded					
Classifier	**SVM**	**ANN**	**J48**	**Simple logistic**	**Kappa**
Training	74 %	**74 %**	69%	65 %	**0.47**
Testing	87 %	**87 %**	73 %	80 %	**0.73**

FOOT CUTANEOUS PROPRIOCEPTION

A model was made to differentiate between the cutaneous proprioception impairment and the control condition. Results of this comparison can be seen in Table 14.

TABLE 14: COMPARISON OF THE IMPAIRED CUTANEOUS PROPRIOCEPTION CONDITION TO THE CONTROL CONDITION. DATA ARE PERCENT OF CASES CORRECTLY CLASSIFIED. THE TRAINING SET INCLUDED 32 IMPAIRED CASES AND 37 CONTROLS. THE TESTING SET INCLUDED 16 IMPAIRED CASES AND 14 CONTROLS.

Young Control compare to foot cutaneous proprioception young degraded					
Classifier	**SVM**	**ANN**	**J48**	**Simple logistic**	**Kappa**
Training	74 %	71 %	67 %	**71 %**	**0.41**
Testing	67 %	70 %	57 %	**73 %**	**0.47**

HIP PROPRIOCEPTION

A model was made to differentiate between the hip proprioception impairment and the control condition. Results of this comparison can be seen in Table 15.

TABLE 15: COMPARISON OF THE IMPAIRED HIP PROPRIOCEPTION CONDITION TO CONTROL CONDITION. DATA ARE PERCENT OF CASES CORRECTLY CLASSIFIED. THE TRAINING SET INCLUDED 33 IMPAIRED CASES AND 36 CONTROLS. THE TESTING SET INCLUDED 15 IMPAIRED CASES AND 15 CONTROLS.

Young Control compare to Hip proprioception young degraded					
Classifier	**SVM**	**ANN**	**J48**	**Simple logistic**	**Kappa**
Training	**71 %**	61 %	70 %	67 %	**0.41**
Testing	**77 %**	70 %	67 %	53 %	**0.53**

PERIPHERAL VISION

A model was made to differentiate between the peripheral vision impairment and the control condition. Results of this comparison can be seen in Table 16.

TABLE 16: COMPARISON OF THE IMPAIRED PERIPHERAL VISION CONDITION TO CONTROL CONDITION. DATA ARE PERCENT OF CASES CORRECTLY CLASSIFIED. THE TRAINING SET INCLUDED 31 IMPAIRED CASES AND 39 CONTROLS. THE TESTING SET INCLUDED 18 IMPAIRED CASES AND 12 CONTROLS.

Young Control compare to peripheral vision young degraded					
Classifier	**SVM**	**ANN**	**J48**	**Simple logistic**	**Kappa**
Training	83%	84 %	77 %	**86 %**	**0.71**
Testing	67 %	73 %	70 %	**73 %**	**0.44**

DEPTH VISION

A model was made to differentiate between the depth vision impairment and the control condition. Results of this comparison can be seen in Table 17.

TABLE 17: COMPARISON OF THE IMPAIRED DEPTH VISION CONDITION TO CONTROL CONDITION. DATA ARE PERCENT OF CASES CORRECTLY CLASSIFIED. THE TRAINING SET INCLUDED 34 IMPAIRED CASES AND 36 CONTROLS. THE TESTING SET INCLUDED 15 IMPAIRED CASES AND 15 CONTROLS.

Young Control compare to depth vision young degraded					
Classifier	**SVM**	**ANN**	**J48**	**Simple logistic**	**Kappa**
Training	81 %	**79 %**	66 %	80 %	**0.57**
Testing	70 %	**77 %**	63 %	67 %	**0.53**

VISUAL ACUITY

A model was made to differentiate between the visual acuity impairment and the control condition. Results of this comparison can be seen in Table 18.

TABLE 18: COMPARISON OF THE IMPAIRED VISUAL ACUITY CONDITION TO CONTROL CONDITION. DATA ARE PERCENT OF CASES CORRECTLY CLASSIFIED. THE TRAINING SET INCLUDED 33 IMPAIRED CASES AND 36 CONTROLS. THE TESTING SET INCLUDED 15 IMPAIRED CASES AND 15 CONTROLS..

Young Control compare to visual acuity young degraded					
Classifier	**SVM**	**ANN**	**J48**	**Simple logistic**	**Kappa**
Training	67 %	68 %	65 %	**75 %**	**0.51**
Testing	80 %	70 %	60 %	**90 %**	**0.80**

VISUAL CONTRAST

A model was made to differentiate between the visual contrast impairment and the control condition. Results of this comparison can be seen in Table 19.

TABLE 19: COMPARISON OF THE IMPAIRED VISUAL CONTRAST CONDITION TO CONTROL CONDITION. DATA ARE PERCENT OF CASES CORRECTLY CLASSIFIED. THE TRAINING SET INCLUDED 34 IMPAIRED CASES AND 35 CONTROLS. THE TESTING SET INCLUDED 17 IMPAIRED CASES AND 16 CONTROLS.

Young Control compare to visual acuity young degraded					
Classifier	**SVM**	**ANN**	**J48**	**Simple logistic**	**Kappa**
Training	67 %	74 %	**83 %**	79%	**0.65**
Testing	70 %	67 %	**76 %**	70 %	**0.52**

The models built to classified young control versus each degraded control show accuracy results between 67% and 86% success.

4.3.1.3 CLASSIFICATION AMONG SEVERAL CONDITIONS

After validation of the individual models for single impairments, the next step of the model construction was to compare models that regrouped at least two conditions together. The full data set was used for the initial classification of each model tested, without splitting the data into training and testing sets. Thereafter, the best models containing all data were chosen, before being tested using a data split 70% for training and 30% for testing. The first model tested contained all 10 conditions tested together, with classification of each case into the appropriate condition. The total data set included 51 control cases, 48 cases with impaired ankle proprioception, 49 cases with impaired ankle range of motion, 47 cases with impaired muscle power (fatigue), 48 cases with impaired hip proprioception, 46 cases with an impaired vestibular system, 48 cases of impaired visual acuity, 49 cases of impaired depth vision, 49 cases with impaired peripheral vision, and 48 cases with impaired cutaneous proprioception. The results are presented Table 20.

TEN CONDITIONS

TABLE 20: COMPARISON OF THE TOTAL MODEL FOR ALL IMPAIRMENTS AND THE CONTROL CONDITION. DATA ARE PERCENT OF CASES CORRECTLY CLASSIFIED.

All impairments compared to the control condition					
MODEL	**SVM**	**J48**	**ANN**	**Simple Logistic**	**Kappa**
Full model 10 conditions	31%	27%	31%	32%	**0.25**

THREE CONDITIONS

All of the ten conditions were tested using each three-way combination to detect the most accurate models to discriminate between conditions. All models were constructed using only training data sets containing 100% of all available cases. In total 121 models were tested. The Table 21 resumed the results of the construction of 3 conditions models.

TABLE 21: COMPARISON OF THREE-WAY MODELS TO DISCRIMINATE BETWEEN ALL POSSIBLE COMBINATIONS OF IMPAIRMENT CONDITIONS. DATA ARE PERCENTAGE CLASSIFICATIONS IN THE CORRECT CONDITION. THE MOST ACCURATE CLASSIFIER FOR EACH MODEL IS SHOWN IN GREY.

Three-condition models					
MODEL	SVM	J48	ANN	Simple Logistic	Kappa
3001-FA HP VP	65	49	65	61	**0.48**
3002- AR HP VP	69	77	71	81	**0.69**
3003 AP HP VP	55	56	60	63	**0.44**
3004 HP VP CU	67	66	66	62	**0.51**
3005- AR FA VP	70	73	74	78	**0.67**
3006- AP FA VP	64	49	68	65	**0.52**
3007- FA VP CU	68	58	69	67	**0.54**
3008- AR HP FA	73	67	73	81	**0.72**
3009- AP FA HP	49	47	52	53	**0.28**
3010- FA HP CU	74	52	64	68	**0.62**
3011- AP AR FA	70	68	69	73	**0.59**
3012- AR FA CU	81	74	79	81	**0.72**
3013- AP AR CU	72	77	71	70	**0.55**
3014- AP AR HP	66	54	70	65	**0.55**
3015- AR HP CU	74	68	74	74	**0.62**
3016- VP VD VA	40	32	31	43	**0.15**
3017- VE VD VP	56	45	53	50	**0.35**
3018 HP VD VP	53	47	53	58	**0.36**
3019- FA VD VP	64	53	63	61	**0.46**
3020- FA VD VP	63	53	63	64	**0.41**
3021- AP VD VP	57	51	52	60	**0.38**
3022- VD VP CU	58	42	50	50	**0.35**
3023- VE VA VP	51	48	45	46	**0.27**
3024- HP VA VP	51	55	46	53	**0.38**
3025- FA VA VP	59	53	51	53	**0.39**
3026- AR VA VP	63	56	58	68	**0.53**
3027- AP VA VP	51	43	46	52	**0.29**
2028- VA VP CU	50	40	50	50	**0.27**
3029- HP VE VP	49	45	49	46	**0.22**
3030- FA VE VP	72	50	72	66	**0.58**
3031- AR VE VP	71	75	76	75	**0.65**
3032- VE VP AP	58	49	66	58	**0.49**

3033- VE VP CU	60	64	64	62	**0.46**
3034- AP HP CU	56	47	53	53	**0.33**
3035- VE VA VD	50	47	44	43	**0.24**
3036- HP VA VD	46	37	38	45	**0.17**
3037- FA VA VD	54	49	53	53	**0.32**
3038- AR VA VD	57	53	55	53	**0.35**
3039- AP VA VD	46	48	37	48	**0.21**
3040- VA VD CU	42	37	41	39	**0.13**
3041- HP VE VD	45	45	42	45	**0.17**
3042- FA VE VD	61	59	56	61	**0.42**
3043- AR VE VD	72	70	78	77	**0.67**
3044- AP VE VD	50	51	51	55	**0.33**
3045- VE VD CU	56	43	58	57	**0.37**
3046- FA HP VD	58	56	59	58	**0.38**
3047- AR HP VD	68	72	73	74	**0.58**
3048- AP HP VD	47	52	51	50	**0.30**
3049- HP VD CU	55	55	52	54	**0.33**
3050- AR FA VD	78	77	76	79	**0.68**
3051- AP FA VD	60	54	60	58	**0.41**
3052- FA VD CU	63	60	58	62	**0.43**
3053- AP VD AR	73	69	75	77	**0.65**
3054- AR VD CU	66	65	66	70	**0.53**
3055-AP VD CU	53	55	57	56	**0.36**
3056- HP VE VA	45	41	48	44	**0.20**
3057- FA VE VA	62	58	62	59	**0.43**
3058- AR VE VA	72	69	73	71	**0.59**
3059- AP VE VA	55	49	50	57	**0.36**
3060- VE VA CU	58	42	56	62	**0.42**
3061-FA HP VA	65	53	57	59	**0.48**
3062- AP HP VA	53	55	50	46	**0.32**
3063- AP HP VA	53	55	50	46	**0.32**
3064- VA HP CU	61	53	57	61	**0.58**
3065- AP HP VE	35	34	35	41	**0.12**
3066- AR HP VE	52	64	58	61	**0.45**
3067- AP HP VE	35	34	35	42	**0.12**
3068- HP VE CU	49	49	48	52	**0.28**
3069- AR FA VE	77	69	75	80	**0.66**
3070- VE FA CU	47	48	49	55	**0.32**
3071- FA VE CU	64	59	61	62	**0.46**
3072- VC VP VD	61	49	55	58	**0.43**
3073- VC VP VA	54	46	45	54	**0.32**

3074- VC VP VE	66	56	67	68	**0.52**
3075- VC VP HP	66	72	64	70	**0.59**
3076- VC VP FA	71	67	71	73	**0.59**
3077- VC VP AR	67	70	75	78	**0.67**
3078 VC VP AP	61	61	62	66	**0.48**
3079- VC VP CU	66	61	62	65	**0.45**
3080- VC VD VA	48	49	45	47	**0.23**
3081- VC VD VE	57	64	59	61	**0.48**
3082- VC VD HP	58	67	61	64	**0.50**
3083 VC VD FA	70	68	70	66	**0.55**
3084- VC VD AR	72	75	70	75	**0.62**
3085- VC VD AP	61	64	61	61	**0.45**
3086-FA AP CU	62	62	57	58	**0.42**
3087- VC VD CU	57	56	60	58	**0.39**
3088- VC VA VE	57	61	56	61	**0.41**
3089- VC VA HP	63	61	63	63	**0.45**
3090-VC VA FA	70	71	66	69	**0.54**
3091- VC VA AR	72	69	76	72	**0.64**
3092 VC VA AP	63	57	62	58	**0.45**
3093- VC VA CU	64	50	64	62	**0.46**
3094- VC VE HP	44	47	41	42	**0.17**
3095-VC VE FA	58	53	60	61	**0.42**
3096-VC VE AR	73	73	71	73	**0.59**
3097-VC VE AP	51	58	55	48	**0.38**
3098-VC VE CU	63	62	68	66	**0.52**
3099-VC HP FA	62	61	66	60	**0.49**
3100-VC HP AR	77	74	75	81	**0.69**
3101- VC HP AP	49	60	53	55	**0.41**
3102-VC HP CU	67	69	67	69	**0.55**
3103-VC FA AP	52	53	55	56	**0.32**
3104-VC FA CU	75	69	75	71	**0.62**
3105-VC AR AP	71	72	74	71	**0.61**
3106-VC AR CU	74	70	80	74	**0.70**
3107-VC AP CU	63	71	65	62	**0.56**
3108 VP AR AP	71	72	72	76	**0.58**
3109 VP AR CU	78	66	75	78	**0.67**
3110 VP AP CU	62	56	61	66	**0.38**
3111 VA FA AR	75	73	74	81	**0.71**
3112 VA FA HP	59	51	62	59	**0.43**
3113 VA FA CU	63	51	61	60	**0.46**
3114 VA AR AP	74	67	74	72	**0.62**

3115 VA AR CU	68	57	68	61	**0.52**
3116 VA AP CU	59	46	52	58	**0.39**
3117 VE AR AP	65	62	67	68	**0.52**
3118 VE AR CU	71	68	76	78	**0.64**
3119 VE AP CU	53	49	54	51	**0.30**
3120 HP AP CU	58	56	57	59	**0.42**
3121 VC FA AR	78	73	80	80	**0.68**

Impairments tested: AR: Ankle Range of Motion; AP: Ankle Proprioception; VE: Vestibular; FA: Fatigue (muscle strength); CU: Cutaneous Proprioception; HP: Hip Proprioception; VP: Peripheral Vision; VD: Depth Vision; VC: Visual Contrast; VA: Visual Acuity.

The ten most accurate models and the ten least accurate models are presented in Table 22. In each case, the model presented is for the most accurate classifier for the given three-condition comparison.

TABLE 22: MOST ACCURATE AND LEAST ACCURATE THREE-CONDITION MODELS. DATA ARE PERCENTAGE CLASSIFICATIONS IN THE CORRECT CONDITION.

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Most accurate three-condition models		
Model 3 classes	**Accuracy**	**Kappa**
3008- AR HP FA	81 %	0.72
3012- AR FA CU	81 %	0.72
3111 VA FA AR	81 %	0.71
3100-VC HP AR	81 %	0.69
3002- AR HP VP	81 %	0.69
3121 VC FA AR	80 %	0.68
3106-VC AR CU	80 %	0.70
3069- AR FA VE	80 %	0.66
3050- AR FA VD	79 %	0.68
3118 – VE AR CU	78 %	0.64

Least accurate three-condition models		
Model 3 classes	**Accuracy**	**Kappa**
3080- VC **VD VA**	49 %	0.23
3039- **AP VA VD**	48 %	0.21
3056- **HP VE VA**	48 %	0.20
3094- VC **VE HP**	47 %	0.17
3036- **HP VA VD**	46 %	0.17
3041- **HP VE VD**	46 %	0.17
3016- VP **VD VA**	43 %	0.15
3040- **VA VD** CU	42 %	0.13
3065- **AP HP VE**	42 %	0.12
3067- **AP HP VE**	42 %	0.12

The results will be discussed in the next chapter, however few comments are necessary here to explain the sub-sequent analysis.

The most accurate models indicate those conditions for which major systematic changes in balance data occur. In contrast, the least accurate models indicate those conditions for which balance data is similar or follows no systematic pattern across subjects. It appears that restricting ankle range of motion (AR) and the presence of fatigue (FA) are the conditions that appear most often in the most accurate models. In fact, AR appears in each of the 10 most accurate models while fatigue (FA) appears six times. Other conditions that appeared regularly were hip proprioception (HP), cutaneous proprioception (CU), and visual contrast (VC), all of which appeared three times. Of the remaining conditions, vestibular impairment (VE) appeared twice, while visual acuity (VA), depth vision (VD), and peripheral vision (VP) appeared only once each. The ankle proprioception (AP) condition did not appear in any of the ten most accurate models.

In respect to the least accurate models, not surprisingly, the findings were reversed, with the best conditions for the most accurate models rarely appearing in the least accurate models. The VD, VA, and HP conditions were included in six of the ten models, while VE appeared five times. The AP condition was included three times, while the VC condition was included twice. The VP and CU conditions were included once each while the two most successful conditions from the most accurate models, AR and FA, were never included in the least accurate models.

Knowing the conditions giving the best accuracy has an incidence on the choice of the condition to include in the following models. The conditions showing poor results were dropped.

NINE CONDITIONS

The next step was to construct models with fewer conditions than the total model of ten conditions. The first models tested included nine conditions, with in each case one of the conditions left out. Classification accuracy results of these models can be seen in Table 23.

TABLE 23: ACCURACY OF NINE-CONDITION MODELS. DATA ARE PERCENTAGE CLASSIFICATIONS IN THE CORRECT CONDITION. THE MOST ACCURATE CLASSIFIER FOR EACH MODEL IS SHOWN IN GREY. MODELS ARE ARRANGED IN ORDER FROM MOST ACCURATE TO LEAST ACCURATE.

Nine-condition models						
Number	**Missing Condition**	**SVM**	**J48**	**ANN**	**Simple Logistic**	**Kappa**
9006	VE	38	32	38	38	0.30
9008	VD	36	34	38	35	0.30
9005	HP	35	30	38	37	0.30
9007	VA	36	32	36	37	0.29
9002	CU	34	30	34	37	0.29
9003	AP	35	32	33	36	0.28
9010	VP	34	35	35	34	0.27
9001	VC	30	25	35	35	0.26
9005	FA	34	30	35	33	0.26
9004	AR	28	29	26	31	0.24

EIGHT CONDITIONS

The next step was to test the model with eight conditions.

Table 24 shows the classification of eight-condition. In order to decrease the number of combinations tested, only those conditions that were shown to give the lowest accuracy in the three-condition models were excluded from eight-condition model testing, with a total of 30 models tested.

TABLE 24: ACCURACY OF EIGHT-CONDITION MODELS. DATA ARE PERCENTAGE CLASSIFICATIONS IN THE CORRECT CONDITION. THE MOST ACCURATE CLASSIFIER FOR EACH MODEL IS SHOWN IN GREY. MODELS ARE ARRANGED IN ORDER FROM MOST ACCURATE TO LEAST ACCURATE.

Eight-condition models						
Number	**Missing conditions**	**SVM**	**J48**	**ANN**	**Simple Logistic**	**Kappa**
8010	HP, VD	40	35	40	45	0.36
8006	VE, VP	41	38	41	45	0.34
8009	HP, VA	39	37	42	43	0.36
8020	VD, VP	40	35	41	43	0.37
8026	VA, VD	39	35	42	43	0.32
8027	VA, VP	39	39	42	43	0.33
8001	VE, VA	41	39	35	42	0.34
8004	VE, AP	39	33	41	42	0.34
8023	AP, VD	39	36	40	42	0.33
8024	AP, VP	39	36	40	41	0.34
8008	HP, AP	41	34	37	41	0.32
8005	VE, VD	41	36	41	41	0.32
8011	HP, VP	37	33	39	41	0.33
8003	VE, HP	40	34	41	40	0.32
8022	AP, VA	38	40	41	40	0.32
8015	CU, VA	38	30	40	37	0.31
8012	HP, CU	37	36	39	39	0.29
8016	CU, VD	37	36	39	39	0.29
8014	CU, AP	36	34	33	38	0.27
8002	VE, CU	38	35	36	37	0.29
8028	VA, VC	33	30	35	38	0.30
8017	CU, VP	37	36	36	37	0.28
8013	HP, VC	34	26	33	37	0.29
8007	VE, VC	37	30	37	35	0.28
8019	VD, VC	32	28	33	37	0.28
8025	AP, VC	32	27	36	33	0.27
8018	CU, VC	33	26	29	35	0.26
8021	VP, VC	32	27	31	33	0.25

SEVEN CONDITIONS

Following on from the eight-condition models, successive models were built with less and less conditions. A series of seven-condition models is presented in
Table 25. Eighteen models were tested, with the least accurate conditions from previous models chosen for exclusion. As for the eight-condition models, all data was included in the training set and no test set was used.

TABLE 25: ACCURACY OF SEVEN-CONDITION MODELS. DATA ARE PERCENTAGE CLASSIFICATIONS IN THE CORRECT CONDITION. THE MOST ACCURATE CLASSIFIER FOR EACH MODEL IS SHOWN IN GREY. MODELS ARE ARRANGED IN ORDER FROM MOST ACCURATE TO LEAST ACCURATE.

Seven-condition models						
Number	**Missing conditions**	**SVM**	**J48**	**ANN**	**Simple Logistic**	**Kappa**
7004	VE, VA, VD	45	47	52	49	0.44
7002	VE, VA, HP	48	42	48	49	0.38
7018	VE, AP, VD	43	38	47	49	0.40
7013	VE, HP, VD	43	41	47	46	0.39
7005	VE, VA, VP	44	46	47	45	0.39
7003	VE, VA, AP	47	41	47	46	0.38
7017	VE, AP, VP	44	39	47	44	0.38
7009	VE, CU, VD	42	37	46	44	0.37
7007	VE, CU, HP	41	41	42	46	0.35
7012	VE, HP, AP	44	38	46	45	0.36
7006	VE, VA, VC	44	34	43	44	0.34
7008	VE, CU, AP	41	37	42	44	0.33
7016	VE, AP, VC	37	32	42	43	0.34
7014	VE, HP, VP	42	38	42	43	0.35
7010	VE, CU, VP	42	43	41	42	0.34
7015	VE, HP, VC	42	28	38	40	0.34
7011	VE, CU, VC	40	33	40	39	0.34
7001	VE, VA, CU	31	27	30	32	0.26

SIX CONDITIONS

Results for the six-condition models are presented in Table 26. All data was included in the training set for these models, with no test set used.

TABLE 26: ACCURACY OF SIX-CONDITION MODELS. DATA ARE PERCENTAGE CLASSIFICATIONS IN THE CORRECT CONDITION. THE MOST ACCURATE CLASSIFIER FOR EACH MODEL IS SHOWN IN GREY. MODELS ARE ARRANGED IN ORDER FROM MOST ACCURATE TO LEAST ACCURATE.

Six-condition models						
Number	**Missing conditions**	**SVM**	**J48**	**ANN**	**Simple Logistic**	**Kappa**
6007	VE, VA, AP, VP	50	50	55	58	0.45
6003	VE, VA, HP, VD	48	48	56	53	0.47
6006	VE, VA, AP, VD	53	47	54	56	0.47
6002	VE, VA, HP, VP	50	44	52	56	0.45
6004	VE, VA, HP, CU	52	44	53	55	0.45
6001	VE, VA, AP, HP	53	46	53	53	0.43
6005	VE, VA, HP, VC	44	37	47	52	0.41
6008	VE, VA, AP, CU	51	49	51	49	0.41
6009	VE, VA, AP, VC	45	39	44	47	0.36

FIVE CONDITIONS

The best five-condition models were examined, with the results presented in Table 27. It should be noted that the conditions indicated in the table were those included in the models, not those excluded, as was the case for the previous models shown. All data was included in the training set for these models, with no test set used.

TABLE 27: ACCURACY OF FIVE-CONDITION MODELS. DATA ARE PERCENTAGE CLASSIFICATIONS IN THE CORRECT CONDITION. THE MOST ACCURATE CLASSIFIER FOR EACH MODEL IS SHOWN IN GREY. MODELS ARE ARRANGED IN ORDER FROM MOST ACCURATE TO LEAST ACCURATE. THE CONDITIONS SHOWN IN THE TABLE ARE THOSE INCLUDED IN THE MODELS.

Five-condition models						
Number	**Conditions included**	**SVM**	**J48**	**ANN**	**Simple Logistic**	**Kappa**
5010	AR, FA, HP, CU, VC	61	52	63	64	0.53
5003	AR, FA, VD, VP, VC	60	52	55	62	0.51
5008	AR, FA, HP, VP, VC	55	55	59	61	0.51
5001	AR, FA, VD, CU, VC	59	50	59	61	0.53
5002	AR, FA, VD, CU, VC	59	50	59	61	0.53
5009	AR, FA, HP, VP, CU	54	48	61	60	0.51
5005	AR, AP, FA, VP, VC	55	49	60	58	0.50
5007	AP, AR, FA, VD, VP	53	41	52	58	0.47
5013	AP, AR, FA, HP, VD	47	44	54	58	0.46
5012	AP, AR, FA, HP, VP	51	43	56	57	0.43
5014	AP, AR, FA, HP, CU	52	41	56	56	0.45
5004	AR, FA, VD, VP, CU	53	46	56	56	0.45
5006	AP, AR, FA, VP, CU	52	49	53	55	0.42
5011	AP, AR, FA, HP, VC	51	50	55	53	0.44

FOUR CONDITIONS

The results of the four-condition models are shown in
Table 28. All data was included in the training set for these models, with no test set used.

TABLE 28: ACCURACY OF FOUR-CONDITION MODELS. DATA ARE PERCENTAGE CLASSIFICATIONS IN THE CORRECT CONDITION. THE MOST ACCURATE CLASSIFIER FOR EACH MODEL IS SHOWN IN GREY. MODELS ARE ARRANGED IN ORDER FROM MOST ACCURATE TO LEAST ACCURATE. THE CONDITIONS SHOWN IN THE TABLE ARE THOSE INCLUDED IN THE MODELS.

Four-condition models						
Number	**Conditions included**	**SVM**	**J48**	**ANN**	**Simple Logistic**	**Kappa**
4004	AR, FA, CU, VC	70	69	75	71	0.66
4026	AR, FA, VD, VC	70	62	70	68	0.61
4019	AR, FA, VE, VC	66	54	65	70	0.59
4023	AR, FA, VA, VC	65	66	66	70	0.58
4022	AR, FA, VA, CU	65	53	64	70	0.51
4028	AR, FA, VP, VC	68	59	68	69	0.58
4025	AR, FA, VD, CU	62	58	61	68	0.56
4027	AR, FA, VP, CU	64	60	67	66	0.56
4018	AR, FA, VE, CU	65	58	66	63	0.55
4006	AR, FA, AP, VP	58	56	60	66	0.56
4002	AR, FA, VE, VA	62	56	58	65	0.53
4009	AR, FA, AP, VC	63	57	62	65	0.54
4015	AR, FA, HP, VC	61	64	65	64	0.53
4005	AR, FA, AP, VA	65	56	63	63	0.52
4003	AR, FA, VD, VP	64	52	57	59	0.53
4017	AR, FA, VE, VD	60	55	64	61	0.53
4007	AR, FA, AP, VD	60	55	64	63	0.52
4014	AR, FA, HP, CU	63	58	63	64	0.53
4013	AR, FA, HP, VP	58	58	58	63	0.56
4008	AR, FA, AP, CU	60	52	62	63	0.48
4010	AR, FA, HP, VA	60	56	59	62	0.52
4012	AR, FA, HP, VD	57	56	61	60	0.48
4020	AR, FA, VA, VD	55	55	53	60	0.45
4016	AR, FA, VE, VP	53	50	58	59	0.51
4021	AR, FA, VA, VP	53	50	57	58	0.47
4011	AR, FA, HP, VE	55	53	54	56	0.40
4001	AR, FA, AP, HP	56	49	56	58	0.46

RESUME

A summary of the number of models with the highest accuracy built by each classifier can be found in the
Table 29.

TABLE 29: NUMBERS OF MODELS WITH THE HIGHEST ACCURACY BUILT BY EACH CLASSIFIERS FOR ALL THE COMBINATIONS OF CONDITIONS.

Classifiers	SVM	J48	ANN	Simple Logistic
3 conditions	42	25	34	51
4 conditions	4	0	8	17
5 conditions	0	0	5	11
6 conditions	1	0	3	7
7 conditions	4	1	8	8
8 conditions	5	0	8	22
9 conditions	1	1	6	6
TOTAL	57	27	72	122

4.3.2 TESTING THE MODELS

The most accurate models were analysed in more detail by creating training and testing data sets. Only those models that exceeded 60% accuracy, irrespective of the number of conditions used, were analysed with training and testing data sets.

FIVE-CONDITION MODELS

The results of the training and testing analyses for five conditions models are shown in Table 30.

TABLE 30: CLASSIFICATION ACHIEVED BY THE MOST ACCURATE FIVE-CONDITION MODELS. DATA ARE PERCENTAGE CLASSIFICATIONS OF THE CORRECT CONDITION. THE MOST ACCURATE CLASSIFIER FOR EACH MODEL IS SHOWN IN GREY. MODELS ARE ARRANGED IN ORDER FROM MOST ACCURATE TO LEAST ACCURATE IN RESPECT TO THE TESTING CLASSIFICATION. THE EXACT NUMBER OF CASES IN EACH TRAINING AND TESTING SET CAN BE FOUND IN ANNEX 13.

Five-condition models							
Number	**Conditions included**		**SVM**	**J48**	**ANN**	**Simple Logistic**	**Kappa**
5008	AR, FA, HP, VP, VC	Training	50	56	49	55	0.35
		Testing	62	68	61	58	0.51
5003	AR, FA, VD, VP, VC	Training	62	57	53	63	0.52
		Testing	53	55	61	51	0.41
5010	AR, FA, HP, CU, VC	Training	62	64	52	57	0.39
		Testing	45	53	55	55	0.43

FOUR-CONDITION MODELS

The results of the training and testing analyses for four conditions models are shown in Table 30.

TABLE 31: CLASSIFICATION ACHIEVED BY THE MOST ACCURATE FOUR-CONDITION MODELS. DATA ARE PERCENTAGE CLASSIFICATIONS OF THE CORRECT CONDITION. THE MOST ACCURATE CLASSIFIER FOR EACH MODEL IS SHOWN IN GREY. MODELS ARE ARRANGED IN ORDER FROM MOST ACCURATE TO LEAST ACCURATE IN RESPECT TO THE TESTING CLASSIFICATION. THE EXACT NUMBER OF CASES IN EACH TRAINING AND TESTING SET CAN BE FOUND IN ANNEX 13.

Four-condition models							
Number	**Conditions included**		**SVM**	**J48**	**ANN**	**Simple Logistic**	**Kappa**
4026	AR, FA, VD, VC	Training	64	66	66	63	0.53
		Testing	76	76	58	68	0.38
4004	AR, FA, CU, VC	Training	71	77	63	70	0.46
		Testing	64	70	64	70	0.46
4023	AR, FA, VA, VC	Training	66	67	60	64	0.46
		Testing	76	70	66	73	0.55
4028	AR, FA, VP, VC	Training	68	70	55	66	0.40
		Testing	64	68	46	70	0.31
4022	AR, FA, VA, CU	Training	61	63	56	63	0.51
		Testing	55	62	45	64	0.52
4006	AR, FA, VE, CU	Training	56	57	44	59	0.44
		Testing	62	64	52	62	0.50
4027	AR, FA, VP, CU	Training	64	72	61	62	0.48
		Testing	67	60	59	62	0.43
4019	AR, FA, VE, VC	Training	59	62	52	57	0.45
		Testing	57	60	60	71	0.42
4025	AR, FA, VD, CU	Training	57	54	60	57	0.38
		Testing	62	71	55	64	0.61

THREE-CONDITION MODELS

The results of the training and testing analyses for three conditions models are shown in Table 32.

TABLE 32: CLASSIFICATION ACHIEVED BY THE MOST ACCURATE THREE-CONDITION MODELS. DATA ARE PERCENTAGE CLASSIFICATIONS OF THE CORRECT CONDITION. THE MOST ACCURATE CLASSIFIER FOR EACH MODEL IS SHOWN IN GREY. MODELS ARE ARRANGED IN ORDER FROM MOST ACCURATE TO LEAST ACCURATE IN RESPECT TO THE TESTING CLASSIFICATION. THE EXACT NUMBER OF CASES IN EACH TRAINING AND TESTING SET CAN BE FOUND IN ANNEX 13

Three-condition models							
Number	**Conditions included**		**SVM**	**J48**	**ANN**	**Simple Logistic**	**Kappa**
3005	VP, FA, AR	Training	72	73	72	79	0.70
		Testing	100	100	98	98	0.92
3100	VC, HP, AR	Training	73	72	66	76	0.59
		Testing	84	82	73	78	0.76
3050	VD, FA, AR	Training	74	72	69	71	0.59
		Testing	78	73	84	76	0.66
3053	VD, AR, AP	Training	75	74	67	67	0.62
		Testing	82	77	75	77	0.73
3104	VC, FA, CU	Training	71	69	71	75	0.53
		Testing	77	77	82	73	0.66
3013	AR, AP, CU	Training	73	70	67	68	0.57
		Testing	70	77	81	67	0.54
3002	VP, HP, AR	Training	71	75	68	73	0.51
		Testing	80	75	64	73	0.45
3106	VC, AR, CU	Training	80	84	66	80	0.65
		Testing	80	80	64	73	0.47
3069	VE, FA, AR	Training	72	70	61	72	0.54
		Testing	74	70	67	79	0.53
3012	FA, AR, CU	Training	74	73	72	79	0.61
		Testing	73	75	68	77	0.62
3109	VP, AR, CU	Training	70	72	60	75	0.40
		Testing	77	77	75	71	0.62
3108	VP, AR, AP	Training	63	68	71	58	0.56
		Testing	75	71	64	73	0.46
3121	VC, FA, AR	Training	79	82	69	85	0.74
		Testing	73	73	66	75	0.66
3118	VE, AR, CU	Training	76	77	68	71	0.65
		Testing	75	71	64	71	1.00
3031	VP, VE, AR	Training	75	76	68	75	0.63
		Testing	72	70	74	74	0.62
3111	VA, FA, AR	Training	73	70	75	77	0.55
		Testing	73	66	73	57	0.49
3008	HP, FA, AR	Training	68	70	64	70	0.56
		Testing	68	73	57	71	0.46
3077	VC, VP, AR	Training	73	67	64	73	0.59
		Testing	56	60	60	67	0.50
3091	VC, VA, AR	Training	73	73	62	55	0.59
		Testing	62	62	64	62	0.42
3043	VD, VE, AR	Training	67	70	65	68	0.47
		Testing	61	61	59	61	0.39

4.3.3 FEATURE SELECTION FOR THE BEST MODELS

In order to improve the accuracy of the model, features selection was performed. The following part exposes the same models presented in the previous part of chapter 4 but those models are in this part submitted to features selection.

FIVE-CONDITION MODELS

The parameters chosen for the models after feature selection are shown in Table 33.

TABLE 33: PARAMETERS RETAINED BY FEATURE SELECTION FOR FIVE-CONDITION MODELS.

Parameters chosen by feature selection for five-condition models							
		Parameters selected					
Model	**Conditions included**	**SVM**			**Simple Logistic**		
		SU	**SW**	**SD**	**SU**	**SW**	**SD**
5008	AR, FA, HP, VP, VC	impZ(tVP), FC1	RDISTAP, FREQAP, FD, POWERAP, vDELTAFML, HLAP, RPSAP6, RPSML2, RPSML6	rAP0, APA, dAPP, intZ(tt), iintX(tt), impZ(ITOTAL), IAPAZ, IWTY, AP0(FO1), accXR(FO1), accZN(FC1d)	TOTEXAP	FDCE, XCRD, CTMML, RPSAP5	FO2, accZN(FC1d)
5003	AR, FA, VD, VP, VC	FO2, dST, impZ(tVP), impZ(FC2), VV6, TOTEXML	MFREQAP, FREQDML, DLML, HLRD, LyapuY6.	rML0, IAPAZ, IWTZ, AP0(FO1), ML0(FO1), TOTEX, TOTEXAP	tf, impZ(FC2), AREASW	DSAP, HLRD.	intZ(tt)
5010	AR, FA, HP, CU, VC	dTOTAL, dSW, accXN(FC1), impZ(tVP), VV6	uDELTAFAP, SML, DLAP, HSRD, RPSAP4, RPSML4, LyapuY2	poids, FC1d, intZ(tt), impZ(ITOTAL), IAPAZ, ISWY, AP0(FO1), ML0(FO1), MDISTAP, TOTEXAP, TOTEXML, AREASW, RANGEAP	FC1, dTOTAL, VV6, VD6	MFREQ, HSAP, RPSAP7	rML0, t0, intX(tt), iintX(tt), IWTZ

Results of these classifications, for both training and testing data sets, are shown in Table 34.

TABLE 34: CLASSIFICATION ACHIEVED BY THE MOST ACCURATE FIVE-CONDITION MODELS WITH FEATURE SELECTION. DATA ARE PERCENTAGE CLASSIFICATIONS OF THE CORRECT CONDITION. THE MOST ACCURATE CLASSIFIER FOR EACH MODEL IS SHOWN IN GREY. MODELS ARE ARRANGED IN ORDER FROM MOST ACCURATE TO LEAST ACCURATE IN RESPECT TO THE TESTING CLASSIFICATION. THE EXACT NUMBER OF CASES IN EACH TRAINING AND TESTING SET CAN BE FOUND IN ANNEX 13.

Five-condition models after feature selection								
Number	**Conditions included**	**Feature selection**		**SVM**	**J48**	**ANN**	**Simple Logistic**	**Kappa**
5008	AR, FA, HP, VP, VC	SVM	Training	62	52	44	52	0.53
			Testing	53	60	69	55	0.42
		Simple Log	Training	38	48	41	59	0.48
			Testing	31	54	49	61	0.51
5003	AR, FA, VD, VP, VC	SVM	Training	65	62	49	63	0.56
			Testing	50	54	55	53	0.38
		Simple Log	Training	54	57	47	60	0.50
			Testing	43	41	41	42	0.27
5010	AR, FA, HP, CU, VC	SVM	Training	59	61	51	60	0.47
			Testing	40	38	44	47	0.27
		Simple Log	Training	57	59	52	71	0.63
			Testing	40	48	40	53	0.42

FOUR-CONDITION MODELS

The parameters chosen for the models after feature selection are shown in Table 35.

TABLE 35: PARAMETERS RETAINED BY FEATURE SELECTION FOR FOUR-CONDITION MODELS.

Parameters chosen by feature selection for four-condition models							
		Parameters selected					
Model	Conditions included	SVM			Simple Logistic		
		SU	SW	SD	SU	SW	SD
4026	AR, FA, VD, VC	FO2, FC2, dST, accZN(FC1), accZN(FC2), VD4	RANGEAP, POWERAP, DFARD, HLML, RPSAP6, RPSML4	accZN(FC1d), AREASW	FC1, dTOTAL, TOTEXML	CFREQML, IMEnAP1, IMEnAP3	dAPP, intX(tt), accXN(FC1d)
4023	AR, FA, VA, VC	tf, dTOTAL, dST, accXN(FC1), impZ(tVP)	AREACE, POWERML, HLRD, IMEnAP3, RPSML5	rAP0, FO1, dTOTAL, IAPAZ	FO2, dSW, MDIST, MDISTML	POWERAP, RSAP, HLAP	FO2, dTOTAL, en
4028	AR, FA, VP, VC	FC2, dTOTAL, dST, impX(tVP)	MDISTML, POWERRD, HLAP, RPSAP6, RPSML1, RPSML4	intZ(tt), IAPAZ, AREASW	FC1, impZ(tVP), VV6, TOTEXML	AREACE, MFREQAP	FC1d, IAPAZ
4004	AR, FA, CU, VC	FO2, accZN(FC2), impZ(tVP)	MDIST, RDIST, uDELTAFML, DFAAP, RPSAP1, RPSAP4	rAP0, FO2 , dAPP, IWTZ, MDISTML	FO2, impZ(FC2), MDIST, TOTEXML, AREASW	MVELO, MFREQAP, CTMML, RPSML1, RPSML6, Lyapu2	t0, FC1d, FO2, intZ(tt)
4022	AR, FA, VA, CU	impZ(FC2)	DFAML, HSAP, HLAP, RPSML5	intZ(tt), MDIST, impZ(ITOTAL), ISWZ, AP0(FO1),	accZN(FC2), MDIST, TOTEX	RPSML5	FC1d, impZ(ITOTAL), ISWZ
4006	AR, FA, VE, CU	FC2, dSW, impZ(tVP), TOTEXML, MVELO	RANGE, FDCC, POWERAP, RPSAP6	dAPP, IAPAZ, ML0(FO1)	VD6, TOTEXAP	FREQAP, FREQDML, Lyapu5	MDISTML, MVELOML
4027	AR, FA, VP, CU	tf, accZN(FC2), VV6, VD6, MVELOAP	RDISTAP, MFREQML, RSAP, KSML, RPSAP5	IWTX, AP0(FO1), MDISTML, TOTEXML, AREASW	TOTEXML	RANGEML, HSAP, IMEnAP3	FC1d
4019	AR, FA, VE, VC	FC1, tf, dSW, impX(tVP), VV6, VD5	MDIST, AREACE, FREQDAP, HLRD, XCRD		FO2, FC1, impZ(FC2), VV6	RANGE, AREACC, DSAP, RPSAP6, LyapuY3	FO1, FC1d, FO2, intX(tt), MDISTML
4025	AR, FA, VD, CU	dST, AREASW	MFREQAP, CFREQRD, DFARD, HSRD, CTMAP, CTMEMDML, RPSAP4, LyapuY3, LyapuY4	rAP0, rML0, intX(tt), en, MVELOAP	VV6, AREASW, MVELOML	DSML, TCRD, CTMEMDAP	rAP0, dTOTAL, iintX(tt), TOTEX

Results of these classifications, for both training and testing data sets, are shown in Table 36.

TABLE 36: CLASSIFICATION ACHIEVED BY THE MOST ACCURATE FOUR-CONDITION MODELS WITH FEATURE SELECTION. DATA ARE PERCENTAGE CLASSIFICATIONS OF THE CORRECT CONDITION. THE MOST ACCURATE CLASSIFIER FOR EACH MODEL IS SHOWN IN GREY. MODELS ARE ARRANGED IN ORDER FROM MOST ACCURATE TO LEAST ACCURATE IN RESPECT TO THE TESTING CLASSIFICATION. NOT YET THE EXACT NUMBER OF CASES IN EACH TRAINING AND TESTING SET CAN BE FOUND IN ANNEX 13.

Four-condition models after feature selection								
Number	**Conditions included**	**Feature selection**		**SVM**	**J48**	**ANN**	**Simple Logistic**	**Kappa**
4004	AR, FA, CU, VC	SVM	Training	82	75	63	72	0.66
			Testing	70	71	63	75	0.46
		Simple Log	Training	63	69	61	79	0.77
			Testing	61	73	66	71	0.38
4019	AR, FA, VE, VC	SVM	Training	67	64	51	65	0.54
			Testing	55	69	71	67	0.56
		Simple Log	Training	53	69	59	72	0.62
			Testing	64	71	59	71	0.61
4023	AR, FA, VA, VC	SVM	Training	70	65	63	68	0.58
			Testing	54	63	64	70	0.60
		Simple Log	Training	60	63	54	71	0.61
			Testing	56	63	71	68	0.57
4025	AR, FA, VD, CU	SVM	Training	60	51	52	64	0.42
			Testing	62	71	60	59	0.49
		Simple Log	Training	40	56	59	71	0.61
			Testing	31	45	57	59	0.45
4026	AR, FA, VD, VC	SVM	Training	72	63	52	68	0.62
			Testing	70	56	53	61	0.59
		Simple Log	Training	58	69	56	76	0.68
			Testing	58	63	49	70	0.58
4028	AR, FA, VP, VC	SVM	Training	72	66	58	68	0.57
			Testing	58	64	48	61	0.48
		Simple Log	Training	61	69	60	75	0.67
			Testing	59	64	58	70	0.59
4006	AR, FA, VE, CU	SVM	Training	64	61	53	64	0.51
			Testing	47	62	69	59	0.46
		Simple Log	Training	38	47	56	64	0.51
			Testing	41	36	54	41	0.40
4022	AR, FA, VA, CU	SVM	Training	62	52	58	58	0.49
			Testing	62	57	48	59	0.48
		Simple Log	Training	40	65	57	64	0.53
			Testing	29	40	59	48	0.32
4027	AR, FA, VP, CU	SVM	Training	55	61	56	67	0.55
			Testing	41	59	60	55	0.40
		Simple Log	Training	38	51	58	70	0.59
			Testing	28	59	48	52	0.33

THREE-CONDITION MODELS

The parameters chosen for the models after feature selection are shown in Table 37.

TABLE 37: PARAMETERS RETAINED BY FEATURE SELECTION FOR THREE-CONDITION MODELS.

Parameters chosen by feature selection for three-condition models							
		Parameters selected					
Model	Conditions included	SVM			Simple Logistic		
		SU	SW	SD	SU	SW	SD
3008	HP, FA, AR	SU_dST, dSW, impZ(tVP), VV6	SW_RANGE, DFAML, KSRD, RPSML4, RPSML5, Lyapu2.	SD_poids, dSW, dTOTAL, impZ(ITOTAL), IAPAZ. SD_TOTEXML.	SU_tf, impZ(FC2)	SW_RANGEML. SW_DFAML, CTMAP, RPSAP5.	SD_dAPP, en, IAPAZ, TOTEXML.
3012	FA, AR, CU	SU_dST	SW_RANGEML, FREQDRD, HSAP. SW_CTMML, RPSAP6.	SD_rAP0.	, TOTEX	SW_CTMML	SD_FC1d, dAPA, ISWZ.
3111	VA, FA, AR	VV6 TOTEXML	SW_AREACE, MFREQ. SW_DFARD, HLML, RPSML7, Lyapu2.	SD_impX(ITOTAL). SD_IAPAX.	SU_MDIST, TOTEXAP, MVELO	SW_CTMAP, RPSML4.	SD_FC1d, dSW, RANGE.
3100	VC, HP, AR	FO2, FC1, dSW, accXN(FC2)	SW_FDCC, uDELTAFRD, DFAML, DFARD, RPSAP2.	SD_FO2, dSW, IAPAY, ISWZ, accZN(FC1d).	SU_FO2, FC1, dTOTAL, dST, dSW, accXN(FC2)		SD_FO2, dAPP, MDIST.
3002	VP, HP, AR	impZ(FC2)	SW_vDELTAFAP. SW_RSML.SW_CTMAP.	SD_rAP0, dSW, dTOTAL, IAPAZ.	SU_impX(tVP). SU_MDISTML, TOTEX		SD_TOTEXAP.
3121	VC, FA, AR	SU_FO2, FC2, accYN(FC1). SU_impZ(FC2)	SW_AREASW, MFREQ, DFARD, DLML, DLRD, HLML. SW_KSAP, RPSAP4, RPSAP6, RPSAP7, Lyapu5.	SD_rML0, FC1d, AP0(FO1), accZN(FC1d).	SU_FO2, accXN(tVP), accXN(FC2), impZ(FC2), VV6	SW_FREQDAP, CTMAP.	SD_FO2, intX(tt).
3106	VC, AR, CU	SU_tVP, impZ(tVP), VV6	SW_AREASW, HSRD, IMEnAP3, RPSML2, Lyapu6.	SD_impZ(ITOTAL). SD_ML0(FO1). SD_accZN(FC1d).	SU_FC2, VD6, MDIST, TOTEXAP, TOTEXML	SW_DLML, IMEnAP2.	SD_dTOTAL, AP0(FO1).
3069	VE, FA, AR	SU_dSW	SW_MDISTAP, vDELTAFRD, HSRD, KLML. SW_IMEnAP3, RPSAP2, RPSAP5, RPSAP6, RPSML5, Lyapu6, LyapuY4.	SD_dAPP, intX(tt). SD_iintX(tt). SD_ISWY.	SU_impZ(tVP), VV6	SW_RDISTAP, RPSAP5, LyapuY2.	SD_rAP0, iintX(tt). SD_impY(ITOTAL), RANGEML.
3050	VD, FA, AR	SU_tVP, dST. SU_dSW, accXN(FC2). SU_impX(tVP). SU_VD6	SW_RDIST, RANGEML, FREQDRD, IMEnAP3, RPSML4.	SD_IWTZ, accZN(FC1d).	SU_MDIST, TOTEX, TOTEXML	SW_RPSML4.	SD_FC1d, FO2, intY(tt). SD_en.
3118	VE, AR, CU	SU_impZ(FC2). SU_VV6, VD6	SW_RANGE, RANGEAP, AREASW, MFREQ, DFARD, RSAP, HLRD, TCML, CTMML, Lyapu6. SW_LyapuY1.	SD_iintX(tt). SD_en, IWTY, MDIST, RANGEAP.	SU_VV6. SU_TOTEXML	SW_AREACE, MFREQ, DFARD, HLML, RPSML7, Lyapu2.	SD_impX(ITOTAL). SD_IAPAX.
3109	VP, AR, CU	SU_accZN(FC2). SU_impZ(FC2). SU_TOTEXAP,	SW_DLML, HSML, HSRD. SW_CTMML.	SD_impZ(ITOTAL), IAPAZ, accZN(FC1d),	SU_impZ(FC2). SU_VV6, AREASW	SW_DSRD, IMEnAP2, RPSML7.	SD_IAPAX, IAPAZ, AP0(FO1).

		AREASW	SW_RPSML7.	MDISTAP, MVELOML.			SD_AREASW.
3005	VP, FA, AR		SW_MFREQ SW_RSML, CTMAP	SD_dTOTAL, IWTZ, accZN(FC1d). SD_TOTEXAP.	SU_impZ(tVP). SU_impZ(FC2). SU_VV6	SW_RDISTML, FD.	SD_TOTEX.
3043	VD, VE, AR	U_dST, accXN(FC2). SU_impZ(FC2). SU_VV6	SW_MFREQAP. SW_FREQDRD, DFAML, DSRD. SW_KSML. SW_CTMAP, LyapuY5. S	SD_IAPAX, IAPAY, ISWX.	SU_MDISTAP, TOTEXML		SD_accZN(FC1d).
3077	VC, VP, AR	SU_FO2, tVP, FC2, FC1, accZN(FC2). SU_impX(tVP), impZ(FC2)	SW_POWERAP, XCAP, RPSAP7.	SD_rML0, FC1d, IAPAZ, ISWX, accZN(FC1d). SD_accZN(tPMC) . SD_MDIST, TOTEXML.	SU_FC2, impZ(FC2). SU_VV6	SW_MFREQ, RPSAP7.	SD_FO2, IWTX, MDISTAP.
3053	VD, AR, AP	SU_FC2, accZN(FC2). SU_MDIST	SW_FDCC, DLAP, HLAP.	SD_ML0(FO1). SD_accZN(FC1d) . SD_accZN(tPMC)	SU_FC1, impZ(tVP). SU_impZ(FC2), MDIST, MDISTML, TOTEX, TOTEXML	SW_FD, FDCE, RPSAP3. SW_Lyapu5.	SD_poids, FO1, FO2.
3013	AR, AP, CU	SU_FC2, dSW, impY(tVP). SU_impZ(tVP). SU_VV6	SW_RANGE, vDELTAFRD, DFAAP, HSAP, IMEnAP3.	SD_rAP0, en.	SU_dST, VV6 , TOTEX, TOTEXML	SW_CTMML.	SD_impY(ITOTAL). SD_IAPAX.
3031	VP, VE, AR	SU_dST	SW_FD, FREQDML, RSML, HSAP, KLRD, CTMAP, RPSML4, RPSML5, Lyapu2, LyapuY2.	SD_intY(tt). SD_intZ(tt). SD_IAPAZ. SD_accZN(FC1d) . SD_MDISTAP.	SU_impZ(FC2), VV6, VD6, MVELO, MVELOML	SW_FD, HSAP.	SD_poids, iintZ(tt).
3108	VP, AR, AP	SU_dST, accZN(FC1), impZ(FC2), VD4, MDIST	RANGE, RANGEML, AREACE, MFREQAP, MFREQML, RSML, HSAP, CTMAP, CTMML, IMEnAP3, RPSAP5, RPSAP7, RPSML5, Lyapu6.	SD_IAPAZ, accXR(FO1), accZN(FC1d), accZN(tPMC)	SU_VV6, TOTEXML	SW_AREACC, FD, RPSAP1.	SD_dSW, IAPAZ.
3091	VC, VA, AR	SU_dST, impZ(FC2), VV6	SW_AREACC, POWERML, DFAML, DFARD, DLRD, HLAP, XCAP, RPSAP4, RPSAP6, RPSML7.	SD_rML0, FO1, FO2, dTOTAL, intY(tt), IAPAZ, accZN(FC1d), MVELO., SD_RANGEML.	SU_dTOTAL, impZ(FC2), VV6, MVELOML	SW_CTMML, Lyapu5.	SD_rAP0, FO2, dSW, iintZ(tt), IAPAZ, MDIST, MDISTAP.
3104	VC, FA, CU	SU_tVP, VV6	SW_IMEnAP3.	SD_dTOTAL, IWTZ, accXR(FO1), accZR(FO1).	SU_FC1, MDISTML	SW_FREQDRD, IMEnAP3.	SD_FO1. SD_intY(tt).

Results of these classifications, for both training and testing data sets, are shown in Table 38.

TABLE 38: CLASSIFICATION ACHIEVED BY THE MOST ACCURATE THREE-CONDITION MODELS WITH FEATURE SELECTION. DATA ARE PERCENTAGE CLASSIFICATIONS OF THE CORRECT CONDITION. THE MOST ACCURATE CLASSIFIER FOR EACH MODEL IS SHOWN IN GREY. MODELS ARE ARRANGED IN ORDER FROM MOST ACCURATE TO LEAST ACCURATE IN RESPECT TO THE TESTING CLASSIFICATION. THE EXACT NUMBER OF CASES IN EACH TRAINING AND TESTING SET CAN BE FOUND IN ANNEX 13.

Three-condition models after feature selection								
Number	**Conditions included**	**Feature selection**		**SVM**	**J48**	**ANN**	**Simple Logistic**	**Kappa**
3005	VP, FA, AR	SVM	Training	68	63	66	67	0.44
			Testing	68	83	80	78	0.73
		Simple Log	Training	60	72	72	77	0.59
			Testing	63	83	95	75	0.74
3077	VC, VP, AR	SVM	Training	88	83	77	86	0.78
			Testing	64	76	64	69	0.53
		Simple Log	Training	63	79	70	84	0.75
			Testing	56	80	71	87	0.80
3012	FA, AR, CU	SVM	Training	76	75	64	75	0.63
			Testing	75	77	68	75	0.63
		Simple Log	Training	47	59	70	86	0.79
			Testing	50	75	73	86	0.79
3013	AR, AP, CU	SVM	Training	72	69	66	65	0.56
			Testing	81	70	58	65	0.71
		Simple Log	Training	60	63	77	80	0.71
			Testing	49	70	70	72	0.57
3111	VA, FA, AR	SVM	Training	57	59	78	74	0.61
			Testing	52	68	73	80	0.68
		Simple Log	Training	48	65	79	84	0.76
			Testing	43	57	61	77	0.66
3108	VP, AR, AP	SVM	Training	84	77	70	81	0.77
			Testing	73	66	71	77	0.58
		Simple Log	Training	46	71	67	76	0.59
			Testing	48	64	80	71	0.56
3100	VC, HP, AR	SVM	Training	83	80	76	80	0.73
			Testing	80	76	69	80	0.70
		Simple Log	Training	75	83	64	85	0.76
			Testing	69	67	69	76	0.63
3050	VD, FA, AR	SVM	Training	79	73	59	73	0.59
			Testing	67	78	62	76	0.60
		Simple Log	Training	61	74	73	87	0.80
			Testing	47	64	76	80	0.69
3109	VP, AR, CU	SVM	Training	85	75	56	79	0.78
			Testing	80	64	75	75	0.69
		Simple Log	Training	60	78	66	80	0.71
			Testing	59	77	66	75	0.62
3031	VP, VE, AR	SVM	Training	85	83	73	82	0.78
			Testing	79	72	74	74	0.69
		Simple Log	Training	66	85	68	85	0.49
			Testing	58	77	72	72	0.38
3069	VE, FA, AR	SVM	Training	81	73	76	79	0.71
			Testing	67	63	72	63	0.51
		Simple Log	Training	65	75	68	88	0.47
			Testing	67	79	74	77	0.50
3106	VC, AR, CU	SVM	Training	88	82	66	83	0.83
			Testing	71	60	53	76	0.57
		Simple Log	Training	51	75	69	85	0.77
			Testing	49	62	71	78	0.67

3008	HP, FA, AR	SVM	Training	76	70	66	70	0.55
			Testing	66	75	61	77	0.65
		Simple Log	Training	58	68	68	86	0.79
			Testing	46	59	64	55	0.31
3053	VD, AR, AP	SVM	Training	77	69	63	72	0.65
			Testing	64	61	55	64	0.45
		Simple Log	Training	54	70	73	81	0.72
			Testing	43	75	77	75	0.62
3091	VC, VA, AR	SVM	Training	74	75	69	74	0.53
			Testing	69	76	76	67	0.61
		Simple Log	Training	70	77	77	79	0.67
			Testing	56	73	76	73	0.61
3104	VC, FA, CU	SVM	Training	76	75	76	78	0.63
			Testing	73	66	71	71	0.59
		Simple Log	Training	66	74	69	76	0.63
			Testing	57	68	68	75	0.62
3121	VC, FA, AR	SVM	Training	86	82	67	82	0.80
			Testing	64	75	71	68	0.45
		Simple Log	Training	81	86	79	92	0.88
			Testing	71	73	73	71	0.55
3118	VE, AR, CU	SVM	Training	85	83	67	83	0.77
			Testing	55	68	50	50	0.31
		Simple Log	Training	69	68	68	82	0.73
			Testing	52	61	71	57	0.35
3043	VD, VE, AR	SVM	Training	80	73	68	76	0.70
			Testing	64	55	68	64	0.46
		Simple Log	Training	40	49	62	73	0.59
			Testing	41	55	50	61	0.42
3002	VP, HP, AR	SVM	Training	78	71	67	70	0.55
			Testing	59	66	64	68	0.51
		Simple Log	Training	46	45	64	73	0.59
			Testing	36	46	59	55	0.28

Summary of the 3 condition models with features selection and testing are presented in Table 39.

TABLE 39: SUMMARY OF CLASSIFICATION ACCURACY FOR THREE-CONDITION MODELS AFTER FEATURE SELECTION. DATA ARE PERCENTAGE CLASSIFICATIONS OF THE CORRECT CONDITION. MODELS ARE ARRANGED IN ORDER FROM MOST ACCURATE TO LEAST ACCURATE IN RESPECT TO THE TRAINING CLASSIFICATION.

MODEL		TRAINING			TESTING		
Number	Conditions	BEFORE Feature Selection	AFTER Feature Selection	IMPROVEMENT	BEFORE Feature Selection	AFTER Feature Selection	IMPROVEMENT
3121	VC, FA, AR	85	92	7	75	73	-2
3106	VC, AR, CU	84	88	4	80	76	-4
3069	AR, FA, VE	72	88	16	79	79	0
3077	VC, VP, AR	73	88	15	67	76	9
3050	AR, FA, VD	74	87	13	78	80	2
3008	AR, HP, FA	70	86	16	72	63	-9
3012	AR, FA, CU	79	86	7	77	86	9
3109	VP, AR, CU	75	85	10	71	80	9
3031	AR, VE, VP	76	85	9	70	79	9
3118	VE, AR, CU	77	85	8	71	68	-3
3100	VC, HP, AR	76	85	9	78	76	-2
3108	VP, AR, AP	71	84	13	64	77	13
3111	AR, FA, VA	77	84	7	57	77	20
3053	VD, AR, AP	75	81	6	82	77	-5
3013	AP, AR, CU	73	80	7	70	72	2
3043	AR, VE, VD	70	80	10	61	68	7
3091	VC, VA, AR	73	79	6	62	76	14
3104	VC, FA, CU	75	78	3	73	73	0
3002	AR, HP, VP	75	78	3	75	68	-7
3005	AR, FA, VP	79	77	-2	98	95	-3

4.3.4 VALIDATION OF THE MODELS

THREE CONDITIONS

The models with three conditions including Ankle Range of Motion, Vestibular or Visual acuity were tested with elderly data. The results are presented in Table 40.

The model used for testing are the one chosen to the full complete analysis, including classification, feature selection, training and testing. They are the model presented in the last section.

TABLE 40 : CLASSIFICATION OF IMPAIRED ELDERLY INTO THE BEST THREE CONDITION MODELS.

Model	Validation	% accuracy	Kappa	Right classification	Wrong classification
3121	4 elderly AR	75%	0	3 AR	1 V Contrast
3106	4 elderly AR	50%	0	2 AR	1 CU 1 VC
3069	4 elderly AR	25%	0	1 AR	2 FA 1 VE
3069	4 elderly VE	0%	0	0	2 AR 2 FA
3077	4 elderly AR	25%	0	1 AR	1 VC 2 VP
3050	4 elderly AR	75%	0	3 AR	1VD
3008	4 elderly AR	75%	0	3AR	1 FA
3012	4 elderly AR	50%	0	2 AR	2 FA
3109	4 elderly AR	25%	0	1 AR	3 VP
3031	4 elderly AR	25%	0	1 AR	3 VP
3031	4 elderly VE	25%	0	1 VE	2 VP 1 AR
3118	4 elderly AR	75%	0	3 AR	1 CU
3118	4 elderly VE	25%	0	1 VE	1 AR 1 CU
3100	4 elderly AR	50%	0	2 AR	2 VC
3108	4 elderly AR	50%	0	2 AR	2 VP
3111	4 elderly AR	50%	0	2 AR	2 VA
3111	2 elderly VA	0%	0	0	2 FA
3053	4 elderly AR	75%	0	3 AR	1 AP
3013	4 elderly AR	50%	0	2 AR	1 AP 1 CU
3043	4 elderly AR	0%	0	0	4 VD
3043	4 elderly VE	0%	0	0	4 VD
3091	4 elderly AR	25%	0	1 AR	1 VC 2 VA
3091	2 elderly VA	0%	0	0	2 AR
3002	4 elderly AR	100%	0	4 AR	0
3005	4 elderly AR	50%	0	2 AR	1 FA 1 VP

FOUR CONDITIONS

The models with four conditions including Ankle Range of Motion, Vestibular or Visual acuity were tested with elderly data. The results are presented in Table 41.

TABLE 41 : CLASSIFICATION OF IMPAIRED ELDERLY INTO THE BEST FOUR CONDITION MODELS.

Model	Validation	% accuracy	Kappa	Right classification	Wrong classification
4004	4 elderly AR	50%	0	2 AR	2 VC
4019	4 elderly AR	25%	0	1 AR	2 FA 1 VC
4019	4 elderly VE	0%	0	0	2 FA 2 AR
4023	4 elderly AR	25%	0	1 AR	2 VC 1 FA
4023	2 elderly VA	0%	0	0	1 VC 1 AR
4026	4 elderly AR	50%	0	2 AR	2 VC
4025	4 elderly AR	50%	0	2 AR	2 FA
4028	4 elderly AR	50%	0	2 AR	2 VC
4006	4 elderly AR	25%	0	1 AR	3 VP
4022	4 elderly AR	50%	0	2 AR	1 CU 1 FA
4022	2 elderly VA	0%	0	0	2 AR
4027	4 elderly AR	75%	0	3AR	1 VP

FIVE CONDITIONS

The models with five conditions including Ankle Range of Motion, Vestibular or Visual acuity were tested with elderly data. The results are presented in Table 42.

TABLE 42 : CLASSIFICATION OF IMPAIRED ELDERLY INTO THE BEST FIVE CONDITION MODELS

Model	Validation	% accuracy	Kappa	Right classification	Wrong classification
5008	4 elderly AR	25%	0	1 AR	2 VC 1VP
5003	4 elderly AR	50%	0	2 AR	2 VP
5010	4 elderly AR	50%	0	2 AR	2 FA

Among the models tested, one presented 100% success and six presented 75% success in the classification of the elderly into their rightful impairment. It has to be noted that the successful classification concern only the ankle Range of Motion impairment, the two others impairments tested (vestibular and visual acuity) were not successful.

No five-conditions models were validate, one four-condition model was validated and six three-condition models were validated.

5 CHAPTER 5: DISCUSSION

INTRODUCTION

This PhD included two large-scale experiments, with each one including six separate conditions, three of which included sub-conditions. When the sub-conditions are included, a total of 14 different experimental conditions were performed. The sheer volume of data available made the organization of the thesis somewhat challenging. This chapter presents the discussion and is presented similarly to the previous chapters, first the information about the population, then the tests and degradation performed on the intrinsic factors and finally the discussion about the sway parameters and the construction of models.

5.1 POPULATION

Two different samples consisting of control and elderly subjects were tested in the studies in Auckland and Jodhpur. Subjects in the control population were young healthy adults with no underlying musculoskeletal or neurological conditions that would have excluded them from the study. The recruitment of control subjects in both Jodhpur and in Auckland was performed using the same criterion.

A single elderly sample was tested during the trials in Jodhpur. The inclusion criteria for these subjects included a requirement to be living independently, with no major health problems. The elderly subjects were evaluated using a series of clinical tests in order to quantify their physical capacity. The Timed Up and Go test (TUG) can be used to discriminate between fallers and non-fallers, with a cut-off time of 10-12 s typically used to detect elderly at risk of falling (Boulgarides, et al. 2003). In this study, 20 subjects out of the 25 tested took at least 10s or more at the timed up and go test, indicating that 80% of the elderly population tested could be considered as having a fall risk. If the higher threshold of 12s was taken, 12 subjects out of 25 could be considered to have a fall risk. Irrespective of the threshold used for the TUG, the elderly sample in the study contained a large number of people at risk of falling, and therefore appropriate for use in a fall-risk model. However, in respect to the tests of the six intrinsic factors, almost all of the elderly had multiple impairments, meaning that it was not possible to categorize the elderly into a single condition. Elderly subjects had several co-existing conditions, such as impaired cutaneous sensation, range of motion impairment, and visual impairment. This meant that the elderly subjects could not be classified into any of the models, which were constructed for single impairments. Only a small number of the elderly subjects could be classified into one condition, in cases where they had only a single impairment. In total, only ten elderly subjects had a single impairment (four had ankle ROM impairment, four had vestibular impairment and two had visual acuity impairment). In order to properly test the model it would have required a far greater number of elderly subjects, many of which had only a single impairment. However, recruitment of elderly with such a profile was difficult. For this reason, no elderly subjects were tested in Auckland. Instead, the focus was on better identifying the relationship between a single impairment and a pattern of sway parameters before attempting to construct a complex model with a complicated interaction between multiple impairments.

In total, three samples were tested, consisting of control subjects in Jodhpur and in Auckland, and elderly subjects in Jodhpur. The two control samples in Jodhpur and Auckland were tested before and after degradation of each of the six intrinsic factors. When these subjects were tested before impairment they were referred to as young control subjects, whereas when they were tested after degradation they were referred to as young degraded subjects. When

this distinction is considered, a total of five data sets were compared: elderly, young control Jodhpur, young control Auckland, young degraded Jodhpur, and young degraded Auckland.
The samples were compared according to the clinical measurements and tests of the intrinsic factors. As mentioned previously, the elderly sample was used to test the models created using the control sample with and without impairment from the Jodhpur experiment. The young control populations of Jodhpur and Auckland were then combined to form a single young control population. Similarly, the young degraded populations from the Jodhpur and Auckland studies were combined to a single data set for each intrinsic factor that was young degraded. The two samples were matched for height, weight and physical activity levels. The Jodhpur control population was slightly younger than the Auckland controls, but both populations were well within the normal range for adult populations that did not include elderly subjects.

In future studies, it would be worthwhile using a population with a single quantifiable impairment in order to assess the models developed. For instance, rather than decreasing muscle strength by using fatiguing exercises, a population with a particular myopathy would be more pertinent to evaluate. Similarly, adults with an ankle sprain would be a more pertinent test population than healthy adults wearing an ankle brace. A group of subjects with vestibular neuritis could have been tested rather than healthy adults who had undergone galvanic stimulation. Diabetic populations are also known to have decreased cutaneous proprioception of their feet, and could therefore have been tested in comparison with the model developed. In respect to the visual tests, a range of different conditions could have been used. For instance, epiretinal membrane disease markedly decreases visual acuity, while people with only a single eye that functions have no depth perception. The visual contrast condition could have been evaluated using subjects with cataracts, while subjects with glaucoma or retinal detachment could have been used for the decreased peripheral vision condition. Finally, injuries in the knee, ankle or hip joint reduce proprioception, meaning such a population could be used to assess the model for proprioceptive impairments.
Several studies have investigated the effect of different impairments or diseases on balance. For instance, Horak et al. (2002) investigated diabetic people, Pascolo et al. (2005) investigated Parkinson patients, Paillex et al. (2005) investigated people with stroke, while Black et al. (2008) investigated people with glaucoma. However, all those studies used different balance parameters, thus preventing any comparison or identification of patterns in balance parameters between the populations. It would be of interest to test such populations and to calculate a larger range of balance parameters such as those described in this PhD in order to identify any pattern specific to a particular condition.

SUBJECT NUMBERS:

The number of subjects used to construct a model is a key factor in the effectiveness of the model. The ratio of parameters in the model to the number of cases used in the construction of the model is also an important factor in the performance of the model (Harrell, et al. 1996). The total data set used in this thesis to construct the model for each intrinsic factor contained 50 cases. The most effective models to discriminate between young control and degraded control groups contained between three and four conditions, giving a total number of cases in the models of 150-200. In respect to the parameters used to construct the models, a total of 198 different parameters were available. The number of parameters was reduced by means of feature selection, with an average of around 10 parameters used for each model. The ratio of parameters to cases for the final models was improved, although a larger number of cases for training the models would undoubtedly be beneficial for the performance of the models.

5.2 TESTS AND DEGRADATIONS

5.2.1 PHYSICAL ACTIVITY

The elderly reported lower intensity of physical activity compare to young control. Such a finding was expected, with a reduction in the intensity of physical activity with age reported previously (Baert, et al. 2011; Ewald, et al. 2009).

5.2.2 VISION

The tests used to evaluate vision showed that the young control populations in Jodhpur and Auckland had similar vision. In contrast, the elderly population had significantly lower scores for all visual tests in comparison to the young control subjects. A loss of many of the components of vision in an elderly population has been reported previously in other studies (Addis, et al. 2013).

The degradations used in the current study have been used previously, and have been found to be effective in decreasing vision quality (Anand, et al. 2003a; Deshpande and Patla 2007; Helbostad, et al. 2009). Each component of vision was tested separately, which differs from the other studies. Typically, other studies usually simulate ageing vision, and therefore combine decreases in each component of vision. In contrast, in the current study the effect of each visual component on the balance parameters was analysed.

The visual degradation imposed on the young control subjects in both Jodhpur and Auckland resulted in a significant degradation in the quality of vision, with lower scores observed for all visual tests in comparison to the non-degraded conditions. It can be concluded that the different methods used to impair vision were all effective. However, it should be noted that different results were obtained in respect to the magnitude of the degradations observed in Jodhpur and Auckland. Such differences could have been due to the different lighting used in the two laboratories in which testing occurred. Despite these differences, the use of the combined populations was worthwhile as this gave rise to a slightly more heterogeneous population than was the case for some of the other conditions where the degradation observed was quasi-total.

5.2.3 VESTIBULAR SYSTEM

The Fukuda stepping test was chosen because it was a clinical test that was simple and inexpensive to perform, even though it was known that this test was not fully reliable to precisely detect vestibular impairment (Grommes and Conway 2011; Honaker, et al. 2009). The Fukuda test was the most appropriate tool available at the time of the experimentation, since it is possible to perform the test with every population, and it is straightforward and free to perform. It should be remembered that the testing was performed partly in Jodhpur, and that no expensive equipment was available. In addition, the test was appropriate for the testing context of the study, which took place in a university and a hospital.

Previous studies have shown that an elderly population has a reduced performance of the vestibular system compared to younger subjects (Sloane, et al. 1989). However, the test used in the present study did not show any significant difference between the young control and elderly populations.

Several studies have successfully used the galvanic vestibular stimulation to decrease the efficiency of the vestibular system (Dakin, et al. 2010; Deshpande and Patla 2005; Iles, et al. 2007).
The vestibular test showed that the results varied depending on the vestibular parameter used, the Fukuda stepping test might not have been appropriate to fully show the decrease in vestibular capacity after degradation even if a tendency to higher score was seen for young degraded compared to young control for all three vestibular parameters measured.

5.2.4 JOINTS RANGE OF MOTION

Range of motion differed significantly between the young control and young degraded conditions. However, the degradation used was excessive as the range of motion at the joints tested was completely suppressed, rather than slightly restricted. Furthermore, no significant differences were observed in ankle range of motion between young control and elderly groups. Such a finding is contrary to previous studies in which elderly subjects have a decreased range of motion at the ankle joint (Mecagni, et al. 2000; Sepic, et al. 1986). Such a difference could be due to the exercise habits of the elderly population of India, with Indians of all age regularly practicing yoga as a cultural habit. Yoga has been found to significantly improve the flexibility in elderly population (Brown, et al. 2008; DiBenedetto, et al. 2005). Therefore, it is highly likely that the elderly population in the present study was more flexible than an elderly population of an occidental country.

5.2.5 MUSCLE AND JOINT PROPRIOCEPTION

The tests to measure muscle and joint proprioception were inconclusive. A tendency towards a decrease in proprioception after degradation could be seen, however no significant differences between samples were observed. The lack of any significant differences could have been due to the degradation used, whereby the application of vibrators to the skin overlying tendons could have provided additional proprioceptive information about the position of the joint tested. The degradation used produced vibrations that were designed to perturb the proprioceptive information provided by the tendons, however the force applied could have given proprioceptive information to the receptors in the skin in respect to joint position. One conclusion could be that the vibrations were effective in impairing tendon and muscle proprioception, as has been shown in previous studies in which balance quality was decreased using such techniques (Michel-Pellegrino, et al. 2006). However, the additional cutaneous proprioception obtained from the pressure of the vibrators enabled satisfactory test results to be obtained. In a recent study in which a decrease in hip proprioception with age was identified (Wingert, et al.), a custom-built device to measure joint position error appeared to be more effective than the test used in the current study. However, no easily useable solution has been identified in the literature to counteract the additional clue given by the

vibrators. The only possibility would appear to be the use of subjects with a real and quantifiable degradation in proprioception.

5.2.6 LEG MUSCLE STRENGTH

The isometric fatigue exercise successfully reduced leg muscle strength in the young control population.
In the Jodhpur experiment, the leg muscle power was also measured with the counter movement jump. The test showed a decrease in the height jumped after fatigue compared to before the fatigue, but no changes were observed for impulse. The height jumped depends on the leg muscle strength of subjects to lift their own weight as high as possible. Impulse is measured by the ratio of the quantity of force produced on the force plate and the time of application of that force, which defines leg muscle power. There are two possible explanations for the absence of changes in CMJ impulse after fatigue. Firstly, McLean et al. (2010) showed that the a reduction in power appeared 48h after fatigue activity, whereas the testing in this study was performed immediately after the fatigue bouts. Secondly, Sapstead and Duncan (2013) reported that isometric contractions have different effects on fatigue in comparison to other contraction types. In keeping with the results of the present study, they found no significant changes in power measurements for the CMJ. Therefore isometric fatigue are not recommended to reduce power but the choice of isometric fatiguing exercise was necessary in the present study in order to preserve joint proprioception (Allen and Proske 2006; Changela, et al. 2012).
The countermovement jump was not reproduce in the young control Auckland population since it did not show power change but only strength changes which was already cover by the isometric maximum voluntary contraction test. For the isometric maximum voluntary contraction tests and the degradation of muscle strength, similar process was used for the experiments in Jodhpur and in Auckland. However a more comfortable test was used in Auckland where a leg press was available rather than the sitting chair test used in Jodhpur. In order to be able to compare data from the two samples, the weight of the participants in Jodhpur was added to their maximum score, since the chair position required subjects to support their own body weight during the maximum test in addition to the weight added. In contrast, the Auckland testing did not include the subjects' bodyweight when using leg press, with subjects in a supine position. It was not possible to compare leg strength between young control and elderly groups, as the elderly subjects did not undergo the same test.

5.2.7 FOOT CUTANEOUS PROPRIOCEPTION

The measurement of cutaneous proprioception of the foot differed between Jodhpur and Auckland due to the availability of additional monofilaments in Auckland.
In Jodhpur the number of zones for which a touch was felt constituted the score, while in Auckland the score was taken as the diameter of the last monofilament that could be felt.

In the Jodhpur experiment, the only monofilament available was the index 5.07 which, according to the recommendation of for Semmes Weinstein mono-filaments (North Coast

Medical Inc. Morgan Hill, CA, USA), is a threshold representing a "complete loss of protective sensation of the plantar surfaces" and therefore not appropriate to test young healthy subjects. A mono-filament of 3.84 would have been more appropriate since it corresponds to a threshold for "diminished sensation of the plantar surfaces".
A similar study (Eils, et al. 2002) count the number of zone where the monofilament could be felt, on five zones, the average number of zones able to detect the touch was 3.5, while after icing the average of numbers of zones able to detect the touch dropped to 1.3. The ratio is higher then what we found since in the current study, the young control felt 18 of the 20 zones before the degradation and felt 16.8 zones after icing.

In the Auckland experiment, the index of the monofilament found before and after degradation matched what has been found in the literature. The study of Eils et al. (2002) found an average threshold in normal conditions of 3.7, while after icing the foot soles the average threshold rose to 4. In our study we found average of 3.95 before the degradation and 4.28 after icing.

Due to this difference of testing, it was therefore unfortunately not possible to compare the populations of Jodhpur and Auckland in respect to the degree of impairment produced or the impairment level of the elderly population. Despite this inconvenience, cutaneous proprioception was shown to be significantly degraded in both Jodhpur and Auckland as a result of the degradation used. Furthermore, the elderly subjects tested had significantly lower scores for cutaneous proprioception than the Jodhpur young control subjects. It can be concluded, therefore, that the degradation used in the study was able to decrease cutaneous proprioception.

5.3 BALANCE MEASUREMENTS

A multitude of different parameters have been reported in the literature for the assessment of balance quality or gait analysis. The parameters found in the literature include those related to the centre of pressure (CoP) such as the control strategies of the CoP trajectory (Baratto, et al. 2002; Boucher, et al. 1995a; Collins and Luca 1993; Donker, et al. 2007; Michel-Pellegrino, et al. 2008b; Piirtola and Era 2006; Raymakers, et al. 2005; Swanenburg, et al. 2010; Yagi, et al. 2000). Other CoP parameters widely used include the area and displacement of the trajectory, as well as parameters from the frequency domain (Baratto, et al. 2002; Noda and Demura 2007; Piirtola and Era 2006; Raymakers, et al. 2005; Swanenburg, et al. 2010; Uchiyama and Demura 2007; van Emmerik and van Wegen 2002; Yagi, et al. 2000). Finally, a number of more complex parameters such as the Hurst or Lyupunov exponents have also been reported (Amoud, et al. 2007a; Donker, et al. 2007; Pascolo, et al. 2005; 1995).

Despite the plethora of studies, two major issues arise from those studies, wherein the authors often used simple parameters to describe the change in postural control within the population studied, with degradations in the same parameters commonly reported. In consequence, it is not possible to use a specific combination of parameters to discriminate between different conditions. The second issue is linked to the first, as the use of a small number of simple parameters such as the area of postural sway or the distance covered by the displacement of the CoP might not provide precise enough information to be able to discriminate between populations. In fact, several authors have concluded that the computation of more complex

parameters related to postural control would provide more information for analysis of balance (Johansson, et al. 2009; Pascolo, et al. 2005; Van Dieen, et al. 2010; Yamada 1995).

The current study used a total of 198 parameters measured from the force plate during three phases: stepping up, standing still and stepping down. Since the total number of parameters is so large, it was necessary to apply feature selection on each model built. In this way, the analysis would use only those parameters that were the most relevant to the construction of the model. Feature selection analysis has been widely used in model construction, but few studies have used feature selection of balance parameters. Baratto et al. (2002) used time and frequency domain parameters as well as diffusion plot and sway density plot analysis to found the best parameters for postural stabilisation for clinical use. They started with an ANOVA for 39 parameters, with the number reduced to four significant parameters to discriminate among the three conditions tested (Parkinson's Osteoporosis, and control subjects). The four parameters found were sway path, frequency band, mean value peak of the density plot, and mean inter-peak value of the density plot. Another method was used by Rocchi et al. (2006), who calculated 14 parameters from time and frequency domains, then selected only those parameters that accounted for at least 90% of the variance of the data.
In the current study a large number of models were built it is therefore not possible to discuss the parameters selected by the feature selection for each model. However few parameters were recurrent within the selection of relevant parameters and can therefore be mentioned.
The following parameters were among the most selected as relevant parameters for the discrimination of condition within the model built. The following paragraphs showed that our findings are in accordance with others studies with similar parameters modified with loss of balance and impairment of intrinsic factors.

DISTANCE AND AREA OF SWAY:

The measurement of the distance traced by the displacement centre of pressure (CoP) is the most often used balance parameter (Bauer, et al. 2008; Demura, et al. 2008; Rocchi, et al. 2006; Van Dieen, et al. 2010). This parameter has been found to be significantly higher for elderly with visual acuity impairment, contrast sensitivity impairment, depth perception impairment and a reduced peripheral field (Lord and Menz 2000). Similarly, body displacement has also been found to be greater in elderly people with glaucoma (Black, et al. 2008). In addition to the distance of the CoP, the area covered by this displacement is also analysed. Studies investigating postural sway have used parameters such as sway path, sway length, or the excursion of the CoP (Asai, et al. 1993; Krafczyk, et al. 1999).

VELOCITY AND ACCELERATION:

Parameters related to the velocity and acceleration of the CoP are often used to quantify balance. Analysis of the velocity provides information about the amount of activity required to maintain postural stability (Corbeil, et al. 2003; Doyle, et al. 2007; Karlsson and Frykberg 2000; Winter, et al. 1998). Sway parameters related to the speed of displacement of the CoP have been used to compare various populations and conditions, such as healthy adults during standing posture, elderly subjects, the effect of fatigue, the effect of cutaneous impairment, Parkinson's disease, or lower-limb amputation (Corbeil, et al. 2003; Demura, et al. 2008; Kavounoudias, et al. 1999; Michel, et al. 2005; Michel and Do 2002; Raymakers, et al. 2005; Rocchi, et al. 2006). Across all of these studies, a common thread is that the velocity of the centre of mass (CoM) is higher when stepping up than when stepping down (Jones, et al. 2005). The acceleration of the CoP has also been used by other studies of the control of posture (Michel and Do 2002; Sorensen, et al. 2002; Winter, et al. 1998).

UNLOADING RATE:

Stacoff et al. (2005) described in their study an unloading rate at take-off. They compared young and elderly participants when ascending and descending stairs. They found a higher value for the unloading rate in elderly subject, which they interpreted as a less dynamic gait compared to younger subjects.

IMPULSE:

Measurement of impulse provides another group of parameters that are used to quantify balance quality. Impulse has been used previously in order to discriminate between groups such as elderly and younger adults (Buckley, et al. 2010; Michel-Pellegrino, et al. 2008b; Stacoff, et al. 2005). Impulse has also been found to show differences between conditions, with blurred vision producing greater impulse on the y-axis (Buckley, et al. 2005b), however impulses were not significantly different with reduced plantar sensation (Eils, et al. 2002).

FREQUENCY ANALYSIS:

Frequency analysis has been widely used to quantify balance, with a wide range of parameters computed. The frequency of dispersion has been shown to identify the level of postural control of a Parkinsonian population (Rocchi, et al. 2006). This parameter is a measure of the variability of the power spectral density. The median frequency of the spectrum of the CoP is a parameter that characterises the shape of the frequency spectrum (Rougier 2008). This parameter has been used, for instance Corbeil et al. (2003), who induced fatigue of the ankle plantar flexors and found a greater median frequency after fatiguing exercises. Similarly, Meyer et al. (2004) found an increase in median frequency of after forefoot anaesthesia. Cherng et al. (2003) also used the median frequency of the CoP to compare young children and adults. The observed a higher median frequency in adults, and concluded that young children had not yet not developed the ankle mechanism responsible for postural stabilisation.
Analysis of the power frequency, including median frequency has been performed in multiple studies, in order to gather information about the CoP trajectory (Corbeil, et al. 2003; Rocchi, et al. 2006; Rougier 2008) (Prieto, et al. 1993; Prieto, et al. 1996; Rocchi, et al. 2006). Some studies have shown a shift in the power frequency with age, and also for specific conditions such as fatigue, reduced foot plantar proprioception, or visual impairments (Cherng, et al. 2003; Corbeil, et al. 2003; Meyer, et al. 2004; Prieto, et al. 1993). (Uchiyama and Demura 2007).

Entropy is another frequency-related parameter often used to analyse the irregularity of human postural sway (Ramdani, et al. 2009). This parameter provides information on the temporal pattern of postural sway (Kirchner, et al. 2012) and the complexity of the signal. Entropy could also reflect any underlying impairment in postural control (Rigoldi, et al. 2013), with the persistence and divergence of the displacement of the CoP also identified (Van Dieen, et al. 2010). The measure of entropy was found to significantly decrease when subjects stood with their eyes closed when compared to the eyes open condition (Ramdani, et al. 2009). Entropy is also reduced in subjects with ligament laxity in comparison to healthy subjects (Rigoldi, et al. 2013).

THE HURST EXPONENT:

The Hurst coefficient has been described in studies as a means of analysing the temporal evolution of CoP displacement (Duarte and Zatsiorsky 2000). This parameter gives precise insights into the behaviour of the COP trajectory. Rougier compared the magnitude of the Hurst exponent compared to the median value (Rougier 2008), while Van Dieen et al. quantified the magnitude and persistence of CoP displacement using the Hurst exponent (Van

Dieen, et al. 2010). The Hurst exponent has also been used to interpret the SVMothness and correlation of the postural control (Kirchner, et al. 2012). In respect to applications, the Hurst coefficient has been used to assess the reliability of the CoP in different age groups (Lin, et al. 2008), with lower values observed for long-duration recording and higher values when subjects performed a dual-task condition of identifying missing icons (Kirchner, et al. 2012). Finally, Amoud et al. (2007a) compared the Hurst exponent with Detrended Fluctuation Analysis (DFA) and Stabilogramme Diffusion Analysis, and were able to identify differences in postural stability between control and elderly subject.

LYAPUNOV EXPONENT:

Another parameter often used to analyse balance is the Lyapunov exponent. Yamada (1995) used the Lyapunov exponent to show that the sway is more complex when swinging the arms during quiet stance, than when standing still. Pascolo and al. (2005) used correlation and the largest Lyapunov exponent but were not able to discriminate sway between healthy and Parkinsonian participants. Johansson et al. (2009) investigated the stability of postural sway using the Lyupanov exponent, while Van Dieen et al. (2010) quantified the divergence of CoP state space trajectories using a finite time Lyapunov exponent. However, this study reported a low reliability for Lyapunov and the Hurst exponent.

The results of the study showed that it was possible to discriminate between different impairments based on balance quality parameters. Similar results were found by Krafczyk et al. (2006), who were able to discriminate between young controls and subjects with vestibular impairment using a neural network model built using postural sway parameters. The parameters used in the present study included postural sway as well as parameters obtained from the stepping up and stepping down phases. Accordingly, the three types of parameters have been considered as balance quality parameters rather than simply postural sway parameters, since the parameters used include information pertaining to both static and dynamic balance. Krafczyk et al. (2006) were able to discriminate between three types of vestibular impairment, whereas in the present study it was possible to discriminate between a larger range of conditions including vestibular, visual, joint proprioception, range of motion, and cutaneous proprioception impairments as well as muscular fatigue. However, although single models were able to discriminate between several different conditions, it was not possible to construct a model to discriminate between all six impairments.

Note : computation of parameters

Considering the large number of files required to build a model, it would be of interest in the future and for further analysis of data from this study to optimise calculation of the balance parameters to reduce the processing time. Similarly, many of the studies mentioned in this thesis using balance parameters do no provide exact details related to the interpret of the parameters, meaning that a standardisation of calculation could improve further studies and allow the comparison of data between populations.

5.4 MODELS

5.4.1 FEATURE SELECTION

A large number of variables were available for inclusion in the models constructed, with close to 200 parameters calculated. Even though neural network models have been used in previous studies to handle large numbers of variables, it was necessary to reduce the number of variable to enhance the accuracy of the model (Harrell, et al. 1996). The use of feature selection enables irrelevant variables to be discarded, with only the most relevant parameters retained for classification (Chau 2001). Such a step also makes it possible to draw conclusions based on the individual parameters retained in the models developed.
In respect to other studies in which models have been developed in movement and balance analysis, few studies have used feature selection to reduce the number of parameters and increase accuracy. For instance, Shumway-Cook et al. (1997), who built a model to predict the probability of falls used a forward stepwise regression analysis to select the relevant parameters for the model. Begg and Kamruzzaman (2006), who used neural networks to detect and classify walking pattern changes due to ageing used a forward feature selection algorithm. Similarly, Rocchi et al. (2006), who investigated the identification of people with Parkinson's disease using postural sway, applied a feature selection procedure based on principal component analysis, obtaining a selection of five parameters.

In the present study feature selection was applied to each model tested. All 198 parameters were included in the feature selection process, with the number of variables chosen for each model varying from three to 20 or more variables, depending on the individual model. The feature selection methods used were those built into the Weka software, with two different classifiers used, namely logistic regression and support vector machine. The two methods were applied on each model in order to compare the selected variables and the accuracy of the model resulting from the selection. Somewhat surprisingly, the two methods of feature selection tended to produce markedly different selections of parameters. On average, the support vector machine method included more parameters than logistic regression method, with typically 5-25 and 3-10 parameters for the support vector machine and logistic regression methods, respectively. Not only was the number of parameters selected by each method different, the parameters chosen also differed markedly for most models. Although some models did have one to three parameters in common for the two methods of feature selection, most of our models constructed included completely different variables, according to the method of feature selection used. Interestingly, even though the variables selected were different for the two methods used, the accuracy of both training and testing for each model produced a similar accuracy for the two methods used. Unfortunately, to the best of our knowledge no other study has reported this type of finding in the field of balance, as no other study has reported the use or comparison of two feature selection methods. In other field, several algorithms are often used for feature selection, with the accuracy and effectiveness of the methods compared, such as in the study of Aha et al. (1994) on the classification of cloud for weather prevision. Similarly, in the study of Lewis et al. (1994), the classification of text to categorize natural language documents into predefined content categories compared different methods of feature selection. In both studies the methods procuring the highest accuracy were chosen for the interpretation of the final results.

It was expected that feature selection would enable a pattern of parameters specific to a condition to be identified, with each pattern able to be interpreted according to the parameters chosen. Consequently, each pattern would enable the models to discriminate between conditions by recognizing the appropriate pattern. For each model developed, for instance the three-condition model using fatigue, ankle range of motion, and cutaneous proprioception, different parameters were chosen. In this example, the support vector machine feature selections choose seven parameters (one stepping up, five static, one stepping down)

compared to the five parameters chosen by logistic regression (one stepping up, one static, three stepping down). Only one of the parameters was common to both methods. It should be noted that the randomised selection of cases into training and test sets was used once for each model, meaning that the same cases were used for the two feature selection procedures used to construct the models. After feature selection, the two sets of data containing the parameters selected were submitted to the same training step to build a model. The two models produced similar accuracy when averaged across all models, however differences were observed for individual models. It appears, therefore, that more than one pattern of parameters can discriminate between the conditions tested in this study. Given that no study has reported similar results. The differences are probably due to the methods used by the algorithms to perform the feature selection. Several studies have investigated the methods of feature selection. For instance, Langley et al. (1994), Blum and Langley (1997), Dash and Liu (Dash and Liu 1997), and Kudo and Sklansky (2000) all concluded in their studies that the different algorithms that are used for feature selection have their own search procedure to carry out the selection, and therefore need to be adapted to the objective of the selection. It also seems that algorithms need to be adapted to the size of the data set. A large number of various algorithms for feature selection have been exposed in these articles, with all of the algorithms showing specificities in terms of the objectives, the size of the data set, and the design-decision search procedure (Blum and Langley 1997; Dash and Liu 1997; Kudo and Sklansky 2000; Langley 1994).

In respect to the effect of feature selection on the accuracy of the models, other authors have reported improvements in accuracy. For instance, Begg et al. (2006), Rocchi et al. (2006) and Shumway-Cook et al. (1997), all reported improved accuracy of models after feature selection. In the present study, accuracy improved up to 16%, which seems a considerable improvement, especially since some models produced accuracy over 90% and are therefore considered as highly efficient.

5.4.2 MODEL ACCURACY

PERCENTAGE ACCURACY:

According to the results of models in the literature, it appears that an efficient model has accuracy at 70% and over. In the review by Chau (2001), model accuracies for gait prediction varied from 77-95 %. In other work, Song et al. (2004) obtained 79.2% accuracy for a model to predict survival in the elderly, while Krafczyk et al. (2006) obtained 87-98% accuracy for models to discriminate between vestibular impairments. Begg et al. (2006) reported an accuracy level of 83% for a model analysing gait, while Lin et al. (2010) had an accuracy of 86.8% for training and 71.91 for testing a model predicting mortality in the elderly. Finally, Lai et al. (2012) obtained an accuracy from 70-94% for a model to predict foot clearance during walking.

According to all of studies cited above, models with classification accuracy over 70% were considered to be effective. It should be noted that in many cases, the models developed in this thesis were required to distinguish between far more conditions than in previous studies. The more conditions classified, the harder it is to produce an accurate model. Training three-condition models typically gave accuracy levels from 75-93%, while testing the models gave accuracy from 65-86%. Those models including four conditions had training accuracy between 60-77%, with testing accuracy between 63-76%. Other models were tested with 5-10 conditions, but none of them reached acceptable accuracy levels. Such a finding is probably

due to an insufficient number of cases used to feed the models, with a corresponding decrease in the ratio of cases to conditions. Only 50 cases were available for each condition. A larger number of cases for the development of the model with more conditions would probably have improved the performance of model to discriminate between conditions.

It can also be noted that the studies in the literature do not always give precision on the accuracy presented, in respect to whether the accuracy comes from training or testing the models. In this thesis accuracy for both training and testing each model has been clearly presented. The accuracy results provided in this study showed that it was possible to build accurate model for multiple conditions, with more than twenty models obtaining accuracy levels as good as those found in the literature.

KAPPA COEFFICIENT:

The Kappa coefficient has been used as an assessment of the accuracy, however, to our knowledge, no study involving the construction of a model, such as ours purpose has used the Kappa coefficient. In this study, we used the Kappa coefficient combined to the % accuracy. The scale of magnitude use in this study defined a model showing a large validity when the % accuracy was at least 65 and the Kappa coefficient was at least 0.50. However, using both indices as assessment of accuracy showed that few models had percentage accuracy over 65% but showed a Kappa coefficient lower than 0.50. Therefore, the use of the two indicators allowed better assessment of the accuracy. In our study, the model with "large validity" have been used for further analysis, therefore a correct assessment of validity is essential for the selection of acceptable models to be further analysed.

5.4.3 MODEL VALIDITY

Internal and external validity were performed on the models.

It should be noted, that populations were tested in two different locations. The young control subjects used in Jodhpur and Auckland were selected using the same inclusion criteria, but obvious cultural and lifestyle differences exist between the two groups possibly leading to differences in balance. Even though two populations were available, it was not possible to use one population for training and the second population for testing as the number of subjects was insufficient and all of the additional cases from Auckland were needed for the development of the model. Given that two similar populations tested in different places were included in the data set, it seems reasonable to assume that the internal validity used with two populations would give a good approximation of the external validity of the models for generalization purposes within the same sample (young degraded). It seems clear, however, that testing a population with real impairment for the validation of the models would be highly beneficial.

External validity was performed with a different sample: the elderly. However, the testing was limited due to the few number of elderly cases that could be tested into the models. Indeed the elderly presented multiple impairments and most of them could not be classified into single condition.

Four elderly were placed in the impaired ankle RoM group. These four subjects were tested for the model including ankle RoM. The same procedure was followed for group of four elderly subjects placed in the vestibular disturbance group and similarly for the 2 elderly classified as visual acuity impaired.

It should be noted that the classification of elderly into their impaired condition was made manually and according to a score determined by the investigator. The remaining elderly

subjects tended to have multiple impairments of the conditions tested, with these subjects placed in groups representing their major impairment. This meant that the elderly subjects used in the testing part of the model did not only have ankle RoM or vestibular impairment, but also had other impairments even if present to a lesser extent. Therefore the models tested might have detected other impairments than the impairment detected by the score table. This could partly explain the low accuracy of most of the model when tested with new data.
Seven models were validated with the elderly data. It means that the models were able to determine the impairment of the elderly person tested. It seems obvious that a larger number of elderly is necessary for a better validation of models. Additionally, it would be important to build the model from impairment that really match the impairment found in elderly, therefore when testing elderly, the model wold probably provide better assessment of the impairment.

5.5 Relevance of the Thesis

The aim of the thesis was to create a model for six different intrinsic fall-risk factors, each of which was known to have an adverse effect on balance. The inputs to the model were balance parameters, with a specific pattern of parameters sought in order to identify the underlying factors behind each balance problem. The specific set of parameters for each condition would enable the reason underlying a balance problem and consequent fall risk to be identified. A force plate was used in the experimental work, however the Balance Quality Tester based on a bathroom scale could be used in a clinical setting. After identification of the specific problem, a targeted rehabilitation intervention could then be used to improve balance and therefore decrease the risk of falls.

In reality, this ambitious objective was partially attained but could not be fully attained for a number of reasons. Firstly, the populations tested, both the type of subjects and the number of subjects influenced the results. In respect to subject numbers, a total of 50 young control subjects were tested, with two different study populations from Auckland and Jodhpur. In order to develop a more accurate model that would have been able to discriminate between all of the different intrinsic factors tested, an additional 200 subjects might have been needed. Such an increase in subject numbers, although feasible in theory, would have required an additional 50 days of data collection if four subjects were tested per day, and an additional 320 days of non-stop data processing given the large number of experimental conditions and balance parameters that needed to be calculated. However, despite being limited to only 50 young control subjects, the best models were able to accurately discriminate between as many as four conditions.
Data from the elderly sample were entered into the models created in order to identify their impairments and demonstrate the effectiveness of the models. However, when the elderly data were used, it was difficult to classify the subjects according to the impairment they had. The obvious reason for this finding was that the elderly sample studied was not a *healthy* elderly population. The elderly subjects all had multiple impairments, meaning that models could not accurately classify them according to a single impairment. Furthermore, the elderly population of Indian subjects might not have been representative of other elderly populations. The 25 subjects tested, although not recruited specifically from a frail population, were in actual fact at high risk of falls. In total, 80% of subjects were identified as having a risk of falling due to their slow time for the TUG test. If only those elderly subjects who were not identified as having a fall risk by either of the tests are considered, only two subjects remained. The sample tested can therefore be considered to be at risk of falls.

An additional point related to the elderly subjects tested is worth considering. The elderly subjects were all Indian, thus giving rise to a possible difference due to sociocultural differences. For instance, the definitions used to classify elderly as frail or at risk of falls might not be appropriate for an Indian population. The percentage of the population identified at risk of falls is far greater than that typically found in an occidental population. Other differences between the elderly Indian population and an occidental population could include the prevalence of barefoot walking, thus leading to a decreased cutaneous proprioception, while the prevalence of yoga as a physical activity resulted in elderly subjects that were more flexible than expected

One of the key methods used in the study was an artificial degradation of intrinsic risk factors, with this data used to train and test the models to discriminate between conditions. A series of tests were used in order to quantify the impairments produced by these degradations, and thus ensure that young control subjects had really been degraded, and that the impairment was similar to that found in the elderly group. Although most of the degradations worked well, a couple of problems occurred. Firstly, not all of the tests used to identify the impairments were able to detect a change. This was the case for both vestibular and proprioceptive impairment, with the impairments having little or no discernible effect. Such a finding was most likely due to the sensitivity of the tests used to detect the impairments, which might not have been sufficiently sensitive. In the case of the proprioception test, the presence of the vibrators on the skin of the subjects during the test might have provided information related to the joint position tested, enabling subjects to achieve satisfactory results. However it seems likely that the vibrations applied directly to the tendons decreased balance quality, as reported in previous studies.

Another possible problem with the impairments was that in some cases, the degradations were too drastic, resulting in excessive or even total impairment. This was clearly the case for ankle range of motion, with subjects in both Jodhpur and Auckland being totally restricted in terms of the ankle dorsiflexion and plantar flexion. In contrast, the elderly subjects tested had similar range of motion to the young control subjects without impairment. The relatively good flexibility of the elderly subjects was contrary to reported differences in the literature in terms of the flexibility of elderly subjects. Such a difference could be due to cultural differences in terms of the type of physical activity performed, with the elderly subjects highly active, in particular regularly performing yoga, which would improve their flexibility. The other degradation that was excessive was visual depth perception. The impairment used was a total occlusion of one eye, effectively removing depth vision. Unfortunately, it was not possible to design a partial impairment for depth vision in this study. It seems therefore that the degradations performed on the young control did not always match the impairment of elderly which was the initial goal of the degradation.

Another interesting discussion point relates to the difference between the parameters identified using feature selection. The two methods used often selected completely different parameters, but still found the same results. Such a finding makes it difficult to identify a specific set of parameters to differentiate between impairments. However, it should be noted that many of the 198 parameters included in the analysis are highly correlated, meaning that many of the different parameters included in the different models developed with feature selection might have actually been measuring the same thing. For instance, the duration of the different phases such as the moment during the stepping up process when the subject lifts their second foot off the ground and the moment when this foot is placed onto the force plate

appear in different models, but have a correlation of 0.99. In such a case, the use of these parameters in a model would be effectively interchangeable. It could be possible to attempt to standardise the parameters selected by pre-selecting one parameter to represent a certain class of type of parameters, an approach that will be tested in future work.

Despite the problems outlined above, it is worth noting that the best models were able to distinguish between four different conditions with accuracy of 79%, and a Kappa coefficient of 0.77, which can be considered very large. The best models identified for the four-condition models all contained two conditions, namely fatigue and ankle ROM. Two other conditions were used in five of the nine models, cutaneous proprioception and visual contrast. Similarly, for the three-condition models, 95% of models included the ankle ROM condition, while the fatigue, visual contrast, and cutaneous proprioception conditions were found the most often. Such a finding makes it worthwhile to discuss why these conditions were the best at discriminating between groups. In respect to the most discriminative condition, ankle ROM, it should be noted that this impairment resulted in a total lack of ankle flexion, as opposed to a partial degradation. However, a total degradation of knee or hip joint ROM were never included in the models developed in Jodhpur, and for this reason were not included in the Auckland protocol. One interpretation is that an ankle strategy of postural control is the most involved in postural control, and a severely degraded ankle ROM will significantly decrease balance quality. The same finding holds true for fatigue, with this condition present in most of the better models. The fatigue condition, which was used to decrease muscle strength, was able to decrease the strength of young control subjects by around 30%. It was not possible to compare the strength impairment caused by the fatigue protocol, as elderly subjects were not evaluated with the same test as the young control subjects. Elderly subjects did not perform the MVC or counter-movement jump tests, instead performing the sit-to-stand test and a new "heels-up" test. Their results for these tests were significantly slower than those of young control subjects, averaging twice the time to perform the test. Unfortunately, the only tests performed after the fatigue protocol, were the MVC and counter-movement jump tests, with typical decreases in performance of the order of 30% observed. It seems likely that, although not tested, the young control subjects would have had similar decreases in performance in the other two tests, bringing them into line with the elderly subjects.

The third condition that was commonly observed was cutaneous proprioception. The impairment used was less pronounced than the difference observed with elderly subjects. In addition, different tests were used in Jodhpur and Auckland, due to the presence of a greater number of monofilaments in Auckland. The ice impairment used for the young control subjects of Jodhpur resulted in a small but significant decrease in cutaneous proprioception much less than that observed in the elderly population tested. This finding could have been due to lifestyle differences, in particular the prevalence of barefoot working among the elderly population. Despite the relatively modest reduction in cutaneous proprioception, this condition was included in some of the best models.

5.6 FUTURE RESEARCH

The results of this thesis bring up several questions that need to be answered, with a number of studies that could to undertaken. Firstly, the multiple impairments of the elderly population meant that it was difficult to validate the models' performance against an elderly population without greatly increasing the number of subjects tested. It seems necessary, therefore, to test a range of single impairments in one of the intrinsic risk factors identified in order to test the

performance of the models chosen. Another perspective that will be addressed is the difference between elderly populations in different countries. The published norms for clinical tests such as the TUG and tests of frailty such as that proposed by Fried and colleagues, do not seem to be applicable in India. To rectify this, a study is currently being planned with the All India Institute of Medical Science (AIIMS) Jodhpur and the Indian Institute of Technology Jodhpur (IITJ). This ambitious study will attempt to compare a range of clinical tests, identified by AIIMS, in both rural and urban areas of Indian. Part of the data collection will be undertaken by means of technological devices developed conjointly between UTT and IITJ.

Another interesting perspective is the possibility to study the effect of rehabilitation programmes on individual intrinsic factors. For instance, clear evidence exists regarding the decrease in fall risk after undertaking adapted physical activity programmes that target a specific factor such as strength or cutaneous proprioception. It would be interesting to target one or more factors by a specific intervention programme in order to validate the best models. It seems logical to start the first studies in this area by addressing the three conditions that feature in the majority of the best models, namely strength, ankle ROM, and cutaneous proprioception.

5.7 CONCLUSION

This work produced in this thesis has demonstrated that it is possible to create neural network and logistic regression models that can accurately discriminate between impairment of key intrinsic factors in fall risk in the elderly. The models developed were built using only balance quality parameters extracted from a force plate during stepping up, standing and stepping down phases. Models have been previously used to predict fall risk or to diagnose fallers, however those models were built from data requiring several assessments, which were either clinical tests, questionnaires, or self-reported health information. Such assessments require a large amount of time to perform, and cannot be completed in the standard eight-min clinical consultation. The test used in the present study took only 30s for data collection, including the stepping up, static balance, and stepping down phases. Although a force plate is not a tool available in everyday clinical practice, as was mentioned in the introduction to this thesis, the current work forms part of a larger project addressing fall risk. One of the key elements of the larger project is the development of a bathroom scale that can accurately replicate a force plate. This bathroom scale is an easily transportable and cheap alternative means of assessing balance, with near-identical results to a standard force plate. Such a device could therefore be used in everyday clinical practice once the appropriate algorithms have been included. It could be possible to routinely assess balance and detect any impairment and consequent risk of falls. In addition, the device can be used for self-measurement, meaning that longitudinal monitoring of at-risk elderly could be performed.

Other studies have built models using postural sway parameters to evaluate balance. However such models have typically included very few subjects. One of the original contributions of this thesis was the investigation of a large population range as well as a total of 10 different impairments that have been identified as intrinsic risk factors for falls. The detection of fall risk was, therefore, extended to a larger population than that found in the literature. In addition, studies of the literature that have used sway parameters for the quantification of balance proposed a small number of parameters within their analysis. In this thesis, a total of

198 parameters were tested, showing a thorough analysis of the data extracted from the force plate.

Twenty-five models including different combinations of degraded conditions provided high accuracy in both training and testing models. Although these models proved their performance and validity, some improvements need to be made before any generalisations can be made towards clinical practice. The acceptable models included only 3-4 impairments, while models with more conditions failing to be sufficiently accurate. Further studies are needed to investigate whether the models with high accuracy can be used in a series of successive steps in order to assess all the young degraded population, or whether improvements to the study and analysis could be performed to achieve a model that could identify all of the conditions with an acceptable accuracy. Were such model be developed successfully, it would be possible to diagnose specific impairments in elderly and thus propose a targeted early intervention, something that would be an attractive tool for the prevention of falls in daily clinical practice.

6 REFERENCES

Aalto, H., I. Pyykko, and J. Starck
1988 Computerized posturography, a development of the measuring system. Acta Oto-Laryngologica 105(s449):71-75.
Abdelhafiz, Ahmed H., and Christopher A. Austin
2003 Visual factors should be assessed in older people presenting with falls or hip fracture.
Acheson, J. F., and M. D. Sanders
1995 Vision. http://www.jnnp.com/.
Adachi, N., et al.
2002 Mechanoreceptors in the anterior cruciate ligament contribute to the joint position sense. http://informahealthcare.com.
Addis, Victoria M., Heather K. DeVore, and Michael E. Summerfield
2013 Acute Visual Changes in the Elderly. Clinics in Geriatric Medicine 29(1):165-180.
Agrawal, Yuri, et al.
2009 Disorders of balance and vestibular function in US adults. http://archinte.ama-assn.org/.
Aha, David W., and Richard L. Bankert
1994 Feature selection for case-based classification of cloud types: An empirical comparison. Proceedings of the AAAI worshop on case-based reasoning, Seattle, Washington, 1994.
Aizen, Efraim, and Elena Zlotver
2013 Prediction of falls in rehabilitation and acute care geriatric setting. Journal of Clinical Gerontology and Geriatrics 4(2):57-61.
Albracht, Kirsten, and Adamantios Arampatzis
2013 Exercise-induced changes in triceps surae tendon stiffness and muscle strength affect running economy in humans. European Journal of Applied Physiology 113(6):1605-1615.
Alfuth, Martin, and Dieter Rosenbaum
2011 Are diurnal changes in foot sole sensation dependent on gait activity?
Allen, T. J., and U. Proske
2006 Effect of muscle fatigue on the sense of limb position and movement.
Alpini, D., et al.
2004 Aging and vestibular system: Specific tests and role of melatonin in cognitive invovlement
Altman, Douglas G., and Patrick Royston
2000 What do we mean by validating a prognostic model? Statistics in Medicine 19(4):453-473.
Amiridis, L.G., et al.
2005 Static balance improvement in elderly after dorsiflexors electrostimulation training. European Journal of Applied Physiology 94(4):424-433.
Amoud, H.
2006 Detection d'une evolution du risque de chute chez les personnes agees, Optimisation et Surete des Systemes, France.
Amoud, H., et al.
2007a Fractal time series analysis of postural stability in elderly and control subjects. Journal of NeuroEngineering and Rehabilitation 4.
Amoud, H., et al.
2007b Intrinsic mode entropy for non linear discriminant analysis. IEEE Signal Processing letters 14(5).

Amoud, H., et al.
2008 Univariate and bivariate empirical mode decomposition for postural stability analysis. Eurasip Journal on Advances in Signal Processing 2008.
Anand, Vijay, et al.
2003a Postural stability changes in the elderly with cataract simulation and refractive blur. http://www.iovs.org.
—
2003b Postural stability in the elderly during sensory perturbations and dual tasking: the influence of refractive blur. Investigative Ophthalmology & Visual Science 44(7):2885-2891.
Anand, Vijay, et al.
2002 The effect of refractive blur on postural stability. Ophthalmic and Physiological Optics 22(6):528-534.
Arditi, A.
2005 Improving the design of the letter contrast sensitivity test. Investigative Ophthalmology & Visual Science 46(6):2225-2229.
Arfken, C. L., et al.
1994 Visual acuity, visual disabilities and falling in the elderly. Journal of Aging & Health 6(1):38-50.
Asai, Masatsugu, et al.
1993 Evaluation of vestibular function by dynamic posturography and other equilibrium examinations. Acta Oto-Laryngologica 113(s504):120-124.
Ashley-Jones, Cathryn
2009 National population projections: 2009 (base) -2061. http://www.stats.govt.nz/.
Baert, Veerle, et al.
2011 Motivators and barriers for physical activity in the oldest old: A systematic review. Ageing Research Reviews 10(4):464-474.
Baldi, Pierre, et al.
2000 Assessing the accuracy of prediction algorithms for classification: An overview. Bioinformatics 16(5):412-424.
Banez, C., et al.
2008 Development, implementation, and evaluation of an interprofessional falls prevention program for older adults. Journal of the American Geriatrics Society 56(8):1549-1555.
Baratto, L., et al.
2002 A new look at posturographic analysis in the clinical context: sway-density vs. other parameterization techniques. http://journals.humankinetics.com/mc.
Barker, A. L., et al.
2009 Measuring fall risk and predicting who will fall: clinimetric properties of four fall risk assessment tools for residential aged care. Journals of Gerontology Series A: Biological Sciences & Medical Sciences 64A(8):916-924.
Barker, Susan, et al.
2006 Accuracy, reliability, and validity of a spatiotemporal gait analysis system. Medical Engineering & Physics 28(5):460-467.
Bartlett, Harrison L., Lena H. Ting, and Jeffrey T. Bingham
2014 Accuracy of force and center of pressure measures of the Wii Balance Board. Gait & Posture 39(1):224-228.
Bassey, E.J., M.J. Bendall, and M. Pearson

1988 Muscle strength in the triceps surae and objectively measured customary walking activity in men and women over 65 years of age (abstract). Clinical Science 74(1):85-89.

Bauer, Christoph, et al.
2008 Intrasession reliability of force platform parameters in community-dwelling older adults. Archives of Physical Medicine and Rehabilitation 89(10):1977-1982.

Begg, R., and J. Kamruzzaman
2006 Neural network for detection and classification of working pattern changes due to ageing. http://www.springer.com/biomed/journal/13246.

Beling, J., and M. Roller
2009 Multifactorial intervention with balance training as a core component among fall-prone older adult. http://www.lww.com/product/?1539-8412.

Benvenuti, F., et al.
1999 Kinematic characteristics of standing disequilibrium: Reliability and validity of a posturographic protocol. Archives of Physical Medicine and Rehabilitation 80(3):278-287.

Berg, K.
1989 Balance and its measure in the elderly: A review. Physiotherapy Canada 41(5):240-246.

Bergin, P S, et al.
1995 Body sway and vibration perception thresholds in normal aging and in patients with polyneuropathy. Journal of Neurology, Neurosurgery & Psychiatry 58(3):335-340.

Bergman, Birgitta, and Johan Sjöstrand
2002 A longitudinal study of visual acuity and visual rehabilitation needs in an urban Swedish population followed from the ages of 70 to 97 years of age. Acta Ophthalmologica Scandinavica 80(6):598-607.

Berquin, A. D., et al.
2010 An adaptive procedure for routine measurement of light-touch sensitivity threshold. Muscle & Nerve 42(3):328-338.

Berry, Kenneth J., and Paul W. Mielke
1988 A Generalization of Cohen's Kappa Agreement Measure to Interval Measurement and Multiple Raters. Educational and Psychological Measurement 48(4):921-933.

Bird, Marie-Louise, et al.
2009 Effects of resistance- and flexibility-exercise interventions on balance and related measures in older adults. Journal of Aging & Physical Activity 17(4):444-454.

Bjorklund, M., et al.
2000 Position sense acuity is diminished following repetitive low-intensity work to fatigue in a simulated occupational setting. http://www.springer.com/biomed/human+physiology/journal/421.

Black, Alex A., et al.
2008 Visual impairment and postural sway among older adults with glaucoma. http://journals.lww.com/optvissci/pages/aboutthejournal.aspx.

Blain, H., et al.
2010 Balance and walking speed predict subsequent 8-year mortality independently of current and intermediate events in well-functioning women aged 75 years and older. http://www.springer.com/medicine/family/journal/12603.

Blanpain, Nathalie

2010 [in French] 15 000 centenaires en 2010 en France, 200 000 en 2060? http://www.insee.fr/fr/.

Bleijlevens, M. H. C., et al.
2010 Lessons learned from a multidisciplinary fall-prevention programme: The occupational-therapy element. Scandinavian Journal of Occupational Therapy 17(4):319-325.

Blum, Avrim L., and Pat Langley
1997 Selection of relevant features and examples in machine learning. Artificial Intelligence 97(1–2):245-271.

Boele van Hensbroek, P., et al.
2009 The CAREFALL Triage instrument identifying risk factors for recurrent falls in elderly patients. American Journal of Emergency Medicine 27(1):23-36.

Bohannon, Richard W.
1995 Sit to stand test for measuring performance of lower extremity muscles. Perceptual and Motor Skills 80(1):163-166.

Bohannon, Richard W.
2006 Reference values for the Timed Up and Go Test: A descriptive meta-analysis. Journal of Geriatric Physical Therapy 29(2):64-8.

Bottaro, M., et al.
2007 Effect of high versus low-velocity resistance training on muscular fitness and functional performance in older men. European Journal of Applied Physiology 99(3):257-264.

Boucher, Pierre, et al.
1995a Postural stability in diabetic polyneuropathy. Diabetes Care 18(5):638-645.

—
1995b Postural stability in diabetic polyneuropathy. http://care.diabetesjournals.org/.

Boulgarides, L. K., et al.
2003 Use of clinical and impairment-based tests to predict falls by community-dwelling older adults. http://ptjournal.apta.org/.

Brandt, Thomas, and Michael Strupp
2005 General vestibular testing. Clinical Neurophysiology 116(2):406-426.

Brauer, S.G., Y.R. Burns, and P. Galley
2000 A prospective study of laboratory and clinical measures of postural stability to predict community-dwelling fallers. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences 55(8):M469-M476.

Brown, Kevin D., James A. Koziol, and Martin MLotz
2008 A yoga based exercise program to reduce the risk of falls in seniors: A pilot and feasibility study. The Journal of Alternative Complementary Medicine 14(5):454-457.

Buatois, Severine, et al.
2010 A Simple Clinical Scale to Stratify Risk of Recurrent Falls in Community-Dwelling Adults Aged 65 Years and Older. http://www.ptjournal.org.ezproxy.aut.ac.nz

Buckley, J. G., et al.
2005a Does head extension and flexion increase postural instability in elderly subjects when visual information is kept constant? Gait & Posture 21(1):59-64.

Buckley, J. G., et al.
2005b The effects of blurring vision on medio-lateral balance during stepping up or down to a new level in the elderly.

Buckley, John G., Steven F. Jones, and Louise Johnson

2010 Age-differences in the free vertical moment during step descent. Clinical Biomechanics 25(2):147-153.

Bullock-Saxton, J. E., W. J. Wong, and N. Hogan
2001 The influence of age on weight-bearing joint reposition sense of the knee. Experimental Brain Research 136(3):400-406.

Burroughs, Brian R., et al.
2005 Range of Motion and Stability in Total Hip Arthroplasty With 28-, 32-, 38-, and 44-mm Femoral Head Sizes: An In Vitro Study. The Journal of Arthroplasty 20(1):11-19.

Byrt, Ted, Janet Bishop, and John B. Carlin
1993 Bias, prevalence and kappa. Journal of Clinical Epidemiology 46(5):423-429.

Cameron, I. D., et al.
2010 Interventions for preventing falls in older people in nursing care facilities and hospitals. http://www.mrw.interscience.wiley.com/cochrane/cochrane_clsysrev_articles_fs.html.

Campbell , A. J., et al.
1981 Falls in old age: A study of frequency and related clinical factors. Age and Ageing 10(4):264-270.

Campbell, A. J., et al.
2005 Randomised controlled trial of prevention of falls in people aged >75 with severe visual impairment: The VIP trial. British Medical Journal 331(7520):817-820.

Carpenter, M. G., C. D. Murnaghan, and J. T. Inglis
2010 Shifting the balance: Evidence of an exploratory role for postural sway.

Chang, Chih-Chung, and Chih-Jen Lin
2011 LIBSVM: A library for support vector machines. ACM Trans. Intell. Syst. Technol. 2(3):1-27.

Chang, J. T., and D. A. Ganz
2007 Quality indicators for falls and mobility problems in vulnerable elders. Journal of the American Geriatrics Society 55(SUPPL. 2):327-334.

Chang, J.T., et al.
2004 Interventions for the prevention of falls in older adults: Systematic review and meta-analysis of randomised clinical trials. http://www.bmj.com/.

Changela, P.K., K. Selvamani, and Ramaprahu
2012 A study to evaluate the effect of fatigue on knee joint proprioception and balance in healthy individuals. http://www.medicinasportiva.ro/SRoMS/english/Sport%20Medicine%20Journal.html.

Chatterji, Somnath, et al.
2008 The health of aging populations in China and India. Health Affairs 27(4):1052-1063.

Chau, Tom
2001 A review of analytical techniques for gait data. Part2: Neural network and wavelet methods. http://www.journals.elsevier.com/gait-and-posture/.

Chaudhry, Hans, et al.
2011 Measurement of balance in computer posturography: Comparison of methods—A brief review. Journal of Bodywork and Movement Therapies 15(1):82-91.

Cherng, R. J., H. Y. Lee, and F. C. Su
2003 Frequency spectral characteristics of standing balance in children and young adults. Medical Engineering & Physics 25(6):509-515.

Chester, J.B.

1991 Whiplash, postural control, and the inner ear. journals.lww.com/spinejournal/pages/default.aspx.

Chew, F. L. M., et al.
2010 The association between various visual function tests and low fragility hip fractures among the elderly: A Malaysian experience. Age and Ageing 39(2):239-245.

Chiu, E., et al.
2008 Visual Impairment in Elderly Patients Receiving Long-term Hemodialysis. American Journal of Kidney Diseases 52(6):1131-1138.

Chou, Roger, Tracy Dana, and Christina Bougatsos
2009 Screening Older Adults for Impaired Visual Acuity: A Review of the Evidence for the U.S. Preventive Services Task Force. http://www.annals.org/.

Choy, N.L., J.C. Nitz, and S.R. Hourigan
2004 A theoretical framework for the assessment and treatment of balance and mobility deficits in the elderly. *In* Physiotherapy Practice in Residential Aged Care. Pp. 156-190. Edinburgh: Butterworth-Heinemann.

Cohen, Jacob
1960 A Coefficient of agreement for nominal scales. Educational and Psychological Measurement 20(1):37-46.

Collins, J. J., and C. J. Luca
1993 Open-loop and closed-loop control of posture: A random-walk analysis of center-of-pressure trajectories. Experimental Brain Research 95(2):308-318.

Corbeil, Philippe, et al.
2003 Perturbation of the postural control system induced by muscular fatigue. Gait & Posture 18(2):92-100.

Cotter, P. E., et al.
2006 The financial implications of falls in older people for an acute hospital. http://www.springer.com/medicine/journal/11845.

Croxford, P., K. Jones, and K. Barker
1998 Technical clinical note. Inter-tester comparison between visual estimation and goniometric measurement of ankle dorsiflexion. http://informahealthcare.com/loi/ptp.

Cumming, R. G., et al.
2007 Improving vision to prevent falls in frail older people: A randomized trial. Journal of the American Geriatrics Society 55(2):175-181.

Cunningham, D. A., et al.
1993 Determinants of independence in the elderly (determinants de l'autonomie chez les personnes agees). Canadian Journal of Applied Physiology 18(3):243-254.

Dakin, C. J., et al.
2010 Frequency-specific modulation of vestibular-evoked sway responses in humans. Journal of Neurophysiology 103(2):1048-1056.

Dash, M., and H. Liu
1997 Feature Selection for Classification. Intelligent data analysis 1(3):131-156.

Daubney, M.E., and E.G. Culham
1999 Lower-extremity muscle force and balance performance in adults aged 65 years and older. http://www.ptjournal.org.

Day, B. L.
1999 Galvanic vestibular stimulation: New uses for an old tool. Journal of Physiology 517(3):631.

Delaune, M.F., and C. Ciolek
2007 Falls in community dwelling older adults: Examination and evaluation. http://www.apta.org/AM/Template.cfm?Section=Current_Issue1.

Demura, Shin-ichi, Tamotsu Kitabayashi, and Hiroki Aoki
2008 Body-sway characteristics during a static upright posture in the elderly. Geriatrics & Gerontology International 8(3):188-197.
Deshpande, Nandini, and Aftab Patla
2005 Postural responses and spatial orientation to neck proprioceptive and vestibular inputs during locomotion in young and older adults. Experimental Brain Research 167(3):468-474.
Deshpande, Nandini, and Aftab E. Patla
2007 Visual-vestibular interaction during goal directed locomotion: effects of aging and blurring vision. Experimental Brain Research. Experimentelle Hirnforschung. Expérimentation Cérébrale 176(1):43-53.
DiBenedetto, Margarete, et al.
2005 Effect of a gentle Iyengar yoga program on gait in the elderly: An exploratory study. Archives of Physical Medicine and Rehabilitation 86(9):1830-1837.
Dodrill, C.B.
1978 The hand dynamometer as a neuropsychological measure. http://www.apa.org/pubs/journals/ccp/index.aspx.
Dominguez, R. O., and A. M. Bronstein
2000 Assessment of unexplained falls and gait unsteadiness: The Impact of Age. Otolaryngologic Clinics of North America 33(3):637-658.
Donker, S.F., et al.
2007 Regularity of center of pressure trajectories depends on the amount of attention invested in postural control. Exp Brain Res 181:1-11.
Dougherty, B.E., R.E. Flom, and M. A. Bullimore
2005 An evaluation of the Mars Letter Contrast Sensitivity test. Optometry And Vision Science 82(11):970-975.
Doyle, Richard J., et al.
2007 Generalizability of center of pressure measures of quiet standing. Gait & Posture 25(2):166-171.
Dreiseitl, Stephan, and Lucila Ohno-Machado
2002 Logistic regression and artificial neural network classification models: a methodology review. Journal of Biomedical Informatics 35(5–6):352-359.
Duarte, Marcos, and Sandra M. S. F. Freitas
2010 Revision of posturography based in force plate for balance evaluation. Revista brasileira de fisioterapia 14(3):183-192.
Duarte, Marcos, and Vladimir M. Zatsiorsky
2000 On the fractal properties of natural human standing. Neuroscience Letters 283(3):173-176.
Duchene, J., et al.
2012 Procede, dispositif et systeme d`evaluation de la qualite de l`equilibre: Google Patents.
Duchêne, Jacques, and David J Hewson
2011 Longitudinal evaluation of balance quality using a modified bathroom scale: Usability and acceptability. Journal of Telemedicine and Telecare 17(8):421-426.
Dyck, P.J.
1988 Detection, characterization, and staging of polyneuropathy: Assessed in diabetics. Muscle & Nerve 11(1):21-32.
Eils, E., and D. Rosenbaum
2001 A multi-station proprioceptive exercise program in patients with ankle instability. http://www.acsm-msse.org.

Eils, Eric, et al.
2002 Modified pressure distribution patterns in walking following reduction of plantar sensation. Journal of Biomechanics 35(10):1307-1313.
Eklund, G.
1972 Position sense and state of contraction; the effects of vibration. Journal of Neurology, Neurosurgery & Psychiatry 35(5):606-611.
Elley, C. R., et al.
2007 Falls Assessment Clinical Trial (FACT): Design, interventions, recruitment strategies and participant characteristics. BMC Public Health 7.
Elliot, David B., et al.
1995 The Waterloo Vision and Mobility Study: postural control strategies in subjects with ARM. Ophthalmic and Physiological Optics 15(6):553-559.
Elliott, D. B., et al.
1996 Effect of a cataract simulation on clinical and real world vision. British Journal of Ophthalmology 80(9):799-804.
Emery, C. A.
2003 Is there a clinical standing balance measurement appropriate for use in sports medicine? A review of the literature. Journal of Science and Medicine in Sport 6(4):492-504.
Ewald, Ben, et al.
2009 Physical activity of older Australians measured by pedometry. Australasian Journal on Ageing 28(3):127-133.
Feinstein, Alvan R., and Domenic V. Cicchetti
1990 High agreement but low Kappa: I. the problems of two paradoxes. Journal of Clinical Epidemiology 43(6):543-549.
Fernie, G. R., et al.
1982 The relationship of postural sway in standing to the incidence of falls in geriatric subjects. Age and Ageing 11(1):11-16.
Fife, T. D., et al.
2000 Assessment: Vestibular testing techniques in adults and children - Report of the Therapeutics and Technology Assessment Subcommitte of the American Academy of Neurology. http://www.neurology.org.
Fitzpatrick, R. C., and B. L. Day
2004 Probing the human vestibular system with galvanic stimulation. Journal of Applied Physiology 96(6):2301-2316.
Foldvari, Mona, et al.
2000 Association of muscle power with functional status in community-dwelling elderly women. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences 55(4):M192-M199.
Fong, S.M., and G.Y. Ng
2006 The effects on sensorimotor performance and balance with Tai Chi training. Archives of Physical Medicine & Rehabilitation 87(1):82-87.
Forte, Roberta, and Andrea Macaluso
2008 Relationship between performance-based and laboratory tests for lower-limb muscle strength and power assessment in healthy older women. Journal of Sports Sciences 26(13):1431-1436.
Foss, A. J. E., et al.
2006 Falls and health status in elderly women following second eye cataract surgery: A randomised controlled trial. Age and Ageing 35(1):66-71.
Fransson, P. A., et al.

2003 Postural Control Adaptation during Galvanic Vestibular and Vibratory Proprioceptive Stimulation. IEEE Transactions on Biomedical Engineering 50(12):1310-1319.

Freitas, Sandra M. S. F., et al.
2005 Age-related changes in human postural control of prolonged standing. Gait & Posture 22(4):322-330.

Freudenberger Jett, Kathleen M., et al.
1996 The influence of community context on the decision to enter a nursing home. Journal of Aging Studies 10(3):237-254.

Fu, A.S.N., and C.W.Y. Hui-Chang
2005 Ankle joint proprioception and postural control in basketball players with bilateral ankle sprains. The American Journal of Sports Medicine 33(8):1174-1182.

Fujiwara, K., et al.
2006 Postural muscle activity patterns during standing at rest and on an oscillating floor. Journal of Electromyography and Kinesiology 16(5):448-457.

Futschik, Matthias E., et al.
2003 Prediction of clinical behaviour and treatment for cancers. http://link.springer.com/journal/40282.

Gajdosik, Richard L, and Richard W Bohannon
1987 Clinical measurement of range of motion: Review of goniometry emphasizing reliability and validity. http://ptjournal.apta.org/.

Galvan, Haydee G., et al.
2006 Pain Perception During Repeated Ice-Bath Immersion of the Ankle at Varied Temperatures. http://hk.humankinetics.com/JSR/journalAbout.cfm.

Gananca, F.F., et al.
2006 Circumstance and consequences of falls in elderly people with vestibular disorder. www.scielo.br/scielo,php?pid=0034-7299&script=sci_issues.

Garsden, L., and J. Bullock-Saxton
1999 Joint reposition sense in subjects with unilateral osteoarthritis of the knee. http://cre.sagepub.com/.

Gates, S., et al.
2008 Multifactorial assessment and targeted intervention for preventing falls and injuries among older people in community and emergency care settings: Systematic review and meta-analysis. BMJ 336(7636):130-133.

Gehlsen, G.M., D. Pearson, and R. Bahamonde
1991 Ankle joint strength, total work and ROM: Comparison between prophylactic devices. http://www.nata.org/journal-of-athletic-training.

Gescheider, G. A., S. J. Bolanowski, and R. T. Verrillo
2004 Some characteristics of tactile channels. Behavioural Brain Research 148(1-2):35-40.

Gongbing, Shan, Dayna Daniels, and Rongri Gu
2004 Artificial neural networks and center of pressure modeling: A prctical method for sensorimotor-degradation assessment. http://journals.humankinetics.com/japa.

Goodwin, A.W., and H.E. Wheat
2004 Sensory signals in neural populations underlying tactile perception and manipulation. Annual Review of Neuroscience 27(1):53-77.

Gopalakrishna Prabhu, K., et al.
2001 Parameters for analysis of walking foot pressures at different levels of diabetic neuropathy and detection of plantar ulcers at early stages. 3 vols. Volume 22. Paris, FRANCE: Elsevier.

Granacher, U., L Zahner, and A. Gollhofer
2008 Strength, power, and postural control in seniors: Considerations for functional adaptations and for fall prevention. European Journal of Sport Science 8(6):325-340.
Gras, L. Z., et al.
2004 A comparison of hip versus ankle exercises in elders and the influence on balance and gait. http://www.lww.com/product/?1539-8412.
Grommes, Christian, and Devon Conway
2011 The Stepping Test: A Step Back In History. Journal of the History of the Neurosciences 20(1):29-33.
Guerraz, M., and A.M. Bronstein
2008a Mechanisms underlying visually induced body sway. Neuroscience Letters 443(1):12-16.
Guerraz, M., and A.M. Bronstein
2008b Ocular versus extraocular control of posture and equilibrium. Neurophysiologie Clinique = Clinical Neurophysiology 38(6):391-398.
Hahn, Michael E., et al.
2005 Neural network estimation of balance control during locomotion. Journal of Biomechanics 38:717-724.
Hall, Mark, et al.
2009 The WEKA data mining software: an update. SIGKDD Explor. Newsl. 11(1):10-18.
Hansson, Eva Ekvall, Anders Beckman, and Anders Hakansson
2010 Effect of vision, proprioception, and the position of the vestibular organ on postural sway. Acta Oto-Laryngologica 130(12):1358-1363.
Harrell, FE, Kerry L Lee, and Daniel B Mark
1996 Tutorial in biostatistics multivariable prognostic models: issues in developing models, evaluating assumptions and adequacy, and measuring and reducing errors. http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1097-0258.
Harwood, R. H., et al.
2005 Falls and health status in elderly women following first eye cataract surgery: A randomised controlled trial. British Journal of Ophthalmology 89(1):53-59.
Harwood, Rowan H.
2001 Visual problems and falls. Age & Ageing 30:13-18.
HAS
2005 Prévention des chutes accidentelles chez la personne âgée. http://www.has-sante.fr/.
Hayes, K., et al.
2001 Reliability of five methods for assessing shoulder range of motion. http://www.sciencedirect.com/science/journal/00049514.
Haynes, S.A., et al.
2006 The Letter Contrast Sensitivity test: Clinical evaluation of a new design. Investigative Ophthalmology & Visual Science 47(6):2739-2745.
Hedley, L., et al.
2010 Staying Steady: A community-based exercise initiative for falls prevention. Physiotherapy Theory and Practice 26(7):425-438.
Helbostad, J. L., et al.
2009 Altered vision destabilizes gait in older persons.
Hendriks, Marike R. C., et al.

2008 Lack of effectiveness of a multidisciplinary fall-prevention program in elderly people at risk: A randomized, controlled trial. Journal of the American Geriatrics Society 56(8):1390-1397.

Herdman, S. J., et al.
2000 Falls in patients with vestibular deficits. www.journals.elsevierhealth.com/periodicals/yajot.

Hertel, Jay N., et al.
1996 Effect of lateral ankle joint anesthesia on center of balance, postural sway and joint position sense. http://journals.humankinetics.com/jsr-contents.

Hewson, D. J., et al.
2013 Development of a monitoring system for physical frailty in independent elderly. Engineering in Medicine and Biology Society (EMBC), 2013 35th Annual International Conference of the IEEE, 2013, pp. 6215-6218.

Hohne, Angela, et al.
2011 Effects of reduced plantar cutaneous afferent feedback on locomotor adjustments in dynamic stability during perturbed walking.

Holm, I., et al.
2000 Reliability of goniometric measurements and visual estimates of hip ROM in patients with osteoarthrosis. http://interscience.wiley.com/jpages/1358-2267.

Honaker, J. A., et al.
2009 Fukuda stepping test: sensitivity and specificity. Journal of the American Academy of Audiology 20(5):311-314.

Hong, Y., and J.X. Li
2007 Biomechanics of Tai Chi: A review. Sports Biomechanics 6(3):453-464.

Hopkins, W.G.
2000 A new view of statistics. http://www.sportsci.org/resource/stats/.

Horak, F.B., S.M. Henry, and A. Shumway-Cook
1997 Postural perturbations: New insights for treatment of balance disorders. http://www.ptjournal.org.

Horak, F.B., L.M. Nashner, and H.C. Diener
1990 Postural strategies associated with somatosensory and vestibular loss.

Horak, Fay B., Dicksteinm Ruth, and Peterkam Robert J.
2002 Diabetic neuropathy and surface sway-referencing disrupt somatosensory information for postural stability in stance. Somatosensory & Motor Research 19(4):316-326.

Hurley, M. V., J. Rees, and D. J. Newham
1998 Quadriceps function, proprioceptive acuity and functional performance in healthy young, middle-aged and elderly subjects. http://ageing.oxfordjournals.org/.

Iles, John F., et al.
2007 Human standing and walking: comparison of the effects of stimulation of the vestibular system. Experimental Brain Research 178(2):151-166.

INPES
2008 Prevention of falls in the elderly living at home: Good practice guide. http://www.inpes.sante.fr/.

Ivanenko, Yuri P., Renato Grasso, and Francesco Lacquaniti
1999 Effect of gaze on postural responses to neck proprioceptive and vestibular stimulation in humans. J. Physiol. 519(1):301-314.

Ivers, R.Q., P. Mitchell, and R.G. Cumming
2000 Visual function tests, eye disease and symptoms of visual disability: A population-based assessment. Clinical & Experimental Ophthalmology 28(1):41-47.

Iwasaki, T., et al.
2003 The ageing of human Meissner's corpuscles as evidenced by parallel sectioning.
Jacobson, G. P., et al.
2008 Significant vestibular system impairment is common in a cohort of elderly patients referred for assessment of falls risk. Journal of the American Academy of Audiology 19(10):799-807.
Johansen, A., S. White, and P. Waraisch
2003 Screening for visual impairment in older people: Validation of the Cardiff Acuity Test. Archives of Gerontology and Geriatrics 36(3):289-293.
Johansson, R., P.A. Fransson, and M. Magnusson
2009 Optimal coordination and control of posture and movements. Journal of Physiology-Paris 103(3-5):159-177.
Jones, S. F., et al.
2005 The gait initiation process in unilateral lower-limb amputees when stepping up and stepping down to a new level. Clinical Biomechanics 20(4):405-413.
Karlberg, Mikael, et al.
2002 Vibration-induced shift of the subjective visual horizontal: a sign of unilateral vestibular deficit. http://archotol.ama-assn.org/.
Karlsson, Annica, and Gunilla Frykberg
2000 Correlations between force plate measures for assessment of balance. Clinical Biomechanics 15(5):365-369.
Kars, H.J.J, et al.
2009 The effect of reduced Somatosensation on standing balance: A systematic review. http://www.journalofdst.org/.
Kasabov, Nikola, et al.
2013 Dynamic evolving spiking neural networks for on-line spatio- and spectro-temporal pattern recognition. Neural Networks 41(0):188-201.
Kasabov, Nikola K., et al.
1997 FuNN/2—A fuzzy neural network architecture for adaptive learning and knowledge acquisition. Information Sciences 101(3–4):155-175.
Katz, Michael J, and Edwin B George
1985 Fractals and the analysis of growth paths. Bulletin of Mathematical Biology 47(2):273-286.
Kavounoudias, Anne, Regine Roll, and Jean-Pierre Roll
1999 Specific whole-body shifts induced by frequency-modulated vibrations of human plantar soles.
Kennedy, P.M., and J. T. Inglis
2002 Distribution and behaviour of glabrous cutaneous receptors in the human foot sole. The Journal Of Physiology 538(Pt 3):995-1002.
Kernozek, Thomas W., et al.
2008 The effect of immersion cryotherapy on medial-lateral postural sway variability in individuals with a lateral ankle sprain. Physiotherapy Research International 13(2):107-118.
Kerrigan, D. Casey, et al.
1998 Biomechanical gait alterations independent of speed in the healthy elderly: Evidence for specific limiting impairments. Archives of Physical Medicine and Rehabilitation 79(3):317-322.
Khashei, Mehdi, Ali Zeinal Hamadani, and Mehdi Bijari

2012 A novel hybrid classification model of artificial neural networks and multiple linear regression models. Expert Systems with Applications 39(3):2606-2620.

Kirchner, M., et al.
2012 Evaluation of the temporal structure of postural sway fluctuations based on a comprehensive set of analysis tools. Physica A: Statistical Mechanics and its Applications 391(20):4692-4703.

Kniestedt, Christoph, and Robert L. Stamper
2003 Visual acuity and its measurement. Ophthalmology Clinics Of North America 16(2):155.

Kohavi, Ron, and George H. John
1997 Wrappers for feature subset selection. Artificial Intelligence 97(1–2):273-324.

Kou-Yuan, Huang
1994 Sequential classification by perceptrons and application to net pruning of multilayer perceptron. Neural Networks, 1994. IEEE World Congress on Computational Intelligence., 1994 IEEE International Conference on, 1994. Vol. 1, pp. 561-566 vol.1.

Kraemer, Helena Chmura
1980 Extension of the Kappa coefficient. Biometrics 36(2):207-216.

Krafczyk, Siegbert, et al.
1999 Increased body sway at 3.5–8 Hz in patients with phobic postural vertigo. Neuroscience Letters 259(3):149-152.

Krafczyk, Siergbert, et al.
2006 Artificial neural network: A diagnostic posturographic tool for disorders of stance. Clinical Neurophysiology 117:1692-1698.

Kudo, Mineichi, and Jack Sklansky
2000 Comparison of algorithms that select features for pattern classifiers. http://www.journals.elsevier.com/pattern-recognition/.

Kumar, Vinod
2003 Health status and health care services among older persons in India. Journal of Aging & Social Policy 15(2-3):67-83.

Lafond, Danik, et al.
2004 Intrasession reliability of center of pressure measures of postural steadiness in healthy elderly people. Archives of Physical Medicine and Rehabilitation 85(6):896-901.

Lai, Daniel T. H., Simon B. Taylor, and Rezaul K. Begg
2012 Prediction of foot clearance parameters as a precursor to forecasting the risk of tripping and falling. Human Movement Science 31(2):271-283.

Lamoureux, E., et al.
2010 The relationship between visual function, duration and main causes of vision loss and falls in older people with low vision. Graefe's Archive for Clinical and Experimental Ophthalmology 248(4):527-533.

Landis, J. Richard, and Gary G. Koch
1977 The measurement of observer agreement for categorical data. Biometrics 33(1):159-174.

Langley, Pat
1994 Selection of relevant features in machine learning. Proceedings of the AAAI Fal l Symposium on Relevance, New Orlean, LA, 1994. AAAI Press.

LaRoche, D.P., et al.

2010 Rapid torque development in older female fallers and nonfallers: A comparison across lower-extremity muscles. Journal of Electromyography and Kinesiology 20(3):482-488.

Lattanzio, P. J., et al.
1997 Effects of fatigue on knee proprioception. http://journals.lww.com/cjsportsmed/pages/issuelist.aspx.

Le Bozec, S., and S. Bouisset
2004 Does the postural chain mobility influence muscular control on sitting ramp pushes? Experimental Brain Research 158(4):427-437.

Le Clair, K., and C. Riach
1996 Postural stability measures: What to measure and for how long. Clinical Biomechanics 11(3):176-178.

Lee, H. K. M., and R. J. Scudds
2003 Comparison of balance in older people with and without visual impairment. http://ageing.oxfordjournals.org/.

Lephart, S.M., D.M. Pincivero, and S.L. Rozzi
1998 Proprioception of the ankle and knee. http://sportsmedicine.adisonline.com/pt/.

Lewis, David D., and Marc Ringuette
1994 A comparison of two learning algorithms for text categorization. Third annual symposium on document analysis and information retrieval, Las Vegas, Nevada, 1994. Vol. 33.

Lin, Chen Chiang, et al.
2010 Comparison of artificial neural network and logistic regression models for predicting mortality in elderly patients with hip fracture. Injury 41(8):869-873.

Lin, Dingding, et al.
2008 Reliability of COP-based postural sway measures and age-related differences. Gait & Posture 28(2):337-342.

Lisboa, P. J. G.
2002 A review of evidence of health benefit from artificial neural networks in medical intervention. Neural Networks 15(1):11-39.

Lord, S. R., et al.
2005 The effect of an individualized fall prevention program on fall risk and falls in older people: A randomized, controlled trial. Journal of the American Geriatrics Society 53(8):1296-1304.

Lord, S.R.
2006 Visual risk factors for falls in older people. Age Ageing 35(suppl_2):ii42-45.

Lord, S.R., R.D. Clark, and I. W. Webster
1991a Visual acuity and contrast sensitivity in relation to falls in an elderly population. Age Ageing 20(3):175-181.

Lord, S.R., R.D. Clark, and I.W. Webster
1991b Postural stability and associated physiological factors in a population of aged persons. Journal Of Gerontology 46(3):8-M69.

Lord, S.R., and H.B. Menz
2000 Visual contributions to postural stability in older adults. Gerontology 46(6):306-310.

Lord, S.R., C. Sherrington, and H.B. Menz
2002 Falls in older people: Risk factors and strategies for prevention. Cambridge, England: Cambridges University Press.

Lundborg, G. N., et al.

2010 Cutaneous anaesthesia of the lower leg can improve sensibility in the diabetic foot. A double-blind, randomized clinical trial. Diabetic Medicine 27(7):823-829.
Macefield, V.G.
2005 Physiological characteristics of low-threshold mechanoreceptors in joints, muscle and skin in human subjects. http://www.blackwellpublishing.com/journals/CEP.
MacIntosh, G., and J. Joy
2007 Assessing falls in older people. http://nursingolderpeople.rcnpublishing.co.uk.
Maclure, Malcom, and Walter C. Willet
1987 Misinterpretation and misuse of the Kappa statistic. American Journal of Epidemiology 126(2):161-169.
Margolis, M. K. , et al.
2002 Vision-specific instruments for the assessment of health-related quality of life and visual functioning: A literature review. Article, http://adisonline.com/pharmacoeconomics/pages/default.aspx.
Markhede, Goran, and Lars Nistor
1979 Strength of plantar flexion and function after resection of various parts of the triceps surae muscle. Acta Orthopaedica 50(6):693-697.
Markovic, Goran, et al.
2004 Reliability and factorial validity of squat and countermovement jump tests. http://www.nsca-jscr.org/.
Matheson, A. J., C. L. Darlington, and P. F. Smith
1999 Dizziness in the elderly and age-related degeneration of the vestibular system. http://www.psychology.org.nz/NZ_Journal.
Matsumoto, Hiromi, et al.
2012 Fall incidence and risk factors in patients after total knee arthroplasty. Archives of Orthopaedic and Trauma Surgery 132(4):555-563.
Maurer, C., et al.
2001 Human balance control during cutaneous stimulation of the plantar soles. Neuroscience Letters 302(1):45-48.
Mayagoitia, Ruth E., et al.
2002 Standing balance evaluation using a triaxial accelerometer. Gait & Posture 16(1):55-59.
McDonnell, M., and A. Warden-Flood
2000 Effect of partial foot anaesthesia on normal gait. http://www.physiotherapy.asn.au/index.php/quality-practice/ajp/about-ajp.
McGlone, Francis, and David Reilly
2010 The cutaneous sensory system. Neuroscience & Biobehavioral Reviews 34(2):148-159.
McKeon, P.O., and J. Hertel
2007a Diminushed plantar cutaneous sensation and postural control. Perceptual and Motor Skills 104(1):56-66.
McKeon, P.O., and J. Hertel
2007b Plantar hypoesthesia alters time-to-boundary measures of postural control. Spomatosensory and Motor Research 24(4):171-177.
McKeon, P.O., et al.
2008 Balance Training Improves Function and Postural Control in Those with Chronic Ankle Instability. Medicine & Science in Sports & Exercise 40(10):1810-1819.
McLean, B.D., et al.

2010 Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. International Journal of Sports Physiology and Performance 5(3):367-383.

Mecagni, C., et al.
2000 Balance and ankle range of motion in community-dwelling women aged 64 to 87 years: A correlational study. http://www.ptjournal.org.

Melzer, I., N. Benjuya, and J. Kaplanski
2004 Postural stability in the elderly: a comparison between fallers and non-fallers. Age and Ageing 33(6):602-607.

Menz, H.B., M.E. Morris, and S.R. Lord
2006 Foot and ankle risk factors for falls in older people: A prospective study. http://biomed.gerontologyjournals.org/.

Mergner, T., et al.
2009 Posture control in vestibular-loss patients. Annals of the New York Academy of Sciences 1164:206-215.

Meshkati, Zohreh, et al.
2011 Reliability of force-platform measures of postural sway and expertise-related differences. http://journals.humankinetics.com/jsr-contents.

Meyer, P.F., L.I.E. Oddsson, and C.J. De Lucas
2004 The role of plantar cutaneous sensation in unperturbed stance. Experimental Brain Research 156(4):505.

Michel-Pellegrino, V., et al.
2006 Identification of a degradation in postural equilibrium invoked by different vibration frequencies on the tibialis anterior tendon. Annual International Conference of the IEEE Engineering in Medicine and Biology - Proceedings, New York, NY, 2006, pp. 4047-4050.

Michel-Pellegrino, V., et al.
2008a Stepping down backward as a mean of detecting biomechanical differences between healthy older and younger adults. http://www.springer.com/medicine/family/journal/40520.

Michel-Pellegrino, V., et al.
2009 Techniques d'évaluation à domicile de la qualité de l'équilibre et de la force de préhension chez la personne âgée en perte d'autonomie. IRBM 30(5-6):262-267.

Michel-Pellegrino, Valérie, et al.
2008b Biomechanical Analysis of Older Adults Stepping Up: A Method of Evaluating Balance. http://journals.humankinetics.com/japa-contents.

Michel, V., et al.
2005 2.19 The effect of age on dynamic postural equilibrium when stepping up. Gait & Posture 21, Supplement 1(0):S9-S10.

Michel, V., and M. C. Do
2002 Are stance ankle plantar flexor muscles necessary to generate propulsive force during human gait initiation?

Miller, C. P., et al.
2010 Soft and rigid collars provide similar restriction in cervical range of motion during fifteen activities of daily living. Spine 35(13):1271-1278.

Missaoui, B., et al.
2008 Posture and equilibrium in orthopedic and rheumatologic diseases. Clinical Neurophysiology 38(6):447-457.

Moreland, J., et al.

2003 Evidence-based guidelines for the secondary prevention of falls in older adults. Gerontology 49(2):93-116.
Munn, J., S. J. Sullivan, and A.G. Schneiders
2010 Evidence of sensorimotor deficits in functional ankle instability: A systematic review with meta-analysis. Journal of Science and Medicine in Sport 13(1):2-12.
Muyor, José M.
2013 Exercise intensity and validity of the ratings of perceived exertion (Borg and OMNI Scales) in an indoor cycling session. Journal of Human Kinetics 39:93-101.
Neeter, Camille, et al.
2006 Development of a strength test battery for evaluating leg muscle power after anterior cruciate ligament injury and reconstruction. Knee Surgery, Sports Traumatology, Arthroscopy 14(6):571-580.
Nehme, Ziad, Malcolm J. Boyle, and Ted Brown
2013 Diagnostic accuracy of prehospital clinical prediction models to identify short-term outcomes in patients with acute coronary syndromes: A systematic review. The Journal of Emergency Medicine 44(5):946-954.e6.
Newell, K. M., et al.
1993 On postural stability and variability. Gait & Posture 1(4):225-230 - Abstract.
Noda, M., and S. I. Demura
2007 Influence of lower leg muscle fatigue on the centre of pressure in a static upright posture. European Journal of Sport Science 7(3):135-141.
Nyabenda, A., et al.
2004 A Normative Study of the Vestibulospinal and Rotational Tests. Advances in Physiotherapy 6(3):122-129.
Ohno-Machado, Lucila, and Todd Rowland
1999 Neural network application in physical medicine and rehabilitation. http://journals.lww.com/ajpmr/pages/default.aspx
Oliver, D., et al.
2004 Risk factors and risk assessment tools for falls in hospital in-patients: a systematic review. Age & Ageing 33(2):122-130.
Paillex, R., and A. So
2005 Changes in the standing posture of stroke patients during rehabilitation. Gait & Posture 21(4):403-409.
Pascolo, Paolo B., et al.
2005 Posture as a chaotic system and an application to the Parkinson's disease. Chaos, Solitons & Fractals 24(5):1343-1346.
Patel, M., et al.
2008 The effect of foam surface properties on postural stability assessment while standing. Gait & Posture 28(4):649-656.
Patino, C. M., et al.
2010 Central and peripheral visual impairment and the risk of falls and falls with injury. Ophthalmology 117(2).
Paulus, W., et al.
1989 Visual postural performance in ametropia and with optical distortion produced by bifocals and multifocals. Acta Oto-Laryngologica 108(s468):243-246.
Pedalini, M. E. B., et al.
2009 Sensory organization test in elderly patients with and without vestibular dysfunction. Acta Oto-Laryngologica 129(9):962-965.
Perry, M.C., et al.

2007 Strength, power output and symmetry of leg muscles: Effect of age and history of falling. European Journal of Applied Physiology 100(5):553-561.

Perry, Stephen, D.
2006 Evaluation of age-related plantar-surface insensitivity and onset age of advanced insensitivity in older adults using vibratory and touch sensation tests. Neuroscience Letters 392(1-2):62-67.

Perry, Stephen D., William E. McIlroy, and Brian E. Maki
2000 The role of plantar cutaneous mechanoreceptors in the control of compensatory stepping reactions evoked by unpredictable, multi-directional perturbation. Brain Research 877(2):401-406.

Petrella, R. J. , P. J. Lattanzio, and M. G. Nelson
1997 Effect of age and activity on knee joint proprioception. http://www.amjphysmedrehab.com.

Picard, Richard R., and Kenneth N. Berk
1990 Data Splitting. The American Statistician 44(2):140-147.

Piirtola, M., and P.i Era
2006 Force Platform Measurements as Predictors of Falls among Older People: A Review. Gerontology 52(1):1-16.

Pijnappels, M., M.F. Bobbert, and J.H. Van Dieen
2005 Push-off reactions in recovery after tripping discriminate young subjects, older non-fallers and older fallers. Gait & Posture 21(4):388-394.

Pinsault, Nicolas, and Nicolas Vuillerme
2009 Test–retest reliability of centre of foot pressure measures to assess postural control during unperturbed stance. Medical Engineering & Physics 31(2):276-286.

Platt, J.C.
1998 A fast algorithm for training support vector machines. Microsoft Research.

Podsiadlo, D., and S. Richardson
1991 The timed "Up & Go": A test of basic functional mobility for frail elderly persons (abstract). http://europepmc.org/.

Prieto, T. E., J. B. Myklebust, and B. M. Myklebust
1993 Characterization and modeling of postural steadiness in the elderly: A review. Rehabilitation Engineering, IEEE Transactions on 1(1):26-34.

Prieto, T. E., et al.
1996 Measures of postural steadiness: Differences between healthy yong and elderly adults. Biomedical Engineering; IEEE 43(9):Abstract.

Proske, U., A. K. Wise, and J. E. Gregory
2000 The role of muscle receptors in the detection of movements. Progress in Neurobiology 60(1):85-96.

Purcell, S. B., et al.
2009 Differences in ankle range of motion before and after exercise in 2 tape conditions. American Journal of Sports Medicine 37(2):383-389.

Pyykko, I., et al.
1989 Hierarchy of different muscles in postural control. http://informahealthcare.com/oto.

Quinlan, J. Ross
1986 Induction of decision trees. http://ijcai.org/.

Ramdani, Sofiane, et al.
2009 On the use of sample entropy to analyze human postural sway data. Medical Engineering & Physics 31(8):1023-1031.

Randall, D.L., and J.J. Gerhardt

1995 Current concepts review: Range of motion measurements. http://jbjs.org/.
Ray, C.T., and S.L. Wolf
2008 Review of intrinsic factors related to fall risk in individuals with visual impairments. Journal of Rehabilitation Research & Development 45(8):1117-1124.
Raymakers, J. A., M. M. Samson, and H. J. J. Verhaar
2005 The assessment of body sway and the choice of the stability parameter(s). Gait & Posture 21(1):48-58.
Rigoldi, Chiara, et al.
2013 Measuring regularity of human postural sway using approximate entropy and sample entropy in patients with Ehlers–Danlos syndrome hypermobility type. Research in Developmental Disabilities 34(2):840-846.
Rizzo, J. A., et al.
1998 Health Care Utilization and Costs in a Medicare Population by Fall Status. http://www.lww-medicalcare.com.
Roberts, David, et al.
2003 Effects of Short-Term Cycling on Knee Joint Proprioception in Healthy Young Persons. http://www.sagepub.com/journalsProdDesc.nav?prodId=Journal201672.
Rocchi, Laura, et al.
2006 Identification of distinct characteristics of postural sway in Parkinson's disease: A feature selection procedure based on principal component analysis. Neuroscience Letters 394(2):140-145.
Rogers, M. W., et al.
2001 Passive tactile sensory input improves stability during standing. Experimental Brain Research 136(4):514-522.
Rogind, H., et al.
2003 Comparison of Kistler 9861A force platform and Chattecx Balance System® for measurement of postural sway: Correlation and test-retest reliability. http://au.wiley.com/WileyCDA/WileyTitle/productCd-SMS.html.
Rothstein, J.M., R.L. Lamb, and T.P Mayhew
1987 Clinical uses of isokinetic measurements: Critical issues. http://ptjournal.apta.org/.
Rougier, P. R.
2008 What insights can be gained when analysing the resultant centre of pressure trajectory? Neurophysiologie Clinique/Clinical Neurophysiology 38(6):363-373.
Rubenstein, L.Z.
2006 Falls in older people: epidemiology, risk factors and strategies for prevention. Age and Ageing 35(suppl 2):ii37-ii41.
Rubenstein, Laurence, Z., and Karen R. Josephson
2002 The epidemiology of falls and syncope. Clinics in Geriatric Medicine 18(2):141-158.
Ruck, D. W., et al.
1990 The multilayer perceptron as an approximation to a Bayes optimal discriminant function (abstract only). Neural Networks, IEEE Transactions on 1(4):296-298.
Rydwik, Elisabeth, et al.
2011 Psychometric properties of Timed Up and Go in elderly people: A systematic review. Physical & Occupational Therapy in Geriatrics 29(2):102-125.
Sapstead, Gareth, and Michael J. Duncan
2013 Acute effect of isometric mid-thigh pulls on postactivation potentiation during stretch-shortening cycle and non-stretch-shortening cycle vertical jumps. Medicina Sportiva 17(1):7-12.

Šarabon, Nejc, Boštjan Mlaker, and Goran Markovic
2010 A novel tool for the assessment of dynamic balance in healthy individuals. Gait & Posture 31(2):261-264.
Satariano, William A., et al.
2012 Mobility and aging: New directions for public health action. http://ajph.aphapublications.org/.
Savelberg, H.H.C.M., and A.L.H. De Lange
1999 Assessment of the horizontal, fore aft component of the ground reaction force from insole pressure patterns by using artificial neural networks. http://www.journals.elsevier.com/clinical-biomechanics/.
Schabrun, S. M., and S. Hillier
2009 Evidence for the retraining of sensation after stroke: a systematic review. Clinical Rehabilitation 23(1):27-39.
Schmid, Stefan, Marilyn Moffat, and Gregory M. Gutierrez
2010 Effect of knee joint cooling on the electromyographic activity of lower extremity muscles during a plyometric exercise. Journal of Electromyography and Kinesiology 20(6):1075-1081.
Scinicariello, A. P., J. T. Inglis, and J. J. Collins
2002 The effects of stochastic monopolar galvanic vestibular stimulation on human postural sway. http://www.iospress.nl/loadtop/load.php?isbn=09574271.
Sekir, U., et al.
2007 Effect of isokinetic training on strength, functionality and proprioception in athletes with functional ankle instability. Knee Surgery, Sports Traumatology, Arthroscopy 15(5):654-664.
Sepic, Susan B., et al.
1986 Strength and Range of Motion in the Ankle in Two Age Groups of Men and Women. http://journals.lww.com/ajpmr/pages/default.aspx.
Services, U.S Health Human
2008 2008 Physical activity: Guidelines for Americans. U.S.H.H. Services, ed. Be active, Healthy and Happy. Washington DC.
Shaffer, S.W., and A.L. Harrison
2007 Aging of the Somatosensory System: A Translational Perspective. http://www.ptjournal.org.
Shimba, Takeshi
1984 An estimation of center of gravity from force platform data. Journal of Biomechanics 17(1):53-60.
Shin, Jong.T., et al.
2008 The 17th Annual American Medical Society for Sports Medicine Annual Meeting The Canadian Academy of Sport Medicine 2008 Annual MeetingIn Colloboration With: American Osteopathic Academy of Sports Medicine Australasian College of Sports Physicians Las Vegas, NV March 25-29, 2008. http://www.cjsportmed.com/.
Shumway-Cook, A., et al.
2009 Falls in the medicare population: Incidence, associated factors, and impact on health care. http://www.ptjournal.org.
Shumway-Cook, Anne, et al.
1997 Predicting the probability for falls in community-dwelling older adults. Physical Therapy 77(8):812-9.
Sieri, T., and G. Beretta

2004 Fall risk assessment in very old males and females living in nursing homes. Disability & Rehabilitation 26(12):718-723.

Sim, Julius, and Chris C Wright

2005 The Kappa statistic in reliability studies: Use, interpretation, and sample size requirements. http://ptjournal.apta.org.ezproxy.aut.ac.nz/.

Simoneau, G. G., et al.

1995 Role of somatosensory input in the control of human posture. Gait & Posture 3(3):115-122.

Skelton, D. A., J. Kennedy, and O. M. Rutherford

2002 Explosive power and asymmetry in leg muscle function in frequent fallers and non-fallers aged over 65. http://ageing.oxfordjournals.org/.

Slinde, Frode, et al.

2008 Test-Retest reliability of three different countermovement jumping tests. http://www.nsca-jscr.org/.

Sloane, Philip D., Robert W. Baloh, and Vicente Honrubia

1989 The vestibular system in the elderly: Clinical implications. American Journal of Otolaryngology 10(6):422-429.

Smania, N., et al.

2008 Rehabilitation of sensorimotor integration deficits in balance impairment of patients with stroke hemiparesis: A before/after pilot study. Neurological Sciences 29(5):313-319.

Society, American Geriatrics

2001a Guideline for the Prevention of Falls in Older Persons. Article, http://au.wiley.com/WileyCDA/WileyTitle/productCd-JGS.html.

Society, American Geriatrics

2001b Guideline for the Prevention of Falls in Older Persons. Journal of the American Geriatrics Society 49(5):664-672.

Song, X., et al.

2004 Assessment of individual risk of death using self-report data: An artificial neural network compared with a frailty index. Journal of the American Geriatrics Society 52(7):1180-1184.

Sorensen, K. L., M.A. Hollands, and E. Patla

2002 The effects of human ankle muscle vibration on posture and balance during adaptive locomotion. Experimental Brain Research 143(1):24-34.

Soucie, J. M., et al.

2011 Range of motion measurements: reference values and a database for comparison studies. Haemophilia 17(3):500-507.

Spector, R.H.

1990 Chapter 116 Visual fields. *In* Clinical Methods: The history, Physical and Laboratory examination. H.K. Walker, Hall, W.D., Hurst, J.W., ed. Boston: Butterworths.

Spink, Martin J., et al.

2011 Foot and ankle strength, range of motion, posture, and deformity are associated with balance and functional ability in older adults (abstract). Archives of Physical Medicine and Rehabilitation 92(1):68-75.

Stacoff, Alex, et al.

2005 Ground reaction forces on stairs: Effects of stair inclination and age. http://www.journals.elsevier.com/gait-and-posture/.

Stalenhoef, P. A., et al.

2002 A risk model for the prediction of recurrent falls in community-dwelling elderly: A prospective cohort study. Journal of Clinical Epidemiology 55(11):1088-1094.

Stehman, Stephen V.
1997 Selecting and interpreting measures of thematic classification accuracy. Remote Sensing of Environment 62(1):77-89.

Steinman, B. A., J. Pynoos, and A. Q. D. Nguyen
2009 Fall risk in older adults: Roles of self-rated vision, home modifications, and limb function. Journal of Aging and Health 21(5):655-676.

Steyerberg, Ewout W., et al.
2001 Internal validation of predictive models: Efficiency of some procedures for logistic regression analysis. Journal of Clinical Epidemiology 54(8):774-781.

Straube, A., W. Paulus, and T. Brandt
1990 Influence of visual blur on object-motion detection, self-motion detection and postural balance (abstract). Behavioural Brain Research 40(1):1-6.

Studenski, S., P. Duncan, and J. Chandler
1991 Postural responses and effector factors in persons with unexplained falls: Results and methodologic issues. Journal American Geriatrics Society 39(3):229-234.

Sturnieks, D.L., R. St George, and S.R. Lord
2008 Balance disorders in the elderly. Clinical Neurophysiology 38(6):467-478.

Sutherland, D. H.
2002 The evolution of clinical gait analysis: Part II Kinematics. Gait & Posture 16(2):159-179.

Suzuki, Toshimi, Jonathan F. Bean, and Roger A. Fielding
2001 Muscle power of the ankle flexors predicts functional performance in community-dwelling older women. Article, http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1532-5415.

Swanenburg, J., et al.
2010 Falls prediction in elderly people: A 1-year prospective study. Gait & Posture 31(3):317-321.

Swanenburg, Jaap, et al.
2008 The reliability of postural balance measures in single and dual tasking in elderly fallers and non-fallers. BMC Musculoskeletal Disorders 9(1):162.

Tanaka, T., et al.
1995 Aging and postural stability: Change in sensorimotor function. http://www.informaworld.com/smpp/title~db=jour~content=t792304026.

Tanaka, Toshiaki, et al.
1998 Age-related changes in postural control associated with location of the center of gravity and foot pressure. Physical & Occupational Therapy in Geriatrics 15(2):1-14.

Thayaparan, K., M.D. Crossland, and G.S. Rubin
2007 Clinical assessment of two new contrast sensitivity charts. British Journal of Ophthalmology 91:749-752.

Thompson, W D., and S D. Walter
1988 A reappraisal of the Kappa coefficient. Journal of Clinical Epidemiology 41(10):949-958.

Tinetti, M.E., et al.
2006 Fall-risk evaluation and management: Challenges in adopting geriatric care practices. http://gerontologist.gerontologyjournals.org.

Treleaven, Julia, et al.

2005 Is the method of signal analysis and test selection important for measuring standing balance in subjects with persistent whiplash? Gait & Posture 21(4):395-402.

Tsang, W.W.N., and C.W.Y. Hui-Chan
2004 Effects of exercise on joint sense and balance in elderly men: tai chi versus golf. Medicine & Science in Sports & Exercise 36(4):658-667.

Uchiyama, M., and S. Demura
2007 Influence of changes in visual acuity under various visual field conditions on the spectral characteristics of center of pressure sway. http://proquest.umi.com.ezproxy.aut.ac.nz/pqdweb?RQT=318&pmid=11574&cfc=1.

Unver, B., V. Karatosun, and S. Bakirhan
2009 Reliability of goniometric measurements of flexion in total knee arthroplasty patients: with special reference to the body position. http://www.jstage.jst.go.jp/browse/jpts/_vols/-char/en.

Utz, Kathrin S., et al.
2010 Electrified minds: Transcranial direct current stimulation (tDCS) and Galvanic Vestibular Stimulation (GVS) as methods of non-invasive brain stimulation in neuropsychology--A review of current data and future implications. Neuropsychologia 48(10):2789-2810.

Valverde-Albacete, Francisco J., and Carmen Peláez-Moreno
2014 100% classification accuracy considered harmful: The normalized information transfer factor explains the accuracy paradox. PLoS ONE 9(1):1-10.

Van Deursen, R. W., and G. G. Simoneau
1999 Foot and ankle sensory neuropathy, proprioception, and postural stability. http://www.jospt.org.

Van Dieen, J. H., L. L. J. Koppes, and J. W. R. Twisk
2010 Postural sway parameters in seated balancing; their reliability and relationship with balancing performance. Gait & Posture 31(1):42-46.

van Emmerik, Richard E-A, and Erwin E.H. van Wegen
2002 On the functional aspect of variability in postural control. http://journals.lww.com/acsm-essr/pages/default.aspx.

Van Nispen, R. M. A., et al.
2009 Co-morbidity and visual acuity are risk factors for health-related quality of life decline: Five-month follow-up EQ-5D data of visually impaired older patients. Health and Quality of Life Outcomes 7.

Vandervoot, A.A.
1999 Ankle mobility and postural stability. Physiotherapy Theory and Pratice 15(2):91-103.

Viera, A. J., and J. M. Garrett
2005 Understanding interobserver agreement: The kappa statistic. http://www.stfm.org/NewsJournals/FamilyMedicine.

Voight, M. L., et al.
1996 The effects of muscle fatigue on and the relationship of arm dominance to shoulder proprioception. http://www.jospt.org./.

Vuillerme, N., N. Forestier, and V. Nougier
2002 Attentional demands and postural sway: The effect of the calf muscles fatigue. http://journals.lww.com/acsm-msse/pages/default.aspx.

Vuillerme, Nicolas, and Frederique Hintzy
2007 Effects of a 200 W-15 min cycling exercise on postural control during quiet standing in healthy young adults. European Journal of Applied Physiology 100(2):169-175.

Wade, M. G., and G. Jones
1997 The role of vision and spatial orientation in the maintenance of posture. http://www.ptjournal.org.
Walther, L. E., and M. Westhofen
2007 Presbyvertigo-aging of otoconia and vestibular sensory cells. http://www.jvr-web.org.
Wang, Hsing-Kuo, et al.
2006 Risk-factor analysis of high school basketball–player ankle injuries: A prospective controlled cohort study evaluating postural sway, ankle strength, and flexibility. Archives of Physical Medicine and Rehabilitation 87(6):821-825.
Wang, T.Y., and S.. Lin
2008 Sensitivity of plantar cutaneous sensation and postural stability. Clinical Biomechanics 23(4):493-499.
Watkins, M. A., et al.
1991 Reliability of goniometric measurements and visual estimates of knee range of motion obtained in a clinical setting. http://www.ptjournal.org.
Weirich, Grant, Debra A. PhD Bemben, and Michael G. PhD Bemben
2010 Predictors of balance in young, middle-aged, and late middle-aged women. Journal of Geriatric Physical Therapy 33(3):110-7.
Weiss, Lawrence W, Frank C Clark, and David G Howard
1988 Effects of heavy-resistance triceps surae muscle training on strength and muscularity of men and women. http://ptjournal.apta.org/.
Westlake, K.P., and E.G. Culham
2007 Sensory-specific balance training in older adults: effect on proprioceptive reintegration and cognitive demands. http://www.ptjournal.org.
Whitney, Susan L., et al.
2005 Clinical Measurement of Sit-to-Stand Performance in People With Balance Disorders: Validity of Data for the Five-Times-Sit-to-Stand Test. http://www.ptjournal.org.ezproxy.aut.ac.nz
Williams, T. A., et al.
2007 Evaluation of a falls prevention programme in an acute tertiary care hospital. Journal of Clinical Nursing 16(2):316-324.
Wingert, Jason R., Catherine Welder, and Patrick Foo
Age-Related Hip Proprioception Declines: Effects on Postural Sway and Dynamic Balance. Archives of Physical Medicine and Rehabilitation (0).
Winter, D. A.
1995 Human balance and posture control during standing and walking. Gait & Posture 3(4):193-214.
Winter, D. A., et al.
1998 Stiffness control of balance in quiet standing. http://www.jn.org.
Wist, E. R., M. Schrauf, and W. H. Ehrenstein
2000 Dynamic vision based on motion-contrast: Changes with age in adults. Experimental Brain Research 134(3):295-300.
Yagi, T., et al.
2000 Influence of vibration to the neck, trunk and lower extremity muscles on equilibrium in normal subjects and patients with unilateral labyrinthine dysfunction. http://informahealthcare.com/oto.
Yamada, Norimasa
1995 Chaotic swaying of the upright posture. Human Movement Science 14(6):711-726.

Zhang, Y. & Yang, Y.
2015 Cross Validation for selecting a model selection procedure.Jounral of Economics 187 (2015) 95-112. DOI: 10.1016/j.jeconom.2015.02.006.
Zemkova, E.
2009 Balance readjustment after different forms of exercise: A review. http://www.sports.re.kr/index.php.

7 APPENDICES

7.1 APPENDIX 1 : ETHIC APPROVAL OF THE JODHPUR EXPERIMENT

Dr. Arvind Mathur
M.D.
Professor and Head,
Department of Medicine,
Dr. S.N. Medical College and
Associated Group of Hospitals,
Jodhpur

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Reg. No. 1262/6419 (RMC)

Professor David Hewson
Visiting Professor
Indian Institute of Technology Rajasthan
Jodhpur, Rajasthan

Reference : Your application dated 10/12/2011

Title of Project: Experiments aiming to build correlation between parameters of the sway signal and the quality of the physiological components of balance in young and elderly dwelling adults

Dear Professor Hewson,

Thank you for your request for ethical approval. Approval has been granted effective 28/02/2012.

In keeping with the decision of the committee, the following conditions apply:

1. Approval is granted for a period of 12 months, at the end of which a written report is required. Should an extension be required, an application for renewal must be submitted prior to the end of the 12 month study period.
2. Any alteration to the study protocol must be notified in writing to the committee.
3. Any adverse effects of the intervention on participants must be any event that could affect ethical acceptability must be notified to the committee.

Yours sincerely

Arvind mathur

Dr Arvind Mathur
Chair
Ethical Review Committee
Dr S.N. Medical College, Jodhpur

15/12/2011

7.2 APPENDIX 2 : AUCKLAND ETHIC APPROVAL

AUT UNIVERSITY | AUTEC SECRETARIAT

10 January 2013

Denise Taylor
Faculty of Health and Environmental Sciences

Dear Denise

Re Ethics Application: **12/301 Construction of a physiological model of balance in older adults based on measures of sway.**

Thank you for providing evidence as requested, which satisfies the points raised by the AUT University Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 10 January 2016.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online throughhttp://www.aut.ac.nz/research/research-ethics/ethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 10 January 2016;
- A brief report on the status of the project using form EA3, which is available online throughhttp://www.aut.ac.nz/research/research-ethics/ethics. This report is to be submitted either when the approval expires on 10 January 2016 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this. If your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply there.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Dr Rosemary Godbold
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Jennifer Bassement jwv5016@aut.ac.nz

7.3 APPENDIX 3 : AUCKLAND INFORMATION SHEET

Participant Information Sheet

AUT UNIVERSITY

Date Information Sheet Produced:
15th December 2012

Project Title
Observation of the effects of the manipulation of vision, vestibular system, joints, muscle and foot proprioception on the standing posture.

An Invitation
I am Jennifer Bassement, a French PhD student. This study is part of my PhD which is supervised by Denise Taylor and Peter McNair here in AUT and by David Hewson in France. We wish to recruit you to participate in the study, your participation is voluntary and you may withdraw at any time.

What is the purpose of this research?
The study aims to improve the health of the elderly. The Study is part of a bigger project in France trying to build a tool able to quickly assess the balance of the elderly. Many tests already exist to screen the balance in standing posture but the specificity of our tool is a very quick assessment which would provide details about possible impairments. From the assessment, proper interventions/rehabilitation can be provided to the elderly.
The result of the research will be used for PhD thesis and for scientific journal articles.

How was I identified and why am I being invited to participate in this research?
We are recruiting young healthy adults between 18 and 45 year old with no neurological or musculo-skeletal impairments.

What will happen in this research?
The study includes 2 sessions of 45 minutes to 1 hour each.
You will be required to stand still on a force plate (which is a square plate, a giant bathroom scale) for 30 seconds; while you are standing still, the force plate will measure the forces you apply on it vertically and horizontally, which mean it can give your weight but also the amount of forces you produce sideway and forward/backward.
This "weighting process" will be repeated 3 times for each condition, and you will be submitted to 6 conditions. The conditions are a temporary change in your sensory quality, the sensory quality being the vision, the vestibular system (inner ear), the ankle range of motion and proprioception (how you feel your joint moving), the muscle power and the foot proprioception (how you feel the touch on your foot).
The experimentation aims to temporary decrease the quality of your sensory systems. In order to change the quality of your sensory systems, several devices will be use. To decrease you vision, you will wear modified goggles (producing blur vision, low contrast vision, suppressing the depth perception and the periphery vision.), to decrease your vestibular system, a small current will be sent to your inner ear through the bones behind you ear, to decrease your joint range of motion, you will put on ankle braces, to decrease joint proprioception, your ankle tendons will be submitted to vibration, to decrease your muscle power, you will have to perform muscle fatigue and finally to decrease your foot proprioception you will have to keep your feet on iced water for 15 minutes.
For each condition, you will also be tested to determine the quality of your sensory systems. You will take vision tests, vestibular test, range of motion test, joint proprioception test, muscle power test, and foot proprioception test.
To sum up, you will stand up on the force plate, then be tested for sensory quality then get your sensory system temporary decreased then you will stand still again on the force plate. This will be repeated 6 times on different sensory systems. You will recover your full capacity quickly after the experiment.

What are the discomforts and risks?
There is no risk in the protocol, neither for the test neither for the manipulations. It is possible to feel a little discomfort with the very small electric current if you are able to feel it! The iced water on the foot can also be a bit uncomfortable until you adjust to the temperature.

This version was last edited on 13 October 2010

How will these discomforts and risks be alleviated?

The small electrical current applied behind the ear has a maximum of 2 mA which is usually not felt by the subject. However, if you do feel uncomfortable, we can decrease the current to 1 mA or even withdraw the testing.

Concerning the ice water on the feet, you will be given time to adjust to the temperature before performing the test. If the cold is unbearable, the testing will be stopped.

What are the benefits?

The benefit for your participation is that you will be accurately tested for 6 sensory systems. You will be tested for vision acuity, vision contrast, vision depth perception, vision periphery, vestibular system (inner ear), joint position sense, joint range of motion, leg muscle power and foot sole proprioception. You can compare your score to normative score.

Your participation will help me to obtain my PhD degree in health and rehabilitation, as well as get journal articles published. This study is a small part of the development of an assessment tool, there will be no immediate commercial benefits resulting from this study.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

The study respects confidentiality, no personal information (name, address etc...) will be use or disclose. A number will be attributed to you upon your entry in the study and your data will be recorded under this attributed number.

What are the costs of participating in this research?

Two sessions are required for this study. Each session requires 30 minutes to 1 hour depending on the time needed to perform each sensory test.

What opportunity do I have to consider this invitation?

The study will run during December 2012 and January 2013. You can join anytime from now until the end of the study.

How do I agree to participate in this research?

After reading this information sheet, if you agree to take part in this study you have to sign two copies of the consent form provide along with the information sheet. One copy is for you, one copy is for the archives of AUT.

Will I receive feedback on the results of this research?

You will get immediate feedback on the quality of your sensory input while performing the test. For the general results of the study you can thick YES on the consent form and a resume of the study will be sent to you by email when the study will be published.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Denise Taylor, denise.taylor@aut.ac.nz +64-9-921 9860

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Dr Rosemary Godbold, rosemary.godbold@aut.ac.nz 921 9999 ext 6902.

Whom do I contact for further information about this research?

Researcher Contact Details:

Jennifer Bassement,
AB 114, AUT Akoranga Campus
90 Akoranga Drive
Northcote,
Auckland 0627
New Zealand
jwy5016@aut.ac.nz
..... extension 7079

Project Supervisor Contact Details:

Denise Taylor
AA 115, AUT Akoranga Campus
90 Akoranga Drive
Northcote,
Auckland, 0627
New Zealand
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Approved by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*, **AUTEC Reference number** *type the reference number*.

This version was last edited on 13 October 2010

7.4 APPENDIX 4 : CONSENT FORM FROM JODHPUR EXPERIMENT

INDIAN INSTITUTE OF TECHNOLOGY RAJASTHAN
भारतीय प्रौद्योगिकी संस्थान राजस्थान

utt

AUT

CONSENT FORM

Study: Evaluation of balance and physiological testing.
Experiments aiming to build correlation between parameters of the sway signal and the quality of the physiological components of equilibrium in young and elderly dwelling adults.

Name of the researchers: Jennifer Bassement & Dhruv Gupta.

Name of the subject : ..... **ID number**:.....

Location: Indian Institute of Technology Rajasthan, Old Residency Road, Ratanada, Jodhpur - 342 011, Phone: +91 291 244 9024, Fax: +91 291 251 6823

Please tick to confirm

- I confirm that I have read and understand the information sheet dated 03 March 2012 for the above study ☐
- I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐
- I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected ☐
- I understand that relevant sections of any of my medical notes and data collected during the study may be looked at by responsible individuals from IITJ, UTT, AUT or from regulatory authorities, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records. ☐
- I agree to take part in the above research study. ☐

I would like to received the result of the study YES ☐ NO ☐

My email address to receive the results:.....

Name of the subject	Date	Signature
Name of the researchers	Date	Signature

3 copies, 1 copy for the subject, 1 copy for the researcher, 1 copy for medical notes.

7.5 APPENDIX 5– CONSENT FORM IN HINDI FOR THE JODHPUR EXPERIMENT

INDIAN INSTITUTE OF TECHNOLOGY RAJASTHAN
भारतीय प्रौद्योगिकी संस्थान राजस्थान

utt
universite de recherche et de technologie Troyes

AUT
UNIVERSITY

सहमति □ □

अध्ययन : संतुलन और शारीरिक परीक्षण का मूल्यांकन.

प्रोजेक्ट □□ □ □ : Jennifer Bassement and Dhruv Gupta

समन्वयक □ ..... आईडी □ स □ : ...ह.... □ या

पता □ : इंडियन इंस्टिट्यूट ऑफ टैक्नोलॉजी राजस्थान, पुरानी रेजीडेंसी रोड, Ratanada, जोधपुर - 011 342, फोन: 291 +91 244 ९०२४, फैक्स: +91 251 6823 291

शोधकर्ता □□□ □ :

- मैं इस बात की पुष्टि करता हू कि मैंने ऊपर के अध्ययन के लिए जानकारी शीट (संस्करण 2) दिनांक 02 नवम्बर 2011 मे लिखित, पढी और समझी.
- मुझे इस जानकारी पर विचार करने का और सवाल पूछने का अवसर मिला है और मुझे इसका संतोषजनक जवाब मिला.
- मैं समझता हूँ कि मेरी भागीदारी स्वैच्छिक है और मैं बिना किसी कारण, मेरी चिकित्सा देखभाल या कानूनी अधिकार को प्रभावित किये बिना, किसी भी समय प्रयोग से वापस आ सकता हूँ.
- मै समझता हूँ कि मेरे चिकित्सा नोट्स और अध्ययन के दौरान एकत्र आंकड़ों के किसी भी प्रासंगिक वर्गों IITJ, UTT, AUT या नियामक अधिकारियों , जहां यह मेरे इस शोध में भाग लेने के लिए प्रासंगिक है, के जिम्मेदार व्यक्तियों द्वारा देखा जा सकता है. मैं इन व्यक्तियों को मेरे रिकॉर्ड उपयोग करने की अनुमति देता हूँ.
- मैं ऊपर लिखे शोध अध्ययन में भाग लेने पर सहमत हूँ.

  मैं अध्ययन का परिणाम प्राप्त कारना चाहता हूँ. हाँ नही

  मेरा ईमेल परिणाम पता करने के लिए : .....

आपका नाम	दिनांक	हस्ताक्षर
शोधकर्ताओं का नाम	दिनांक	हस्ताक्षर

7.6 APPENDIX 6 : AUCKLAND CONSENT FORM

Consent Form

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: ***Study on the effects of the manipulation of the sensory inputs on the displacement of the centre of pressure in standing posture.***

Project Supervisors: ***Denise Taylor, Peter McNair, David Hewson***

Researcher: ***Jennifer Bassement***

- O I have read and understood the information provided about this research project in the Information Sheet dated 07 October 2012
- O I have had an opportunity to ask questions and to have them answered.
- O I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- O I am not suffering from any chronic diseases neither musculo-skeletal or neuronal impairments
- O I agree to take part in this research.
- O I wish to receive a copy of the report from the research (please tick one): Yes O No O

Participant's signature: .....

Participant's name: .....

Participant's Contact Details (if appropriate):

.....

.....

.....

.....

Date:

Approved by the Auckland University of Technology Ethics Committee on *type the date on which the final approval was granted* ***AUTEC Reference number*** *type the AUTEC reference number*

Note: The Participant should retain a copy of this form.

This version was last edited on 13 October 2010

7.7 APPENDIX 7 : QUESTIONNAIRE EXPERIMENT JODHPUR

QUESTIONNAIRE for participants

Information :

Name: _____ Surname: _____

Date of birth: _____ Age: _____

Phone number: _____ Gender ☐ Female - ☐ Male

Contact email or Address: _____

I'm taking part in another research ☐ YES ☐ NO which one? : _____

_____

Daily Physical Activities:
Sports/activities:

1_____ - Frequency _____/ week - Hours _____/ session

2_____ - Frequency _____/ week - Hours _____/ session

3_____ - Frequency _____/ week - Hours _____/ session

4_____ - Frequency _____/ week - Hours _____/ session

5_____ - Frequency _____/ week - Hours _____/ session

Main occupation:
Job / occupation: _____

Injuries/ illness :
Have you ever been injured?

- Ankles ? ☐ Yes ☐ No explain : .....
.....
- Knees ? ☐ Yes ☐ No explain : .....
.....
- Hips ? ☐ Yes ☐ NO explain : .....
.....

Have you ever had problems with

- Vision ? ☐ Yes ☐ No explain : .....
.....
- Inner ears? (vertigo) ☐ Yes ☐ No explain : .....
.....
- muscles? ☐ Yes ☐ No explain : .....
.....
- Foot numbness? ☐ Yes ☐ No explain : .....

Do you have a chronic disease?
☐ Yes ☐ No, which one? : .....
.....

Are you currently taking any medication? :
☐ Yes ☐ No, which one ? : .....
.....

7.8 Appendix 8 : Score of the intrinsic factors tests

Results of the Vision tests in Control young adults tested in Jodhpur

Control	YI1	YI2	YI3	YI4	YI5	YI6	YI7	YI8	YI9	YI10	YI11	YI12	YI13	YI14	YI15	YI16	YI17	YI18	YI19	YI20	YI21	YI22	YI23	YI24	YI25
Acuity	9	5	9	9	4	9	10	10	10	10	5	8	5	8	9	8	10	8	9	8	8	10	9	8	9
Contrast	1,76	1,76	1,76	1,76	1,76	1,76	1,76	1,8	1,76	1,76	1,72	1,76	1,76	1,76	1,8	1,8	1,76	1,76	1,76	1,76	1,68	1,8	1,76	1,84	1,76
Depth	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Field	170	180	176	157	164	169	180	180	167	180	180	165	180	180	180	180	180	180	169	180	180	180	180	158	180

Results of the Vision tests in impaired young adults tested in Jodhpur

Impaired	YI1	YI2	YI3	YI4	YI5	YI6	YI7	YI8	YI9	YI10	YI11	YI12	YI13	YI14	YI15	YI16	YI17	YI18	YI19	YI20	YI21	YI22	YI23	YI24	YI25
Acuity	4	2	5	4	1	4	4	5	4	3	2	4	1	3	4	5	4	4	2	4	2	4	4	3	5
Contrast	1,2	0,72	0,6	0,72	0,2	0,96	0,88	0,08	0,72	0,08	1,16	0,88	0,92	0,48	1,36	0	0,68	1,52	1,32	0,68	1,24	1,2	1	0,84	0,64
Depth	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Field	84	98	82	72	84	66	68	71	82	85	78	67	77	76	76	83	83	80	72	90	77	70	77	63	91

Results of the Vision tests in Elderly adults tested in Jodhpur

Elderly	EL1	EL2	EL3	EL4	EL5	EL6	EL7	EL8	EL10	EL12	EL14	EL15	EL16	EL17	EL18	EL19	EL20	EL21	EL22	EL23	EL24	EL25	EL26	EL27	EL28
Acuity	4	3	4	1	5	8	3	4	6	4	0	2	1	1	2	0	6	3	3	5	4	4	7	6	4
Contrast	1,52	1,28	1,32	1,36	1,08	1,44	1,52	0,8	1,44	1,44	1,32	1,44	0,96	1,48	1,44	0,92	1,12	1,44	1,08	1,44	1,28	1,44	1,44	1,44	0,96
Depth	3	0	3	0	1	3	2	1	3	2	1	3	2	2	2	0	0	1	2	2	1	3	3	2	2
Field	160	163	161	145	130	161	138	153	133	108	104	140	100	144	142	70	144	79	126	138	130	133	144	154	146

Result of the vestibular test, value of the angle of rotation for the young Control population tested in Jodhpur.

Control	YI1	YI2	YI3	YI4	YI5	YI6	YI7	YI8	YI9	YI10	YI11	YI12	YI13	YI14	YI15	YI16	YI17	YI18	YI19	YI20	YI21	YI22	YI23	YI24	YI25
A value	5	34	15	10	14	8	12	34	38	33	12	34	23	12	26	3	10	31	24	24	12	44	29	27	28
B value	6	20	5	4	3	11	17	30	7	7	13	26	0	3	20	14	19	3	49	7	0	17	22	15	4
C value	73	82.5	50	71.5	96	41	28	78	71.5	32.5	39	52	82	98	46.5	54.5	41	57	33	54	51	94	77	142.5	91.5

Result of the vestibular test, value of the angle of rotation for the young impaired population tested in Jodhpur.

Impaired	YI1	YI2	YI3	YI4	YI5	YI6	YI7	YI8	YI9	YI10	YI11	YI12	YI13	YI14	YI15	YI16	YI17	YI18	YI19	YI20	YI21	YI22	YI23	YI24	YI25
A value	36	80	15	3	21	8	1	7	83	20	35	9	33	19	11	5	31	19	58	27	58	82	36	9	10
B value	26	41	1	9	12	18	3	29	44	40	21	16	25	8	16	28	45	9	77	16	46	38	11	7	6
C value	16	27	32.50	21.50	9.50	0.50	23	27	19	7.50	12	4.50	32	36.50	40	3	8.5	7	4.5	15.5	19.5	30.5	25	10.5	45

Result of the vestibular test, value of the angle of rotation for the elderly population tested in Jodhpur.

Elderly	EL1	EL2	EL3	EL4	EL5	EL6	EL7	EL8	EL10	EL12	EL14	EL15	EL16	EL17	EL18	EL19	EL20	EL21	EL22	EL23	EL24	EL25	EL26	EL27	EL28
A value	27	73	0	20	22	11	48	117	14	49	56	33	33	98	64	0	41	NO	95	162	15	31	64	6	15
B value	12	73	39	20	30	4	48	78	14	21	15	14	12	57	17	0	50	NO	25	49	8	22	11	15	22
C value	92	45	39,5	108	90,5	71	49,5	70,5	93	89	49	61	133	68	56	69	64	NO	81	64.5	48	62,5	116	109	44

Joint proprioception tests for young Control people tested in Jodhpur.

Control	YI1	YI2	YI3	YI4	YI5	YI6	YI7	YI8	YI9	YI10	YI11	YI12	YI13	YI14	YI15	YI16	YI17	YI18	YI19	YI20	YI21	YI22	YI23	YI24	YI25
Ankle pro	0	3	4	0	6	0	7	1	15	0	5	5	4	1	1	0	1	0	0	1	3	5	6	0	4
Knee pro	3	0	1	3	7	2	3	5	5	10	2	9	5	1	1	5	5	6	3	0	0	20	8	2	1
Hip pro	10	4	10	1	2	0	0	1	4	0	1	0	0	8	0	0	8	2	3	2	1	15	4	0	1

Joint proprioception tests for young people with impairment, population tested in Jodhpur

Impaired	YI1	YI2	YI3	YI4	YI5	YI6	YI7	YI8	YI9	YI10	YI11	YI12	YI13	YI14	YI15	YI16	YI17	YI18	YI19	YI20	YI21	YI22	YI23	YI24	YI25
Ankle pro	3	1	9	1	4	5	5	2	15	12	4	7	10	10	7	2	2	4	2	3	3	6	4	6	5
Knee pro	7	1	2	6	15	5	15	4	75	5	13	8	5	8	2	1	3	4	3	7	57	15	4	8	2
Hip pro	13	4	5	2	1	0	10	7	7	2	3	4	6	2	10	1	1	6	2	7	2	14	8	4	7

Joint proprioception tests in elderly people tested in Jodhpur

Elderly	EL1	EL2	EL3	EL4	EL5	EL6	EL7	EL8	EL10	EL12	EL14	EL15	EL16	EL17	EL18	EL19	EL20	EL21	EL22	EL23	EL24	EL25	EL26	EL27	EL28
Ankle pro	7	15	19	9	2	5	60	5	30	0	45	9	0	10	5	6	4	5	11	0	5	15	1	0	1
Knee pro	7	0	5	7	5	4	4	5	10	0	30	10	0	8	5	10	4	5	5	5	21	0	0	0	0
Hip pro	4	0	9	16	1	5	15	5	25	2	0	0	10	6	15	0	0	8	11	0	1	0	5	5	3

Joint range of Motion tests for the young Control people tested in Jodhpur

Control	YI1	YI2	YI3	YI4	YI5	YI6	YI7	YI8	YI9	YI10	YI11	YI12	YI13	YI14	YI15	YI16	YI17	YI18	YI19	YI20	YI21	YI22	YI23	YI24	YI25
Ankle ROM	52	44	81	71	47	68	66	63	79	40	48	54	59	53	75	64	33	63	44	58	56	31	55	63	33
Knee ROM	144	133	130	143	142	134	133	135	144	135	141	149	136	125	132	156	110	151	142	131	132	135	129	130	131
Hip ROM	56	86	107	104	89	81	99	96	131	109	93	93	99	80	97	106	82	116	99	83	85	80	90	97	88

Joints Range of Motion tests for the young population after impairment

Impaired	YI1	YI2	YI3	YI4	YI5	YI6	YI7	YI8	YI9	YI10	YI11	YI12	YI13	YI14	YI15	YI16	YI17	YI18	YI19	YI20	YI21	YI22	YI23	YI24	YI25
Ankle ROM	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Knee ROM	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Hip ROM	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

Joint Range of Motion tests for the elderly population tested in Jodhpur

Elderly	EL1	EL2	EL3	EL4	EL5	EL6	EL7	EL8	EL10	EL12	EL14	EL15	EL16	EL17	EL18	EL19	EL20	EL21	EL22	EL23	EL24	EL25	EL26	EL27	EL28
Ankle ROM	36	73	38	46	43	49	52	43	51	64	47	46	45	41	53	52	40	57	37	65	49	26	54	95	34
Knee ROM	145	130	130	115	122	141	117	138	130	128	134	133	151	140	155	138	140	134	112	142	110	139	130	150	127
Hip ROM	111	101	80	71	53	79	70	48	76	91	85	94	106	57	97	71	71	44	70	73	65	99	76	71	84

Results of the cutaneous test for Control young population tested in Jodhpur.

Control	YI1	YI2	YI3	YI4	YI5	YI6	YI7	YI8	YI9	YI10	YI11	YI12	YI13	YI14	YI15	YI16	YI17	YI18	YI19	YI20	YI21	YI22	YI23	YI24	YI25
Cutaneous	17	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18

Results of the cutaneous test for the Healty population after degradation.Jodhpur testing.

Impaired	YI1	YI2	YI3	YI4	YI5	YI6	YI7	YI8	YI9	YI10	YI11	YI12	YI13	YI14	YI15	YI16	YI17	YI18	YI19	YI20	YI21	YI22	YI23	YI24	YI25
Cutaneous	12	17	18	17	18	18	15	16	16	18	18	18	18	16	15	16	18	18	16	18	18	17	16	18	16

Results of the Cutaneous test for the elderly population tested in Jodhpur

Elderly	EL1	EL2	EL3	EL4	EL5	EL6	EL7	EL8	EL10	EL12	EL14	EL15	EL16	EL17	EL18	EL19	EL20	EL21	EL22	EL23	EL24	EL25	EL26	EL27	EL28
Cutaneous	13	15	11	12	5	9	9	18	12	11	14	4	13	12	11	4	8	2	8	9	7	4	7	8	8

Results of the muscle strength tests for the Control young population. Jodhpur testing

	YI1	YI2	YI3	YI4	YI5	YI6	YI7	YI8	YI9	YI10	YI11	YI12	YI13	YI14	YI15	YI16	YI17	YI18	YI19	YI20	YI21	YI22	YI23	YI24	YI25
StS	8,9	8,6	7,4	6,6	7,2	7,6	6,1	6	8,3	5,1	8,1	9,3	10	4,4	7,3	8	6,22	9,7	7	7,4	9,8	10,7	9,1	8,5	10,6
HU	5,6	7	2,3	3,4	4,2	4,1	4,3	2,9	4,3	3,7	3,9	4,4	4,1	3,3	4,3	4,2	3,73	3,5	4,8	4,1	5,3	4,4	4,4	4,6	3,7
Hei	21,04	17,97	25,20	17,62	11,51	19,19	23,14	26,69	19,90	18,48	13,97	16,13	19,13	20,92	19,84	19,98	26,45	23,46	27,21	21,29	20,78	15,42	22,03	16,47	13,70
Imp	419,01	473,85	374,51	288,28	332,14	452,37	305,15	473,68	313,67	321,88	349,29	340,57	408,48	391,73	382,71	431,54	435,99	262,89	323,75	417,59	376,57	532,61	467,85	471,21	466,57
MVC	35	15	40	25	55	65	84	65	50	84	65	50	82	84,5	80	80	50	84	84	84,5	80	0	80	70	60

Results of the muscle strength tests for the young population after degradation. Jodhpur testing

	YI1	YI2	YI3	YI4	YI5	YI6	YI7	YI8	YI9	YI10	YI11	YI12	YI13	YI14	YI15	YI16	YI17	YI18	YI19	YI20	YI21	YI22	YI23	YI24	YI25
StS	Not measured																								
HU	Not measured																								
Hei	17,75	12,67	17,99	13,02	12,27	11,45	17,77	14,86	10,50	21,61	10,27	10,82	6,48	17,69	15,82	5,43	11,67	1,70	19,63	11,61	8,75	14,81	11,90	8,39	4,77
Imp	437,75	565,84	464,45	293,95	385,53	502,09	304,86	545,57	315,78	333,99	281,83	336,35	466,94	406,85	381,22	556,38	416,83	264,48	309,12	322,59	377,84	525,46	422,58	419,33	534,26
MVC	15	10	20	10	20	45	65	45	30	42	20	25	42	50	35	40	25	42	52	50	40		40	20	30

Results of the muscle strength tests for the elderly population tested in Jodhpur

Elderly	EL1	EL2	EL3	EL4	EL5	EL6	EL7	EL8	EL10	EL12	EL14	EL15	EL16	EL17	EL18	EL19	EL20	EL21	EL22	EL23	EL24	EL25	EL26	EL27	EL28
Sit to stand	17,1	15	8,4	18,4	16,1	10,1	12,4	14,7	10,5	8,9	17,7	18,5	12	18,4	12,3	17,8	10	25	12,3	9,8	17	18,9	14	7,8	11
Hells up	4,3	10,3	7,4	9,4	8,1	5,6	7,7	8	5,6	8,5	13,8	13,9	6,2	10,7	7,7	No	7	6,1	11,3	7	11	9,1	7,3	6,6	5,4
Height	Not measured																								
Impulsion	Not measured																								

Results of the visual tests for the control population tested in the Auckland study.

Control	YA01	YA02	YA03	YA04	YA05	YA06	YA07	YA08	YA09	YA10	YA11	YA12	YA13	YA14	YA15	YA16	YA17	YA18	YA19	YA20	YA21	YA22	YA23	YA24	YA25	YA26
Acuity	10	10	10	9	9	10	10	9	9	10	7	8	6	10	10	9	10	10	9	8	10	10	7	10	8	9
Contrast	1,8	1,8	1,8	1,76	1,76	1,76	1,76	1,8	1,92	1,76	1,92	1,76	1,92	1,76	1,92	1,92	1,8	1,8	1,76	1,8	1,92	1,76	1,76	1,76	1,76	1,8
Depth	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Field	208	162	166	164	145	141	158	138	172	179	162	172	180	198	168	163	160	172	165	159	188	170	181	195	180	170

Results of the visual tests for the impaired population tested in the Auckland study.

Impaired	YA01	YA02	YA03	YA04	YA05	YA06	YA07	YA08	YA09	YA10	YA11	YA12	YA13	YA14	YA15	YA16	YA17	YA18	YA19	YA20	YA21	YA22	YA23	YA24	YA25	YA26

Acuity	1	1	0	0	0	0	0	0	1	0	1	1	1	0	0	1	1	0	0	0	0	2	0	0	1	0
Contrast	1,64	1,64	1,4	1,64	1,36	1,16	1,28	0,96	1,48	1,6	1,56	1,36	1,32	1,24	1,44	1,44	1,76	1,48	1,32	1,2	1,28	1,44	1,32	1,64	1,6	1,76
Depth	2	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	0	0	0	0	0	1	1	1	0	0
Field	111	80	117	118	90	69	90	85	90	111	96	62	125	91	74	83	87	110	62	40	98	68	89	78	90	74

Results of the vestibular test for the control population in the Auckland study.

Control	YA01	YA02	YA03	YA04	YA05	YA06	YA07	YA08	YA09	YA10	YA11	YA12	YA13	YA14	YA15	YA16	YA17	YA18	YA19	YA20	YA21	YA22	YA23	YA24	YA25	YA26
A value	0	-25	0	76	30	-21	40	0	0	-34	-8	39	-20	-68	-9	0	31	0	-36	0	-37	-12	0	-35	-35	0
B value	0	77	0	-75	-80	75	-75	0	82	80	85	-65	79	70	71	42	-59	-12	78	78	33	85	0	0	99	-67
C value	37	114	66	50	65	55	72	99	5	90	112	57	64	77	50	-10	63	36	53	68	77	93	90	22	82	21

Results of the vestibular test for the impaired population tested in the Auckland study.

Impaired	YA01	YA02	YA03	YA04	YA05	YA06	YA07	YA08	YA09	YA10	YA11	YA12	YA13	YA14	YA15	YA16	YA17	YA18	YA19	YA20	YA21	YA22	YA23	YA24	YA25	YA26
A value	-15	-50	0	-21	-11	0	20	-27	-14	-36	0	-3	50	-80	0	-92	-17	-15	0	40	19	1	-52	40	-16	0
B value	79	57	0	69	82	91	-79	70	54	76	-82	87	0	59	96	59	73	57	0	-76	-79	-52	57	-75	75	-43
C value	55	113	34	35	76	46	93	106	12	107	80	78	54	32	86	10	58	22	52	86	100	120	88	56	75	-11

Results of the muscles strength tests of the control and impaired population in the Auckland study.

Auckland	YA01	YA02	YA03	YA04	YA05	YA06	YA07	YA08	YA09	YA10	YA11	YA12	YA13	YA14	YA15	YA16	YA17	YA18	YA19	YA20	YA21	YA22	YA23	YA24	YA25	YA26
MVC Control	106	106	146	86	116	106	136	106	116	146	66	166	116	126	116	116	186		76	126	96	96	146	156	176	236
MVC impaired	76	76	106	76	86	56	96	76	86	106	46	86	86	86	86	86	96		36	86	56	66	106	76	86	166

Results of the joint range of motion test for the control and impaired population tested in the Auckland study

Auckland	YA01	YA02	YA03	YA04	YA05	YA06	YA07	YA08	YA09	YA10	YA11	YA12	YA13	YA14	YA15	YA16	YA17	YA18	YA19	YA20	YA21	YA22	YA23	YA24	YA25	YA26
Ankle ROM Control	71	62	65	71	57	69	50	53	62	55	72	62	68	62	78	53	63	66	76	67	62	59	43	58	50	58
Ankle ROM impaired	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Results of the cutaneous test for the control and impaired population tested in Auckland.

Auckland	YA01	YA02	YA03	YA04	YA05	YA06	YA07	YA08	YA09	YA10	YA11	YA12	YA13	YA14	YA15	YA16	YA17	YA18	YA19	YA20	YA21	YA22	YA23	YA24	YA25	YA26
Cutaneous Control	3,84	4,17	4,08	4,08	4,08	3,84	4,08	4,31	4,08	4,17	3,61	4,56	3,22	4,31	3,81	4,08	3,22	3,61	4,08	3,61	4,17	4,17	4,08	3,22	4,17	4,08
Cutaneous impaired	4,31	4,31	4,31	4,31	4,31	3,84	4,31	4,53	4,56	4,74	4,08	4,74	4,08	3,84	4,08	4,17	3,61	4,08	4,31	3,84	4,31	4,56	4,56	4,31	4,74	4,31

Results of the joint proprioception tests for the control population tested in Auckland.

Control	YA01	YA02	YA03	YA04	YA05	YA06	YA07	YA08	YA09	YA10	YA11	YA12	YA13	YA14	YA15	YA16	YA17	YA18	YA19	YA20	YA21	YA22	YA23	YA24	YA25	YA26
Ankle pro	3	3	2,5	2	3,5	1	0	6,5	3,5	2,5	3,5	5	5	2,5	1	4	4	1,5	0,5	1	9	2,5	5,5	7,5	6,5	6,5
Hip pro	4,5	7,5	1,5	2	3	2	3	2,5	1	0	3	5,5	25	1	1	3,5	0,5	9	0	30,5	4	2	2,5	5,5	2	1,5

Results of the joint proprioception test for the impaired population tested in Auckland.

Impaired	YA01	YA02	YA03	YA04	YA05	YA06	YA07	YA08	YA09	YA10	YA11	YA12	YA13	YA14	YA15	YA16	YA17	YA18	YA19	YA20	YA21	YA22	YA23	YA24	YA25	YA26
Ankle pro	3,5	1,5	4	1	2,5	1	5	1,5	4,5	2,5	1	2	4,5	4,5	4	9	3	5	2	3	3	2	23	2,5	3	4,5
Hip pro	2,5	2	3,5	0,5	0,5	2	1	2,5	3	1,5	2	4,5	0,5	2,5	2	4	1	16	1,5	5	13	0,5	3	5	1	10,5

7.9 APPENDIX 9 : PARAMETERS NUMBER CODE PHASE AND FULL NAME

N°	Parameter Code	Unit	Phases	Full Name
1	SD_poids	N	Stepping Down	Weight of the subject
2	SD_rAP0	cm	Stepping Down	Mean position of the CoP during stable phase on AP
3	SD_rML0	cm	Stepping Down	Mean position of the CoP during stable phase on ML
4	SD_t0	s	Stepping Down	Time setting the beginning of the Stepping Down Phase
5	SD_FO1	s	Stepping Down	First Foot Off the force plate.
6	SD_FC1d	s	Stepping Down	First Foot Contacts the ground
7	SD_tPMC	s	Stepping Down	Time when 90% of the weight is on the force plate
8	SD_FO2	s	Stepping Down	Second Foot leaving the force plate
9	SD_fin	s	Stepping Down	Time of the end of the stepping down phase.
10	SD_dAPA	s	Stepping Down	Duration of the Anticipatory Postural Adjustment
11	SD_dSW	s	Stepping Down	Duration of the Swing Phase
12	SD_dAPP	s	Stepping Down	Duration of the double limbs stance
13	SD_dTOTAL	s	Stepping Down	Total duration of the stepping down phase
14	SD_intX(tt)	cm/s	Stepping Down	Velocity of the Centre of Mass on the X axis
15	SD_intY(tt)	cm/s	Stepping Down	Velocity of the Centre of Mass on the Y axis
16	SD_intZ(tt)	cm/s	Stepping Down	Velocity of the Centre of Mass on the Z axis
17	SD_iintX(tt)	cm	Stepping Down	Displacement of the Centre of Mass on the X axis
18	SD_iintY(tt)	cm	Stepping Down	Displacement of the Centre of Mass on the Y axis
19	SD_iintZ(tt)	cm	Stepping Down	Displacement of the Centre of Mass on the Z axis
20	SD_en	cm/s^3	Stepping Down	Loading rate between FC1 and FO2
21	SD_impX(ITOTAL)	cm/s	Stepping Down	Antero posterior impulse between t0 and FO2
22	SD_impY(ITOTAL)	cm/s	Stepping Down	Medio Lateral impulse between t0 and FO2
23	SD_impZ(ITOTAL)	cm/s	Stepping Down	Vertical impulse between t0 and FO2
24	SD_IAPAX	cm/s	Stepping Down	Antero Posterior impulse between FO1 and T0
25	SD_IAPAY	cm/s	Stepping Down	Medio Lateral impulse between FO1 and T0
26	SD_IAPAZ	cm/s	Stepping Down	Vertical impulse between FO1 and T0
27	SD_ISWX	cm/s	Stepping Down	Antero-Posterior Impulse between FC1d and F01
28	SD_ISWY	cm/s	Stepping Down	Medio-Lateral Impulse between FC1d and F01
29	SD_ISWZ	cm/s	Stepping Down	Vertical Impulse between FC1d and F01
30	SD_IWTX	cm/s	Stepping Down	Antero-Posterior Impulse between FO2 and

				FC1d
31	SD_IWTY	cm/s	Stepping Down	Medio-Lateral Impulse between FO2 and FC1d
32	SD_IWTZ	cm/s	Stepping Down	Vertical Impulse between FO2 and FC1d
33	SD_AP0(FO1)	cm	Stepping Down	Position of the CoP on X at FO1
34	SD_ML0(FO1)	cm	Stepping Down	Position of the CoP on Y at FO1
35	SD_accXR(FO1)	cm/s^2	Stepping Down	Acceleration on X at F01 normalized witht he weight
36	SD_accYR(FO1)	cm/s^2	Stepping Down	Acceleration on Y at F01 normalized witht he weight
37	SD_accZR(FO1)	cm/s^2	Stepping Down	Acceleration on Z at F01 normalized witht he weight
38	SD_accXN(FC1d)	/	Stepping Down	Reaction force on X at FC1d normalized with weight
39	SD_accYN(FC1d)	/	Stepping Down	Reaction force on Y at FC1d normalized with weight
40	SD_accZN(FC1d)	/	Stepping Down	Reaction force on Z at FC1d normalized with weight
41	SD_accXN(tPMC)	/	Stepping Down	Reaction force on X at tPMC normalized with weight
42	SD_accYN(tPMC)	/	Stepping Down	Reaction force on Y at tPMC normalized with weight
43	SD_accZN(tPMC)	/	Stepping Down	Reaction force on Z at tPMC normalized with weight
44	SD_MDIST	cm	Stepping Down	Mean Distance
45	SD_MDISTAP	cm	Stepping Down	Mean Distance Antero-Posterior
46	SD_MDISTML	cm	Stepping Down	Mean Distance Medio-Lateral
47	SD_TOTEX	cm	Stepping Down	Total sway Excursion
48	SD_TOTEXAP	cm	Stepping Down	Total sway Excursion Antero-Posterior
49	SD_TOTEXML	cm	Stepping Down	Total sway Excursion Medio-Lateral
50	SD_AREASW	cm	Stepping Down	Area Sway
51	SD_MVELO	cm/s	Stepping Down	MeanVelocity
52	SD_MVELOAP	cm/s	Stepping Down	MeanVelocity Antero-Posterior
53	SD_MVELOML	cm/s	Stepping Down	MeanVelocity Medio-Lateral
54	SD_RANGE	cm	Stepping Down	Range
55	SD_RANGEAP	cm	Stepping Down	Range Antero-Posterior
56	SD_RANGEML	cm	Stepping Down	Range Medio-Lateral
57	SW_MDIST	cm	Standing	Mean Distance
58	SW_MDISTAP	cm	Standing	Mean Distance Antero-Posterior
59	SW_MDISTML	cm	Standing	Mean Distance Medio-Lateral
60	SW_RDIST	cm	Standing	Rootmean Square Distance
61	SW_RDISTAP	cm	Standing	Root Mean Square Distance Antero-Posterior
62	SW_RDISTML	cm	Standing	Root Mean Square Distance Medio-Lateral
63	SW_MVELO	cm/s	Standing	MeanVelocity
64	SW_MVELOAP	cm/s	Standing	MeanVelocity Antero-Posterior
65	SW_MVELOML	cm/s	Standing	MeanVelocity Medio-Lateral
66	SW_RANGE	cm	Standing	Range

67	SW_RANGEAP	cm	Standing	Range Antero-Posterior
68	SW_RANGEML	cm	Standing	Range Medio-Lateral
69	SW_AREACC	cm^2	Standing	Area Confidence Circle
70	SW_AREACE	cm^2	Standing	Area Confidence Ellipse
71	SW_AREASW	cm^2/s	Standing	Area Sway
72	SW_MFREQ	Hz	Standing	MeanFrequency
73	SW_MFREQAP	Hz	Standing	MeanFrequency Antero-Posterior
74	SW_MFREQML	Hz	Standing	MeanFrequency Medio-Lateral
75	SW_FD	/	Standing	Fractal Dimension
76	SW_FDCC	/	Standing	Fractal Dimension Confidence circle
77	SW_FDCE	/	Standing	Fractal Dimension Confidence Ellipse
78	SW_POWERRD	cm^2/s	Standing	Total Power
79	SW_POWERAP	cm^2/s	Standing	Total Power Antero-Posterior
80	SW_POWERML	cm^2/s	Standing	Total Power Medio-Lateral
81	SW_uDELTAFRD	Hz	Standing	MedianFrequency
82	SW_uDELTAFAP	Hz	Standing	MedianFrequency Antero-Posterior
83	SW_uDELTAFML	Hz	Standing	MedianFrequency Medio-Lateral
84	SW_vDELTAFRD	Hz	Standing	95 % Frequency
85	SW_vDELTAFAP	Hz	Standing	95% Frequency Antero-Posterior
86	SW_vDELTAFML	Hz	Standing	95% Frequency Medio-Lateral
87	SW_CFREQRD	Hz	Standing	CentroidFrequency
88	SW_CFREQAP	Hz	Standing	CentroidFrequency Antero-posterior
89	SW_CFREQML	Hz	Standing	CentroidFrequency Medio-Lateral
90	SW_FREQDRD	Hz	Standing	Frequency of Dispersion
91	SW_FREQDAP	Hz	Standing	Frequency of Dispersion Antero-Posterior
92	SW_FREQDML	Hz	Standing	Frequency of Dispersion Medio-Lateral
93	SW_DFAAP	/	Standing	Detrented Fluctuation Analysis Antero-Posterior
94	SW_DFAML	/	Standing	Detrented Fluctuation Analysis Medio-Lateral
95	SW_DFARD	/	Standing	Detrented Fluctuation AnalysisResultant
96	SW_RSAP	cm	Standing	Rescaled Range Analysis Antero-Posterior
97	SW_RSML	cm	Standing	Rescaled Range Analysis Medio-Lateral
98	SW_RSRD	cm	Standing	Rescaled Range AnalysisResultant
99	SW_DSAP	/	Standing	Diffusion Coefficient short term Antero-Posterior (SDA)
100	SW_DSML	/	Standing	Diffusion Coefficient short term Medio Lateral (SDA)
101	SW_DSRD	/	Standing	Diffusion Coefficient short termResultant (SDA)
102	SW_DLAP	/	Standing	Diffusion Coefficient long term Antero-Posterior (SDA)
103	SW_DLML	/	Standing	Diffusion Coefficient long term Medio-Lateral (SDA)
104	SW_DLRD	/	Standing	Diffusion Coefficient long termResultant (SDA)

105	SW_HSAP	/	Standing	Hurst exponent short term Antero-Posterior (SDA)
106	SW_HSML	/	Standing	Hurst exponent short term Medio-Lateral (SDA)
107	SW_HSRD	/	Standing	Hurst exponent short term Resultant (SDA)
108	SW_HLAP	/	Standing	Hurst exponent long term Antero-Posterior (SDA)
109	SW_HLML	/	Standing	Hurst exponent long term Medio-Lateral (SDA)
110	SW_HLRD	/	Standing	Hurst exponent long term Resultant (SDA)
111	SW_KSAP	/	Standing	Diffusion coefficient Ornstein Uhlenbeck AP (SDA) ?
112	SW_KSML	/	Standing	Diffusion coefficient Ornstein Uhlenbeck ML (SDA) ?
113	SW_KSRD	/	Standing	Diffusion coefficient Ornstein Uhlenbeck RD (SDA) ?
114	SW_KLAP	/	Standing	Derived coefficient Orstein-Uhlenbeck AP (SDA) ?
115	SW_KLML	/	Standing	Derived coefficient Orstein-Uhlenbeck ML (SDA) ?
116	SW_KLRD	/	Standing	Derived coefficient Orstein-Uhlenbeck RD (SDA) ?
117	SW_TCAP	s	Standing	Critical Time Antero-Posterior (SDA)
118	SW_TCML	s	Standing	Critical Time Medio-Lateral (SDA)
119	SW_TCRD	s	Standing	Critical Time Resultant (SDA)
120	SW_XCAP	cm	Standing	Mean quadratic distance Antero-Posterior (SDA)
121	SW_XCML	cm	Standing	Mean quadratic distance Medio-Lateral (SDA)
122	SW_XCRD	cm	Standing	Mean quadratic distance Resultant (SDA)
123	SW_CTMAP	/	Standing	Central tendency Measure Antero-Posterior
124	SW_CTMML	/	Standing	Central Tendency Measure Medio-Lateral
125	SW_CTMEMDAP	/	Standing	Central Tendency Measure Summation IMF Antero-Pos
126	SW_CTMEMDML	/	Standing	Central Tendency Measure Summation IMF Medio-Lat
127	SW_IMEnAP1	/	Standing	Intrinsic Mode Entropy Antero-Posterior 1
128	SW_IMEnAP2	/	Standing	Intrinsic Mode Entropy Antero-Posterior 2
129	SW_IMEnAP3	/	Standing	Intrinsic Mode Entropy Antero-Posterior 3
130	SW_IMEnML1	/	Standing	Intrinsic Mode Entropy Medio-Lateral 1
131	SW_IMEnML2	/	Standing	Intrinsic Mode Entropy Medio-Lateral 2
132	SW_IMEnML3	/	Standing	Intrinsic Mode Entropy Medio-Lateral 3
133	SW_RPSAP1	x	Standing	Reconstructed Phase Space Antero-Posterior 1
134	SW_RPSAP2	x	Standing	Reconstructed Phase Space Antero-Posterior 2
135	SW_RPSAP3	x	Standing	Reconstructed Phase Space Antero-Posterior 3

136	SW_RPSAP4	x	Standing	Reconstructed Phase Space Antero-Posterior 4
137	SW_RPSAP5	x	Standing	Reconstructed Phase Space Antero-Posterior 5
138	SW_RPSAP6	x	Standing	Reconstructed Phase Space Antero-Posterior 6
139	SW_RPSAP7	x	Standing	Reconstructed Phase Space Antero-Posterior 7
140	SW_RPSML1	x	Standing	Reconstructed Phase Space Medio-Lateral 1
141	SW_RPSML2	x	Standing	Reconstructed Phase Space Medio-Lateral 2
142	SW_RPSML3	x	Standing	Reconstructed Phase Space Medio-Lateral 3
143	SW_RPSML4	x	Standing	Reconstructed Phase Space Medio-Lateral 4
144	SW_RPSML5	x	Standing	Reconstructed Phase Space Medio-Lateral 5
145	SW_RPSML6	x	Standing	Reconstructed Phase Space Medio-Lateral 6
146	SW_RPSML7	x	Standing	Reconstructed Phase Space Medio-Lateral 7
147	SW_Lyapu1	x	Standing	LyapunovExponent 1
148	SW_Lyapu2	x	Standing	LyapunovExponent 2
149	SW_Lyapu3	x	Standing	LyapunovExponent 3
150	SW_Lyapu4	x	Standing	LyapunovExponent 4
151	SW_Lyapu5	x	Standing	LyapunovExponent 5
152	SW_Lyapu6	x	Standing	LyapunovExponent 6
153	SW_LyapuY1	x	Standing	LyapunovExponent medio lateral 1
154	SW_LyapuY2	x	Standing	LyapunovExponent medio lateral 2
155	SW_LyapuY3	x	Standing	LyapunovExponent medio lateral 3
156	SW_LyapuY4	x	Standing	LyapunovExponent medio lateral 4
157	SW_LyapuY5	x	Standing	LyapunovExponent medio lateral 5
158	SW_LyapuY6	x	Standing	LyapunovExponent medio lateral 6
159	SU_poids	N	Stepping Up	Weight of the subject
160	SU_FO2	s	Stepping Up	Second foot leaving the ground
161	SU_tVP	s	Stepping Up	Time when 90% of the weight is still on the force plate
162	SU_FC2	s	Stepping Up	Second Foot contact the force plate
163	SU_FC1	s	Stepping Up	First Foot Contacts the force plate
164	SU_tf	s	Stepping Up	End of the Stepping Up phase
165	SU_dTOTAL	s	Stepping Up	Total duration of the stepping up phase
166	SU_dST	s	Stepping Up	Stepping Up movement Duration
167	SU_dSW	s	Stepping Up	Swing Phase Duration
168	SU_accXN(FC1)	/	Stepping Up	Reaction force at FC1 on X normalized with the weight
169	SU_accYN(FC1)	/	Stepping Up	Reaction force at FC1 on Y normalized with the weight
170	SU_accZN(FC1)	/	Stepping Up	Reaction force at FC1 on Z normalized with the weight
171	SU_accXN(tVP)	/	Stepping Up	Reaction force at tVP on X normalized with the weight
172	SU_accYN(tVP)	/	Stepping Up	Reaction force at tVP on Y normalized with the weight

173	SU_accZN(tVP)	/	Stepping Up	Reaction force at tVP on Z normalized with the weight
174	SU_accXN(FC2)	/	Stepping Up	Reaction forceat FC2 on X normalized with the weight
175	SU_accYN(FC2)	/	Stepping Up	Reaction forceat FC2 on Y normalized with the weight
176	SU_accZN(FC2)	/	Stepping Up	Reaction forceat FC2 on Z normalized with the weight
177	SU_impX(tVP)	cm/s	Stepping Up	Impulse antero-posterior at tVP
178	SU_impY(tVP)	cm/s	Stepping Up	Impulse medio-lateral at tVP
179	SU_impZ(tVP)	cm/s	Stepping Up	Impulse vertical axis at tVP
180	SU_impX(FC2)	cm/s	Stepping Up	Impulse antero-posterior at FC2
181	SU_impY(FC2)	cm/s	Stepping Up	Impulse medio-lateral at FC2
182	SU_impZ(FC2)	cm/s	Stepping Up	Impulse vertical axis at FC2
183	SU_VV4	cm/s	Stepping Up	Speed variation on the X axis
184	SU_VV5	cm/s	Stepping Up	Speed variation on the Y axis
185	SU_VV6	cm/s	Stepping Up	Speed variation on the Z axis
186	SU_VD4	cm/s	Stepping Up	Displacement variation ? Acceleration variation ? on X
187	SU_VD5	cm/s	Stepping Up	Displacement variation ? Acceleration variation ? on Y
188	SU_VD6	cm/s	Stepping Up	Displacement variation ? Acceleration variation ? on Z
189	SU_MDIST	cm	Stepping Up	Mean Distance
190	SU_MDISTAP	cm	Stepping Up	Mean Distance Antero-Posterior
191	SU_MDISTML	cm	Stepping Up	Mean Distance Medio-Lateral
192	SU_TOTEX	cm	Stepping Up	Total sway Excursion
193	SU_TOTEXAP	cm	Stepping Up	Total sway Excursion Antero-Posterior
194	SU_TOTEXML	cm	Stepping Up	Total sway Excursion Medio-Lateral
195	SU_AREASW	cm^2/s	Stepping Up	Area Sway
196	SU_MVELO	cm/s	Stepping Up	MeanVelocity
197	SU_MVELOAP	cm/s	Stepping Up	MeanVelocity Antero-Posterior
198	SU_MVELOML	cm/s	Stepping Up	MeanVelocity Medio-Lateral

7.10 Appendix 10 : Description of the number of cases in training and testing sets of the models of 5, 4 and 3 conditions build in chapter 5.

5 conditions models split into training and testing sets

5 conditions models – description of sets for training and testing		
Models	**Training**	**Testing**
5003	34 VD 33 AR 33 FA 38 VP 33 VC	15 VD 16 AR 11 VP 18 VC 14 FA
5008	35 HP 28 VC 37 VP 33 AR 37 FA	16 AR 13 HP 23 VC 10 FA 12 VP
5010	33 CU 31 HP 42 VC 34 AR 30 FA	17 FA 17 HP 15 CU 9 VC 15 AR

4 conditions models split into training and testing sets

4 conditions models – description of sets for training and testing		
Models	**Training**	**Testing**
4004	31 CU 41 VC 35 AR 29 FA	14 AR 18 FA 10 VC 17 CU
4006	AP 30 FA 40 VP 30 AR	17 FA 9 VP 19 AR 13 AP
4019	34 FA 32 VE 35 AR 34 VC	14 AR 13 FA 14 VE 17 VC
4022	34 VA 33 CU 29 AR 38 FA	9 FA 14 VA 15 CU 20 AR
4023	32 VA 37 VC 34 AR 33 FA	16 VA, 14 VC, 14 FA, 15 AR
4025	31 FA, 35 VD, 30 AR, 39 CU	19 AR, 9 CU, 16 FA, 14 VD
4026	36 FA, 34 VD, 30 VC, 37 AR	21 VC, 12 AR, 15 VD, 11 FA
4027	26 CU 33 VP 35 FA 41 AR	22 CU 12 FA 16 VP 8 AR
4028	33 VC, 34 FA, 36 AR, 34 VP	13 FA, 13 AR, 18 VC 15 VP
4029	31 FA 35 AR 34 VC 36 CU	17 VC 14 AR 16 FA 12 CU

3 conditions models split into training and testing sets

3 conditions models – description of sets for training and testing		
Models	**Training**	**Testing**
3005	49 AR 47 FA 49 VP	18 VP 16 AR 11 FA
3100	41 VC 32 AR 30 HP	10 VC 17 AR 18 HP
3050	36 AR 36 FA 28 VD	13 AR 11 FA 21 VD
3053	34 AR 34 AP 34 VD	15 AR 14 AP 15 VD
3104	34 VC 35 FA 33 CU	17 VC 12 FA 15 VC
3013	37 AP 31 AR 34 CU	11 AP 18 AR 14 CU
3002	36 HP 32 VP 34 AR	12 HP 17 VP 15 AR
3106	34 CU 35 AR 34 VC	14 CU 14 AR 17 VC
3069	30 AR 34 FA 35 VC	19 AR 13 FA 11 VE
3012	33 FA 31 CU 36 AR	14 FA 17 CU 13 AR
3109	33 VP 33 CU 36 AR	16 VP 15 CU 13 AR
3108	37 AR 34 AP 21 VP	12 AR 14 AP 18 VP
3121	35 VC 33 FA 35 AR	16 VC 14 FA 14 AR
3118	35 VE 33 AR 31 CU	11 VE 16 AR 17 CU
3031	31 VE 36 VP 34 AR	15 VE 13 VP 15 AR
3011	33 AR 37 VA 30 FA	16 AR 11 VA 17 FA
3008	35 HP 30 AR 35 FA	13 HP 19 AR 12 FA
3077	37 VC 37 VP 30 AR	14 VC 12 VP 19 AR
3091	39 VC 29 VA 35 AR	12 VC 19 VA 14 AR
3043	33 AR 32 VE 35 VD	16 AR 14 VE 14 VD

8 . CONFERENCE & PAPERS

8.1 CONFERENCES

1. Bassement, J.N.C., et al., Construction of a postural sway-based model for rapid detection of physiological risk factors for falls. 7th European Congress of the International Association of Gerontology and Geriatrics, Bologna, Italy 14-17 April 2011. (Abstract published in "Aging Clin Exp Res, vol. 23 suppl .1, Feb 2011, page 213).

2. Bassement J.N.C., and Hewson D.J. Workshop on Gerontechnology. 2nd International Congress on Gerontology and Geriatric Medicine (ICGGM 2012) in New Delhi, India, 24-29 February 2012.

3. Hewson D.J. et al., Development of a monitoring system for physical frailty in independent elderly. 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Osaka, Japan, 03-07 July 2013, pp. 6215-6218.

8.2 PAPERS

1. Bassement, J.N.C., Taylor, D. McNair, P.J., Hewson, D.J., A review of therapeutic intervention on cutaneous receptors to improve balance control, submitted to Eur Rev Aging Phys Activ.

2. Bassement, J.N.C., et al. The effect of cutaneous proprioception impairment on balance quality in older and younger adults, submitted to J. Aging Phys Activ.

9 RESUME EN FRANÇAIS

IDENTIFICATION DES DEGRADATIONS DES FACTEURS DE RISQUE DE CHUTE A PARTIR DE MESURES DE LA QUALITE DE L'EQUILIBRE POSTURAL

Cette thèse fait partie d'un ambitieux projet de recherche qui a pour objectif la construction d'un outil précis, peu coûteux, facile et rapide à utiliser pour la détection des dégradations des facteurs des risques de chute. La thèse décrit le développement d'une série de modèles capables de détecter ces dégradations responsables de la perte d'équilibre. Un tel outil aiderait les professionnels de santé à mettre en place des programmes d'intervention personnalisés adaptés aux besoins des individus.

9.1 CHAPITRE 1 : REVUE DE LA LITTERATURE

9.1.1 EQUILIBRE POSTURALE CHEZ LES PERSONNES AGEES.

9.1.1.1 RISQUES DE CHUTES

Les chutes chez les personnes âgées relatent un problème social majeur avec des conséquences médicales, sociales et financières. Le pourcentage de personnes âgées de plus de 65 ans vivant à domicile et victimes de chutes est évalué entre 30 et 60% chaque année. Le problème des chutes c'est qu'il est grandissant car la population est vieillissante, il y aura 10 fois plus de personnes centenaires en 2060 comparé à 2010. En Nouvelle Zélande le pourcentage de personnes âgées passera à 25% de la population en 2050. Une augmentation du nombre de personnes âgées a de forte chance d'être lié à une augmentation du nombre de chutes.

9.1.1.2 CONSEQUENCES ET CAUSES DES CHUTES

Les chutes peuvent conduire à de graves conséquences physiques, psychologiques et également sociales. La combinaison de ces trois conséquences augmente le déclin des capacités fonctionnelles et mène à la morbidité. Les conséquences physiques peuvent être des fractures ou blessures au crâne provoquant des réductions de mobilité et de possibilité de réaliser les tâches quotidiennes. Les conséquences psychologiques concernent la peur des chutes qui entraine une perte de confiance et la restriction des activités sociales. Entre 25 et 75% des personnes âgées qui subissent une chute avec conséquences physiques ne récupère jamais leur niveau de mobilité d'avant la chute entraînant dans 30% des cas une entrée en institution ou maison de retraite.
Le coût lié aux chutes est considérable, le prix des chutes est estimé à près de 11 millions d'euros par an par hôpital. Avec le vieillissement de la population le coût des chutes risque d'augmenter avec l'âge de la population.
Les causes des chutes ont largement étaient discutées dans la littérature, les facteurs environnementaux, comportementaux et intrinsèques catégorisent ces causes.
Les causes environnementales inclus les risques de trébucher dans la maison comme à l'extérieur comme les tapis ou les sols glissants ou encore des zones peu éclairées.

Les causes comportementales incluent la baisse de l'activité physique, le port de chaussures inappropriées, la prise multiple de médicaments, une mauvaise alimentation, un manque de vitamine D, la présence de maladies chroniques, le manque de support social, la peur des chutes et l'état cognitif.
Enfin les causes intrinsèques de chute concernent les facteurs liés au système locomoteur et sensoriel comme des déficiences visuelles, musculaires, articulaires et proprioceptives.

Un grand nombre d'études ont mis en place avec succès des programmes de prévention des chutes avec une évaluation des facteurs de risques de chute. La détection des facteurs de risque de chute vise à déceler les causes des chutes et cibler les interventions liées aux facteurs dégradés. De nombreux outils sont disponibles pour la détection des facteurs de chute mais même le meilleur des outils ne peut pas détecter tous les risques de chute. Il semble donc important de se concentrer sur l'amélioration de l'équilibre postural en ciblant les risques facteurs qui sont réversibles grâce à des programmes de rééducation.

9.1.1.3 ANALYSE DES RISQUES FACTEURS DE CHUTE INTRINSEQUE

Au vue de mes centres d'intérêts et domaines de compétence et de recherche, ce projet de recherche se focalise sur l'étude des facteurs de risque de chute intrinsèque. Une autre raison de se focaliser sur ces facteurs de risque intrinsèque est qu'il a été montré dans la littérature que la dégradation de ces facteurs est réversible après intervention tel que le Tai Chi l'entrainement de force musculaire ou de proprioception.

Les facteurs de risque de chute intrinsèque étudiés dans ce projet de recherche sont la vision, le système vestibulaire, la proprioception articulaire, l'amplitude articulaire, la force musculaire et la proprioception cutanée plantaire.

9.1.1.3.1 LA VISION

Il a été montré que l'absence de vision ou la diminution des performances visuelles réduisent la stabilité posturale. Il y a plusieurs composants visuels responsables de la qualité de vision : l'acuité visuelle, la sensibilité aux contrastes, la perception des profondeurs et le champ périphérique de vision. Les personnes âgées présentent une dégradation de la performance due à l'âge, mais en plus de ces dégradations naturelles, une proportion importante de personnes âgées présente des troubles visuels importants. Ces personnes âgées affectées montrent habileté fonctionnelles réduite, un manque d'équilibre et de plus gros risque de morbidité.
L'acuité visuelle est l'habileté à détecter les détails, elle décroit avec l'âge. La sensibilité aux contrastes permet de distinguer les objets de leur contexte, habileté particulièrement importante pour détecter les dangers. La perception des profondeurs est l'habileté de percevoir en trois dimensions. Enfin la vision périphérique est utile pour la perception des mouvements notamment de la prise d'information dans le contexte.
Les personnes avec des dégradations visuelles montrent une diminution de l'équilibre postural et des pertes d'habileté fonctionnelle nécessaire à la vie quotidienne et sociale. Certains composants de la vision ont aussi été associés à de plus grand risques de chute chez les personnes âgées.

9.1.1.3.2 LE SYSTEME VESTIBULAIRE

Le système vestibulaire est composé de trois canaux semi-circulaires et de deux organes otolithes. La structure est composée de récepteurs pileux et de liquide. Le mouvement des liquides dans les canaux semi-circulaire stimule les récepteurs pileux et donne ainsi l'information sur l'accélération et l'inclinaison de la tête ce qui est interprété par le cerveau comme information posturale. La dégradation du système vestibulaire provoque des troubles de l'équilibre et une augmentation des risques de chute. Les personnes âgées avec une diminution de l'équilibre ont montré des problèmes vestibulaires.

9.1.1.3.3 L'AMPLITUDE ARTICULAIRE

Les personnes âgées montrent une réduction de l'amplitude articulaire notamment au niveau des articulations des membres inférieurs, les hanches, les genoux et les chevilles.
La plupart des activités quotidiennes dont la marche et la montée et descente des marches nécessite une amplitude articulaire suffisante pour se propulser puis redresser le pied lors d'une foulée. Les personnes âgées chuteuses ont montré une réduction d'amplitude articulaire de ces articulations des membres inférieurs.

9.1.1.3.4 LA PROPRIOCEPTION MUSCULAIRE ET ARTICULAIRE.

La proprioception musculaire et articulaire réfère à la collection d'information par les récepteurs des articulations et des muscles. Les récepteurs musculaires sont appelé les fuseaux neuromusculaires et donnent le sens du mouvement et de position. Les récepteurs articulaires sont les récepteurs de Ruffini qui donnent le sens de position des articulations, les récepteurs de Golgi qui donnent le sens du mouvement et l'intensité du mouvement et les récepteurs des corpuscules de Pacinian qui sont sensibles aux mouvements fins.
La dégradation de ces récepteurs a montré une perturbation de l'équilibre dynamique et statique chez les jeunes aussi bien que chez les personnes âgées.
Il existe un vieillissement naturel de ces structures, mais la dégradation excessive a été liée à de plus gros risques de chute chez les personnes âgées.

9.1.1.3.5 LA FORCE MUSCULAIRE

L'importance de la force musculaire pour le maintien de l'équilibre a été largement démontrée dans la littérature. Cependant, certains muscles sont plus importants et ont une action directe sur le maintien de l'équilibre.
Les fléchisseurs de cheville, de hanche et de genoux sont importants pour le maintien de l'équilibre statique en empêchant le corps de basculer vers l'arrière et pour le maintien de l'équilibre dynamique en assurant la flexion de hanche genou et cheville pour la jambe retour lors de la marche. Les extenseurs de chevilles sont eux nécessaires pour empêcher la chute vers l'avant en équilibre statique et permettre la propulsion en équilibre dynamique.
La perte de force musculaire des jambes a été montré comme responsable d'augmentation du stabilogramme lors de la station debout et donc de diminution de l'équilibre.
Des études ont également montré que la puissance musculaire est importante pour le maintien de l'équilibre. En effet la combinaison de la force et de la vitesse serait plus importante pour permettre la réalisation de mouvement rapide pour assurer l'équilibre ou récupérer l'appui lors d'un trébuchement.
La force musculaire décroit avec l'âge et les personnes chuteuses ont montré une force musculaire diminuée comparé aux personnes non chuteuses.

9.1.1.4 LA PROPRIOCEPTION CUTANEE PLANTAIRE

Les récepteurs cutanés plantaires sont particulièrement importants pour le maintien de l'équilibre postural car ils fournissent des informations directes sur le contact avec le sol lors de la station debout mais aussi la marche. Il y a quatre catégories de récepteurs cutanées qui fournissent des informations sur la pression plantaire, les forces de frottement, l'étirement de la peau, les vibrations et tous stimuli appliqués sur la surface plantaire.
Les récepteurs cutanés plantaires sont pensés être l'origine d'information sur l'évaluation de la surface du sol mais également responsable de la mise en place de réponses posturales pour le maintien de l'équilibre.
La perte de sensibilité plantaire a été associée à une réduction de l'équilibre se traduisant par une augmentation du stabilogramme mesuré sur les plates formes de force. Cette perte de sensibilité a été décrite chez les personnes âgées.

9.1.2 LES OUTILS DE DIAGNOSTIC ET EVALUATION

Plusieurs études ont été publiées sur les évaluations proposées pour la détection de facteurs de risques de chute. Tous ont souligné l'importance de trouver la cause de la chute pour pouvoir la traiter efficacement. De nombreux tests ont été mis en place, le plus souvent nécessitant des installations de laboratoire comme les machines iso cinétique, les accéléromètres, dynamomètre, plateforme de force, les systèmes de capture de mouvement 3D, les chaises rotationnelles pour test vestibulaire. Cependant ces techniques de laboratoire sont coûteuses, demandent un niveau de maîtrise technique des appareils et ne sont pas appropriés pour les tests cliniques ou sur le terrain.

Des tests cliniques ont aussi été développés, les plus utilisés sont le Timed up and go nécessitant de se lever de marcher trois mètres et de se rasseoir le tout chronométré, le test fonctionnel de capacité d'atteindre des objets en dehors de la base de support, les tests de marche, les tests de montée de marches, les tests d'équilibre comme le Berg Balance test ou le test de Tinetti.

Le test Timed up and Go est d'un intérêt particulier pour cette étude, il a été montré que c'est un test valide et fiable. C'est un test clinique rapide et qui en nécessite aucun équipement, des données normatives sont disponibles pour les personnes âgées saines et chuteuses.

Plusieurs études ont conclu que les tests cliniques ont besoin d'être mis en place accompagnés de tests de force musculaire, de proprioception, d'amplitude articulaire pour trouver les problèmes liés à la perte d'équilibre. Plusieurs études ont testé des équipements portables pour analyser l'équilibre comme la balance Wii board ou d'autre plateforme de force portable qui est capable de différentier un stabilogramme d'une personne saine et d'une personne en perte d'équilibre même si les données sont moins précises qu'une plateforme de force.

9.1.3 STABILOGRAMME

L'enregistrement de stabilogramme enregistre les déplacements du centre de pression sur trois axes : antéro-postérieur, médiolatéral et vertical.
L'analyse de l'enregistrement du stabilogramme consiste en le calcul de variables ou paramètres. Un grand nombre de paramètres ont été cités dans la littérature.
Ces paramètres ont été calculés dans de nombreuses études et de variables populations. Les personnes âgées présentent des paramètres du stabilogramme différents comparés aux populations jeunes.
Les facteurs de chute intrinsèques étudiés dans cette thèse ont tous montré des variations de ces paramètres du stabilogramme lors de dégradation naturelle ou expérimentale.
Il semblerait que les facteurs intrinsèques affectent particulièrement certains paramètres.
Plusieurs études ont montré qu'il était possible d'analyser le stabilogramme pour distinguer entre des personnes chuteuses et non-chuteuses et une étude à montrer qu'il était possible de différentier des personnes atteintes de différentes dégradations vestibulaires par l'analyse des paramètres de stabilogramme.
Les études ont utilisé un grand nombre de paramètres et tous différents d'une étude à l'autre, ce qui rend les comparaisons d'études compliqués.
En effet le nombre de paramètres existant dans la littérature est considérable, plusieurs catégories de paramètres ont été décrites, la première étant les paramètres géométriques et temporales du centre de pression (comme la distance la vitesse, l'aire parcourue par le centre de pression), la deuxième catégorie est les paramètres spatio-temporels (concerne majoritairement les paramètres de fréquence), enfin la troisième catégorie concerne les paramètres stochastiques (incluant les paramètres de corrélation, de diffusion et d'entropie).

9.1.4 MODELES DE CLASSIFICATION, POTENTIEL ET INNOVATION

La construction de modèle vient de domaine statistique de machine learning. Les modèles ont été largement utilisés dans le domaine de la santé pour le pronostic, diagnostic, analyse de chance de survie, et aide à la prise de décision.
Les modèles les plus utilisés sont les modèles utilisant les méthodes de régression logistique, les arbres décisionnels, les supports vector machine et les réseaux artificiels de neurones.

Le pourcentage de précision est la méthode la plus utilisée pour évaluer la performance de classification des modèles. Cependant il n'existe pas de norme pour définir la réussite ou l'échec d'un modèle. Les études dans le domaine médical semblent prendre 60% comme minimum pour définir la réussite d'un modèle.
Un autre indice est utilisé dans l'évaluation des modèles : le coefficient de Kappa. Le coefficient de Kappa est habituellement utilisé comme coefficient d'accord, mais également être utilisé comme mesure de fiabilité, de validité et de probabilité et certaines études utilisent le coefficient de Kappa pour l'évaluation de modèles de classification multi-catégories.

Les modèles sont validés de manière interne et de manière externe. La validation interne consiste en différentes méthodes de tests des données tandis que la validation externe consiste à tester les modèles avec des données supplémentaires extérieures à celles utilisées pour la construction du modèle. Ces validations permettent de connaître la capacité du modèle à généraliser pour les données extérieures aux modèles.

9.1.5 OBJECTIF DE LA THESE

Cette thèse fait partie d'un large projet conduit à l'université de Technologies de Troyes (UTT) en France. L'UTT a un laboratoire d'E-santé qui développe des outils pour identifier la fragilité des personnes âgées. Ces outils ont été développés pour faciliter l'évaluation de santé des personnes âgées. Ces outils sont conçus pour être utilisé facilement, rapidement sans l'aide de professionnel de santé tout en étant fiables.
Un des outils développé par l'UTT est un pèse personne appelé testeur de qualité d'équilibre (Balance Quality tester), qui a été modifié pour fournir des données de qualité d'équilibre provenant de plateforme de force. Ce pèse personne a été breveté et fournit des données de stabilogramme sur les axes antéro-postérieur, médiolateral et vertical. Les données sont transférer par système sans fil et peuvent être transférer par téléphone ou tout système relais par Bluetooth. Cet outil a déjà été utilisé dans plusieurs études.

Même si cet outil est capable de mesure la qualité de l'équilibre et donc identifier les dégradations de l'équilibre qui peuvent apparaître avant une chute, les informations concernant les causes de ces pertes d'équilibre et de chute ne sont pas être détecté par cet outil. Le travail de cette thèse a pour objectif de permettre la détection de ces causes de baisse d'équilibre. L'idée est d'identifier les causes intrinsèques de risques de chute responsable de la perte d'équilibre chez les personnes âgées. Cela permettrait d'avoir un outil efficace, rapide et peu couteux pour la détection des risques facteurs intrinsèques de chute pour la population âgée.

L'objectif général de la thèse est donc de développer un outil capable de détecter les dégradations des facteurs de risques intrinsèques de chute chez les personnes âgées. La détection de ces dégradations permettrait aux professionnels de santé d'obtenir des informations sur l'état d'équilibre des patients et possiblement intervenir pour la prévention des chutes en ciblant les besoins des personnes testées.

9.1.6 LIMITATIONS

Cette étude se limite aux 6 facteurs intrinsèques de risque de chute décrit dans ce chapitre. Cette étude inclus principalement des adultes sains et jeunes, c'est-à-dire que les adultes testés n'ont pas ou peu de dégradation dues à l'âge, ni maladie chronique ou maladie dégénérative.

Question de Recherche

- Est-ce que les dégradations expérimentales des facteurs intrinsèques correspondent aux dégradations des personnes âgées.
- Quels sont les paramètres de stabilogramme qui peuvent être utilisé pour caractériser l'équilibre.
- Est-il possible de construire un modèle basé sur les paramètres de stabilogramme pour différentier les personnes saines des personnes montrant des dégradations.
- Est-il possible de construire un modèle sur les bases des paramètres du stabilogramme pour différentier les dégradations des participants parmi les 6 risques facteurs de chute testés dans cette étude.

- Est-ce qu'un tel modèle est efficace pour classifier des personnes âgées avec de réelles dégradations.

9.1.7 OUTCOMES OF WORK

Les résultats de cette thèse sont inclus dans un large projet de l'UTT. Les modèles construits dans cette thèse ont pour but d'être appliqué sur le pèse personne (Balance Quality Tester). Il sera donc possible dans de futures études d'évaluer à domicile la qualité d'équilibre et la qualité des facteurs intrinsèque de chute. Avant, ces études, il sera cependant nécessaire de valider les modèles par une étude clinique.

9.2 CHAPITRE 2 : PROTOCOLE

9.2.1 ORGANISATION DE L'EXPERIENCE

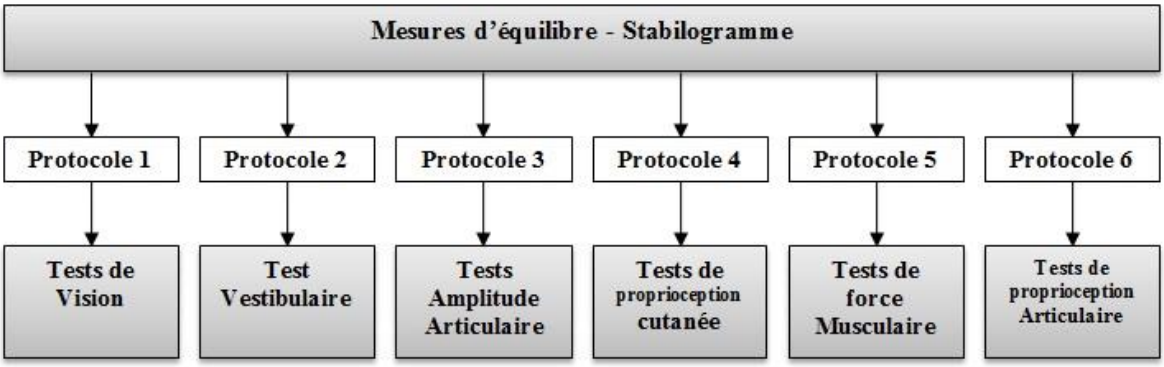
Cette thèse est un projet collaboratif entre l'Université de Technologies d'Auckland (AUT) et l'université de Technologies de Troyes (UTT). La thèse fait partie d'un plus grand projet au sein de l'Université de Troyes (UTT), projet qui est en collaboration avec l'Institut de Technologies de Jodhpur of India (IITJ). Le projet France/ India dans lequel cette thèse est incluse a pour objectifs d'adapter les outils construit par l'UTT pour la population indienne.
Par conséquent, il a été décidé de mener la première expérience à l'institut de Technologie de Jodhpur (IITJ) dans les installations du laboratoire d'analyse de mouvement de l'IITJ et du département de kinésithérapie de l'hôpital de Jodhpur. Les expériences n'ont pas pu être conduites toutes au même endroit car la thèse a été répartie géographiquement en France, Nouvelle Zélande plus quelques mois en Inde.
Une seconde expérience identique à la première a ensuite été conduite en Nouvelle Zélande.

Les deux expériences ont été validées par le comité d'éthique des deux pays, le comité d'éthique du SN Medical College of Jodhpur, Rajasthan, India a validé l'expérience en Inde et le comité d'éthique d'Auckland université de Technologies a validé l'expérience en Nouvelle Zélande.

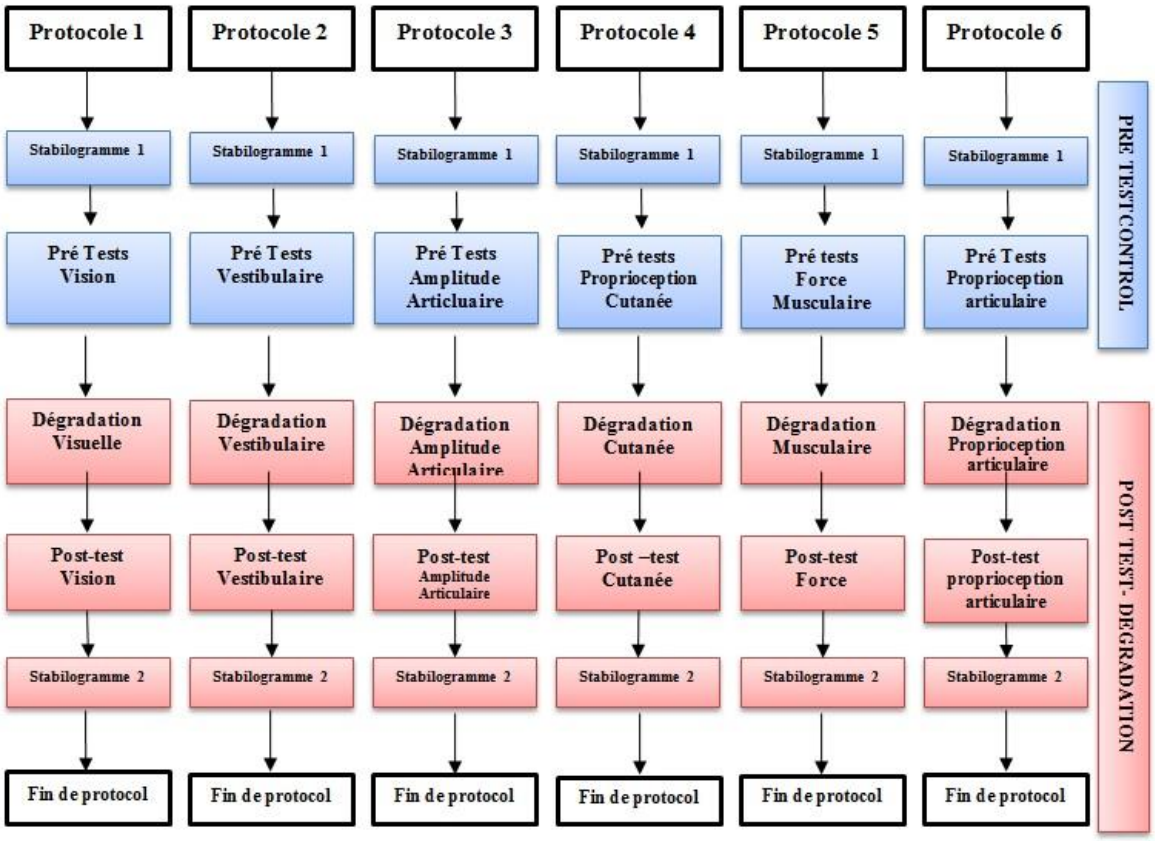
9.2.2 PROTOCOL

L'objectif des expériences est d'analyser l'effet des facteurs intrinsèques de risque de chute sur les paramètres de l'équilibre mesuré par une plateforme de force.

Les expériences ont testé plusieurs populations, des jeunes adultes sains en Inde, des jeunes adultes sains en Nouvelle Zélande et des personnes âgées en Inde.
Les personnes âgées ont participé à une série de tests cliniques et à des mesures d'équilibres sur une place forme de force comme indiqué sur la figure A.



La population de jeunes adultes est testée avant et après dégradation temporaire et expérimentale des facteurs intrinsèques de chute. Le protocole pour les jeunes adultes est exposé sur la figure B.



L'ordre des tests est semi aléatoire, pour les personnes âgées, l'évaluation musculaire est toujours testée en dernier pour éviter que la fatigue musculaire influence les résultats des autres tests.
Pour les jeunes adultes, deux sessions sont nécessaires pour tester les 6 facteurs intrinsèques de chute. La force musculaire et la proprioception plantaire sont toujours testées en fin de chaque session, les autres facteurs sont testés en ordre aléatoire.

Les participants ont lu la feuille d'information, signé les formulaires de consentement et répondu à un questionnaire sur leur âge leur activité physique, leur travail et loisirs ainsi que leur maladie.
Les mesures de stabilogramme ont été mesurées par une plateforme de force Bertec pour l'expérience de Jodhpur et Kistler pour l'expérience d'Auckland.

Les tests de visions utilisés sont le test de Snellen pour l'acuité visuelle, le test Perceptrix pour la vision des contrastes et le test de champ de vision pour la vision périphérique. Le système vestibulaire est testé par le test de Fukuda. Le test de Semmes Weinsein est utilisé pour l'évaluation de la proprioception cutanée plantaire, le même test plantaire a été utilisé pour les deux expériences mais le nombre de zones sensibles est compté à Jodhpur car un seul mono-filament était disponible alors que l'index du mono-filament est enregistré à Auckland car une gamme complète de mono filaments était disponible. L'amplitude articulaire a été mesurée de manière passive et la proprioception articulaire et musculaire de manière active. Un goniomètre manuel a été utilisé à Jodhpur et un goniomètre électrique a été utilisé à Auckland. La force musculaire a été mesurée par un test maximal isométrique en position de chaise pour Jodhpur et avec une presse inclinée pour Auckland. Pour les personnes âgées, le test de force musculaire est différent, le test de « 5 sit to stand » et « heel raises » ont été réalisés et chronométrés. Les personnes âgées ont également réalisé le test de « times up and go ».

Les dégradations réalisées dans l'étude ne concernent que la population jeune. Ces dégradations ont pour but de correspondre à un vieillissement des systèmes physiologique et musculo-squelettique étudiés. Les dégradations pour la vision ont été mise en place par le port de lunette de protection (couvrant entièrement les yeux) modifiées. Les lunettes pour l'acuité visuelle étaient couvertes d'un papier flou, les lunettes pour réduire la sensibilité aux contrastes étaient couvertes de point blanc et une lumière forte était pointés vers ses points blancs, les lunettes réduisant la perception des profondeurs avaient un œil couvert, les lunettes réduisant la vision périphérie étaient couvertes de papier noir sauf un trou devant chaque pupille pour fournir une vision centrale. La dégradation du système vestibulaire a été faite avec un système de stimulation galvanique placé derrière les oreilles pour perturber le nerf vestibulaire. La dégradation des amplitudes articulaires ont été faites par le port d'orthèse. A Jodhpur les hanches, genoux et hanches sont testés, seules les chevilles sont testées dans l'expérience d'Auckland (les hanches et genoux n'ont pas montré de résultats convaincants lors des tests à Jodhpur). La dégradation de la proprioception articulaire et musculaire a été réalisée par la vibration des tendons, hanches, genoux et chevilles pour Jodhpur et hanches et chevilles pour Auckland. La dégradation musculaire a été mise en place par un exercice de fatigue musculaire des jambes similaire aux tests de force musculaire. La dégradation de la proprioception cutanée plantaire est effectuée par l'hypothermie de la voûte plantaire.

L'organisation du protocole est la suivante :

- Pour les personnes âgées
    - Feuille d'information et explication orale.
    - Formulaire de consentement
    - Questionnaire
    - Mesures de stabilogramme
        - 3 x 30 secondes (monter sur la plateforme, rester debout puis redescendre de la plateforme).
    - Le test de Timed up and go
    - Tests de facteur intrinsèque de chute (test vision)

- Tests de facteur intrinsèque de chute (test vestibulaire)
- Tests de facteur intrinsèque de chute (test d'amplitude articulaire)
- Tests de facteur intrinsèque de chute (test de proprioception articulaire et musculaire)
- Tests de facteur intrinsèque de chute (test de proprioception cutanée)
- Tests de facteur intrinsèque de chute (test de force musculaire)

- Pour les jeunes adultes.

- <u>Session 1</u>
  - Feuille d'information et explication orale
  - Formulaire de consentement
  - Questionnaire
  - Pré-test stabilogramme
    - 3x30s (monter sur la plateforme, rester debout puis redescendre de la plateforme).
  - Pré-test de facteur intrinsèque (1)
    - Pre-test (Vision)
    - Degradation (lunettes)
    - Post-tests (Vision)
    - Post-test stabilogramme avec dégradation
      - 4 x 30s (1 x acuité visuelle, 1x vision des contraste, 1x vision des perception et 1x vision périphérique *(x3 pour l'étude à Auckland)*
    - Retrait des dégradations
  - Pré-test de facteur intrinsèque (2)
    - Pre-test (Vestibulaire)
    - Degradation (galvanic stimulation)
    - Post-tests (Vestibulaire)
    - Post-test stabilogramme avec dégradation
      - 1 x 30s *(x3 pour l'étude à Auckland)*
    - Retrait de la dégradation
  - Pré-test de facteur intrinsèque (3)
    - Pre-test (force musculaire)
    - Degradation (exercise fatigue musculaire)
    - Post-tests (force musculaire)
    - Post-test stabilogramme avec dégradation
      - 1 x 30s *(x3 pour l'étude à Auckland)*
    - Retrait de la dégradation

- <u>Session 2</u>
  - Pré-test stabilogramme
    - 3x30s (montrer sur la plateforme, rester debout puis redescendre de la plateforme).
  - Pré-test de facteur intrinsèque (4)
    - Pre-test (Amplitude articulaire)
    - Degradation (orthèses)
    - Post-tests (Amplitude articulaire)
    - Post-test stabilogramme avec dégradation

                - 1 x 30s *(x3 pour l'étude à Auckland)*
            - Retrait de la dégradation
    - Pré-test de facteur intrinsèque (5)
        - Pre-test (Proprioception articulaire et musculaire)
        - Degradation (vibration)
        - Post-tests (Proprioception articulaire et musculaire)
        - Post-test stabilogramme avec dégradation
            - 1 x 30s *(x3 pour l'étude à Auckland)*
        - Retrait de la dégradation
    - Pré-test de facteur intrinsèque (6)
        - Pre-test (Proprioception cutanée plantaire)
        - Degradation (hypothermie)
        - Post-tests (Proprioception cutanée plantaire)
        - Post-test stabilogramme avec dégradation
            - 1 x 30s *(x3 pour l'étude à Auckland)*
        - Retrait de la dégradation

Note: pour l'étude de Jodhpur, 3 mesures de stabilogramme ont été enregistrées puis 1 mesure de stabilogramme après chaque dégradation. Pour l'étude d'Auckland, 3 mesures ont été enregistrées avant la dégradation et 3 mesures après chaque dégradation.
Pour l'amplitude articulaire, les hanches, genoux et chevilles ont été testés à Jodhpur et seulement les hanches et les chevilles à Auckland. Pour la proprioception articulaire, les hanches, les genoux et les chevilles ont été testé à Jodhpur et seulement les chevilles à Auckland.

9.3 CHAPITRE 3 COLLECTE DES DONNEES ET ANALYSES DES DONNEES.

Les informations concernant les participants (activité physique, poids) ont été directement rentrées dans des feuilles de calculs Excel pour les calculs des valeurs moyennes, d'écart type, minimum et maximum. Les mêmes calculs ont également été faits pour les résultats de tests cliniques. Les scores des tests cliniques ont le plus souvent été fournis par les tableaux de score des tests utilisés. Le score des tests d'acuité visuel est fourni par la fraction de la ligne que le participant est capable de lire. Le score de la vision des contrastes est fourni par l'échelle Perceptrix selon la ligne que le participant est capable de lire. Le score de la perception des profondeurs est compris entre 0 et 3 selon le nombre de planches que le participant peut lire. Le score de la vision périphérique est l'angle de vision du participant. Le test vestibulaire de Fukuda est mesuré avec trois valeurs, l'angle de déplacement, l'angle de rotation et la distance de déplacement par rapport au point de départ du test. La proprioception articulaire et musculaire est mesurée en degrés par l'angle d'erreur entre l'angle testé et l'angle lors du repositionnement. L'amplitude articulaire est mesurée par l'angle total mesuré pour chaque articulation. Le score du test musculaire est le poids maximum que le participant a pu soulever pendant le test isométrique. Le score de la proprioception cutanée est différent pour les deux expériences, à Jodhpur le score est le nombre de zone sur la surface plantaire dont le participant ressent le toucher du mono-filament. L'expérience à Auckland a pour score

pour la proprioception cutanée l'index du mono filament le plus fin que les participants pouvaient sentir.
Pour les personnes âgées, un tableau de score a été créé pour identifier les détériorations les plus importantes parmi les facteurs de chute testés.

Les données de stabilogramme ont été enregistrées directement par les logiciels Bertec pour Jodhpur et Qualysis pour Auckland. Les données ont ensuite été exportées pour être utilisées dans le logiciel Matlab. Le projet UTT dans lequel cette thèse est incluse, a précédemment calculé un grand nombre de paramètres de stabilogramme et créé des programmes Matlab pour le calcul de ces paramètres de montée et descente de la plateforme ainsi que les paramètres du maintien de la station debout.
Cette thèse a revu tous ces paramètres et leurs calculs. Les 198 paramètres de cette thèse sont calculés dans Matlab. La liste complète des paramètres est décrite dans la thèse.

Ces paramètres sont utilisés pour la construction de modèle avec pour objectifs de déterminer les dégradations des facteurs de risques de chute.
Le logiciel utilisé pour la construction des modèles est WEKA. Les modèles construits utilisent plusieurs classificateurs, la régression logistique, les arbres décisionnels, les supports vector machine et les réseaux de neurones artificiels.

Différent modèles ont été créés pour répondre aux objectifs de la thèse :

- Vérifier que les conditions de dégradations diffèrent de la condition contrôle
- Vérifier que les conditions de dégradations diffèrent les unes des autres
- Etudier le pourcentage de précision des modèles selon le nombre de conditions incluses
- Définir la combinaison de conditions qui donne le meilleur pourcentage de précision.
- Mettre en place la sélection de paramètres pour conserver les paramètres les plus importants dans la différentiation des conditions
- Etudier le pourcentage de précision des modèles après la sélection de paramètres.
- Construire un modèle avec les meilleurs conditions et sélections de paramètres donnant le meilleur pourcentage de précision.
- Tester le meilleur modèle construit avec les données provenant des personnes âgées.

Plusieurs options de classification sont disponibles avec le logiciel Weka notamment les méthodes de cross validation et de percentage split. Dans cette étude, la méthode de cross-validation avec 10 fichiers est la méthode utilisée.
Plusieurs informations sont données par le logiciel Weka lors de la construction et l'analyse des modèles. Les informations utilisées dans cette étude sont le pourcentage de précision et le coefficient de Weka. Etant donné qu'il n'y a pas de d'étalon pour définir la validité des modèles, une nomenclature a été mise en place dans cette étude pour pouvoir évaluer la validité des modèles.

Nomenclature	**Insignifiiant**	**Léger**	**Moderé**	**Large**	**très large**	**Presque parfait**	Parfait
Kappa coefficient	0.00	0.10	0.30	0.50	0.70	0.90	1.00
% de precision	/	/	60%	65 %	75%	85%	100%

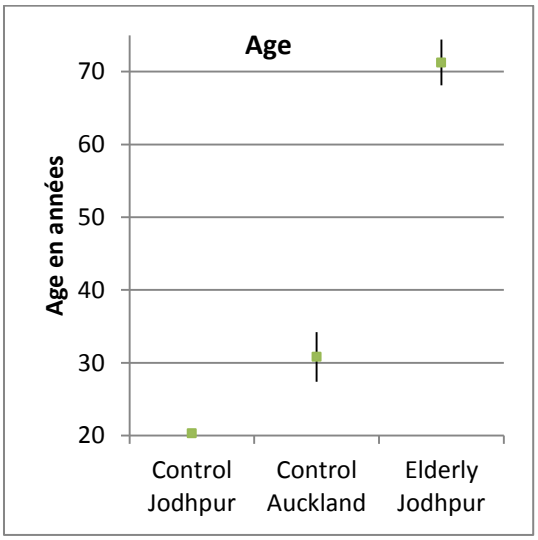
Il est possible d'améliorer les modèles par l'utilisation d'une méthode de sélection de paramètres. Dans le logiciel WEKA la méthode utilisée est Wrapper Subset Eval avec le

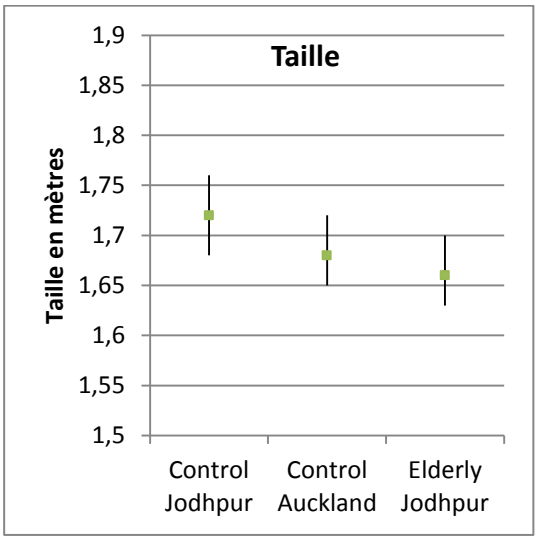
classificateur SVM qui est le plus rapide et plus efficace comparé aux autres classificateurs étudié et la méthode de recherche Be First and Greedy Stepwise.

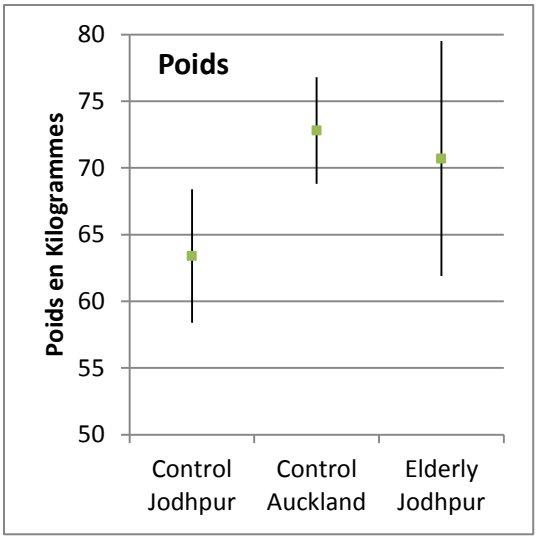
Le modèle est ensuite testé pour confirmer sa validité. La validité interne du modèle est testée grâce à la méthode de séparation des données, 70% des données sont utilisées pour construire le modèle et 30% des données ont été utilisées pour tester la validité interne des modèles. De plus tous les modèles ont été construits par l'utilisation de cross validation (10 folds) qui est en fait une répétition de séparation des données par dossier, avec tests successifs sur chaque dossier. Seuls les modèles avec un pourcentage de 65% et une valeur de Kappa de 0.50 ont été testés en utilisant la validation interne.
La validation externe des modèles a été réalisée en testant les données des personnes âgées sur les modèles montrant 65% o Kappa 0.5 de réussite après la validation interne. Peu de données de personnes âgées étaient disponibles car seuls peu de personnes âgées sur les 25 testés montraient une dégradation unique. Ces données ont toutes été testées sur les modèles pour évaluer la validité externe de ces modèles.

9.4 CHAPITRE 4 : RESULTATS

Les populations testées sont 25 jeunes adultes sains à Jodhpur, 25 jeunes adultes sains à Auckland et 28 personnes âgées à Jodhpur.
Les caractéristiques des populations testées sont présentées dans les graphiques suivants.







Les trois groupes montrent une taille et poids similaire, seul l'âge diffère entre les groupes.

9.4.1 RESULTATS DES TESTS CLINQUES

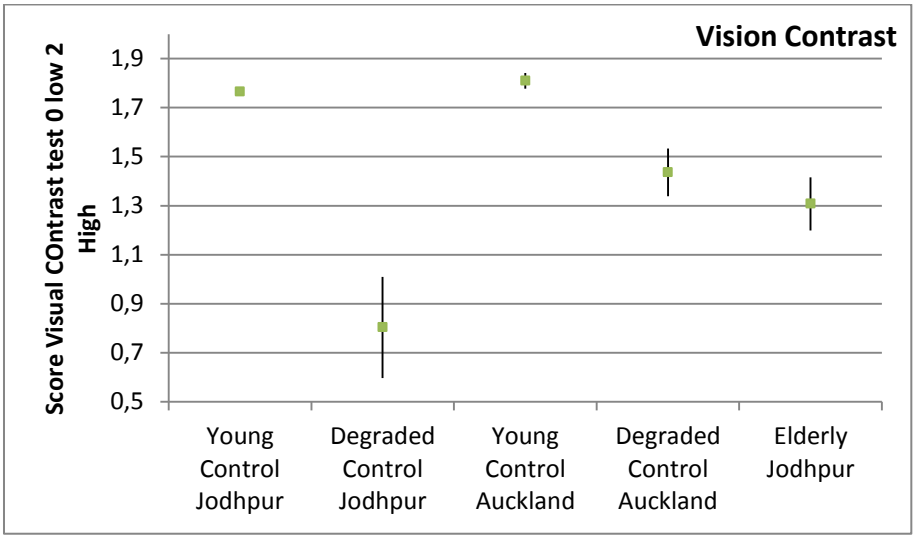
La détérioration des personnes âgées est évaluée selon le score de chacun des tests des risques facteurs de chute. Les scores de chaque personne âgée sont rapportés dans le tableau suivant.

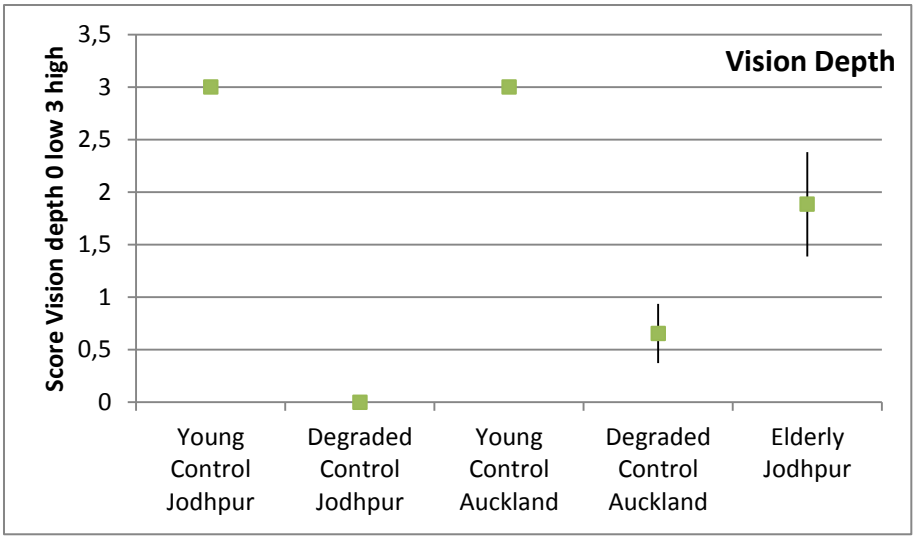
SCORE	Vestibulaire a	Vestibulaire b	Vestibulaire c	Acuité Visuelle	Vision des contrastes	Vision des profondeurs	Vision périphérique	Proprioception cheville	Proprioception Genou	Proprioception Hanche	Amplitude Cheville	Amplitude genou	Amplitude Hanche	Proprioception Plantaire	Force Quadriceps	Gastrocnemius Force	Dégradation principale
P.Agée 1	2	2	3	3	2	2	2	2	2	2	4	2	2	3	3	1	**Amplitude Cheville**
P.Agée 2	3	4	2	3	3	5	2	3	1	1	2	2	2	3	2	2	**Vestibulaire**
P.Agée 3	1	3	2	3	3	2	2	3	2	2	4	2	3	3	1	2	**Amplitude Cheville**
P.Agée 4	2	2	4	4	3	5	3	2	2	3	4	3	3	3	3	2	**Multiple**
P.Agée 5	2	2	3	3	3	4	3	2	2	2	4	3	4	4	3	2	**Multiple**
P.Agée 6	2	2	3	1	3	2	2	2	2	2	4	2	3	4	2	2	**Multiple**
P.Agée 7	3	3	2	3	2	3	3	5	2	3	3	3	3	4	2	2	**Proprioception Cheville**
P.Agée 8	4	4	3	3	4	4	3	2	2	2	4	2	5	1	2	2	**Amplitude Hanche**
P.Agée 10	2	2	3	3	3	2	3	4	2	4	3	2	3	3	2	2	**multiple**
P.Agée 12	3	2	3	3	3	3	3	1	1	2	2	3	2	3	1	2	**multiple**
P.Agée 14	3	2	2	5	3	4	3	4	4	1	4	2	3	3	3	3	**Acuité Visuelle**
P.Agée 15	3	2	3	4	3	2	3	2	2	1	4	2	2	5	3	3	**multiple**
P.Agée 16	3	2	4	4	4	3	3	1	1	2	4	1	2	3	2	2	**multiple**
P.Agée 17	4	3	3	4	2	3	3	2	2	2	4	2	4	3	3	2	**multiple**
P.Agée 18	3	2	3	4	3	3	3	2	2	3	3	1	2	3	2	2	**Acuité Visuelle**
P.Agée 19	1	1	3	5	4	5	4	2	2	1	3	2	3	4	3	5	**multiple**
P.Agée 20	3	3	3	3	3	5	3	2	2	1	4	2	3	3	2	2	**Vision des**

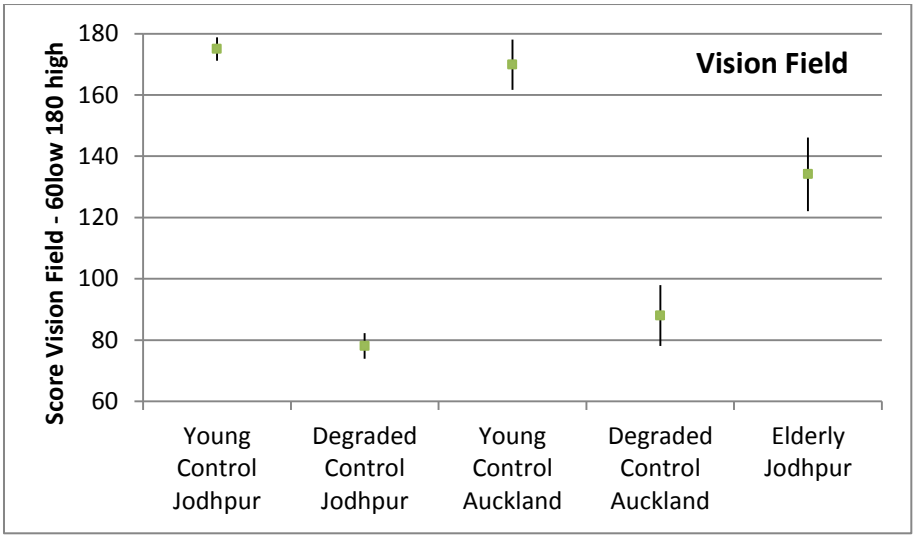
																	profondeurs
P.Agée 21	5	5	5	3	3	4	4	2	2	2	3	2	5	5	4	2	**multiple**
P.Agée 22	4	2	3	3	3	3	3	3	2	3	4	3	3	3	2	3	**multiple**
P.Agée 23	4	3	3	3	3	3	3	1	2	1	2	2	3	2	1	2	**Vestibulaire**
P.Agée 24	2	2	2	3	3	4	3	2	4	2	4	3	4	3	3	3	**multiple**
P.Agée 25	3	2	3	3	3	2	3	3	1	1	5	2	2	4	3	2	**Amplitude cheville**
P.Agée 26	3	2	4	2	3	2	3	2	1	2	3	2	3	3	2	2	**Vestibulaire**
P.Agée 27	2	2	4	3	3	3	3	1	1	2	1	1	3	2	1	2	**Vestibulaire**
P.Agée 28	2	2	2	3	4	3	3	2	1	2	4	3	3	3	2	2	**Amplitude Cheville**

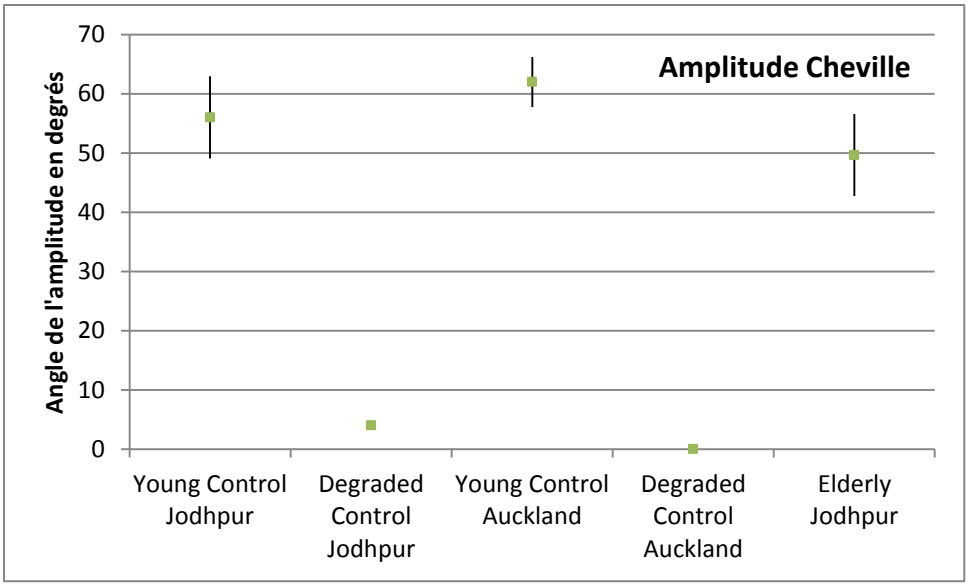
La plupart des personnes âgées montrent plusieurs dégradations, seulement 4 montrent une dégradation de cheville, 4 montrent une dégradation du système vestibulaire et 2 montrent une dégradation de l'acuité visuelle. Les autres montrent principalement de multiples dégradations.

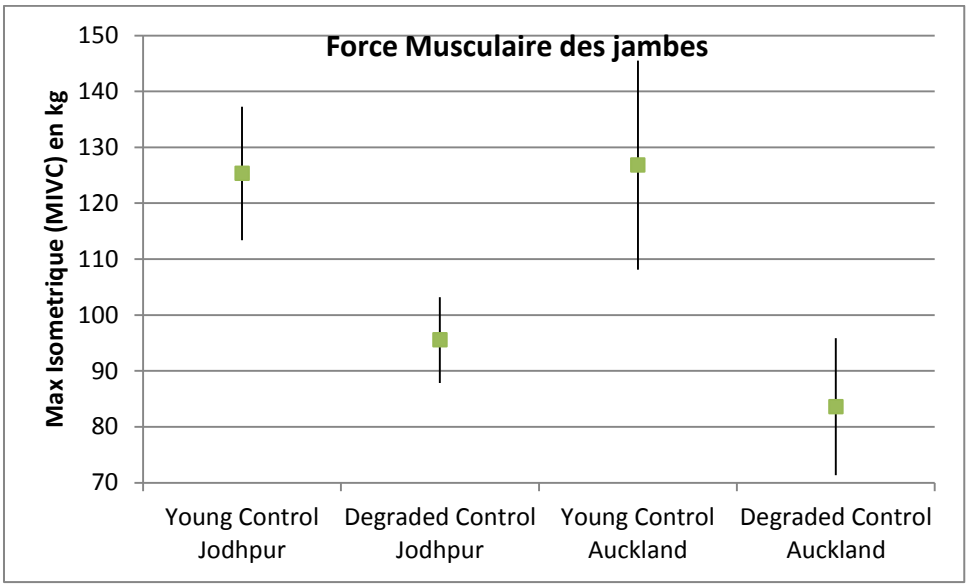
Les tests cliniques réalisés sur les personnes âgées puis sur les jeunes adultes avant et après dégradations montrent les différences entre les populations et montrent notamment l'efficacité des dégradations temporaires appliqués sur les jeunes adultes. Les graphiques suivant exposent les conditions les plus utilisées dans les modèles utilisés pour l'analyse des paramètres du stabilogramme.




Vision Depth
Score Vision depth 0 low 3 high
3,5
3
2,5
2
1,5
1
0,5
0
Young Control Jodhpur
Degraded Control Jodhpur
Young Control Auckland
Degraded Control Auckland
Elderly Jodhpur

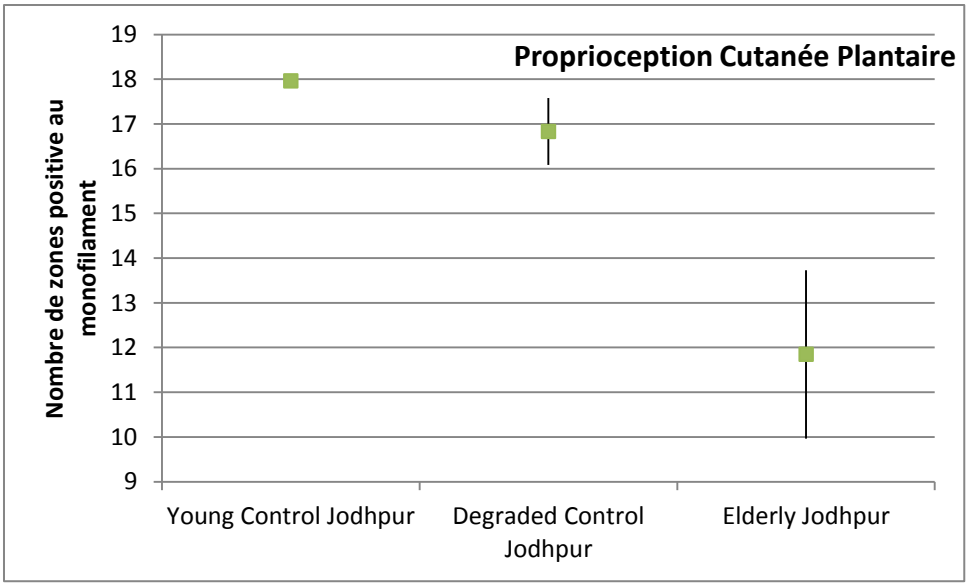

Vision Field
Score Vision Field - 60low 180 high
180
160
140
120
100
80
60
Young Control Jodhpur
Degraded Control Jodhpur
Young Control Auckland
Degraded Control Auckland
Elderly Jodhpur

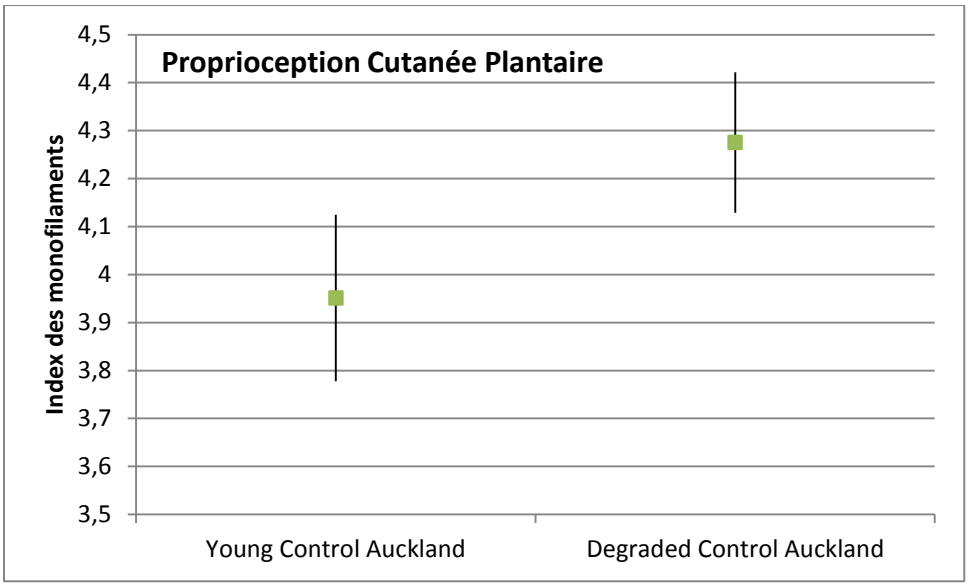




Les tests sont différents pour les personnes âgées, les résultats de ces tests cliniques sont exposés dans les graphiques suivant.

Les résultats des tests de proprioception plantaires sont décrits dans les graphiques suivants.





9.4.2 RESULTATS DES PARAMETRES DE STABILOGRAMME

9.4.2.1 CONSTRUCTION DES MODELES

Le premier modèle construit a pour but de vérifier que les populations dégradées montrent un pattern de stabilogramme différent des populations contrôles. Les résultats du modèle sont exposés dans le tableau suivant.

Les jeunes adultes control comparer aux jeunes adultes dégradés					
Classificateur	**SVM**	**ANN**	**J48**	**Simple logistic**	**Kappa**
Entrainement	88.%	85 %	90 %	89 %	0.42
Test	91 %	81 %	87 %	91 %	0.39

Plusieurs modèles ont ensuite été construits pour comparer chacune des conditions dégradées avec les sujets control. Les résultats sont détaillés dans cette thèse.
La deuxième étape consiste à construire des modèles incluant plusieurs conditions. Le modèle incluant 10 conditions montre 32% de réussite de classification. Au vu du mauvais résultat de classification de ce modèle, des modèles avec trois conditions ont été construit pour déterminer quelles étaient les conditions dégradées montrant le plus haut pourcentage de réussite de classification. Le tableau suivant résume les 10 meilleurs et les 10 moins bons modèles permettant ainsi de déterminer les meilleurs et moins bonnes conditions.

Most accurate three-condition models		
Model 3 classes	**Accuracy**	**Kappa**
3008- AR HP FA	81 %	0.72
3012- AR FA CU	81 %	0.72
3111 VA FA AR	81 %	0.71
3100-VC HP AR	81 %	0.69
3002- AR HP VP	81 %	0.69
3121 VC FA AR	80 %	0.68
3106-VC AR CU	80 %	0.70
3069- AR FA VE	80 %	0.66
3050- AR FA VD	79 %	0.68
3118 – VE AR CU	78 %	0.64
Least accurate three-condition models		
Model 3 classes	**Accuracy**	**Kappa**
3080- VC **VD VA**	49 %	0.23
3039- **AP VA VD**	48 %	0.21
3056- **HP VE VA**	48 %	0.20
3094- VC **VE HP**	47 %	0.17
3036- **HP VA VD**	46 %	0.17
3041- **HP VE VD**	46 %	0.17
3016- VP **VD VA**	43 %	0.15
3040- **VA VD** CU	42 %	0.13
3065- **AP HP VE**	42 %	0.12
3067- **AP HP VE**	42 %	0.12

Les meilleures conditions ont donc été choisies pour construire des modèles avec plus de conditions et les moins bonnes conditions ont été exclues des modèles.
Les modèles avec 9 conditions montrent un pourcentage de validité compris entre 31 et 38%, les modèles avec 8 conditions montrent entre 33 et 43%, les modèles de 7 conditions montrent une réussite entre 32 et 49%, les modèles de 6 conditions montrent entre 47 et 58% de validité, les modèles avec 5 conditions montrent entre 53 et 64% et les modèles de 4 conditions montrent entre 58 et 71 %.

9.4.2.2 VALIDITE INTERNE DES MODELES

Les modèles avec une validité au-dessus de 65% ont été ensuite construits avec 70% et testés avec 30% des données. Les modèles de 5 conditions montrent entre 56 et 64% de validité de construction du modèle et entre 53 et 68% pour les tests de ces modèles.
Les modèles de quatre conditions montrent entre 59 et 77% de réussite pour la construction des modèles et entre 55 et 76% de réussite lors des tests. Les modèles contenant trois conditions montrent entre 68 et 85% de réussite pour la construction des modèles et entre 61 et 98% pour le test des modèles.

9.4.2.3 SELECTION DES PARAMETRES

Les modèles avec plus de 65% de réussite de classification (ou 0.50 kappa) ont été soumis à la sélection de paramètres. Après chaque sélection des paramètres les modèles ont été de nouveau construits avec 70% des données et testés avec les 30 % restant.
L'amélioration obtenue après la sélection des paramètres est montré pour les modèles à trois conditions dans le tableau suivant.

MODEL		TRAINING			TESTING		
Number	Conditions	BEFORE Feature Selection	AFTER Feature Selection	IMPROVEMENT	BEFORE Feature Selection	AFTER Feature Selection	IMPROVEMENT
3121	VC, FA, AR	85	92	7	75	73	-2
3106	VC, AR, CU	84	88	4	80	76	-4
3069	AR, FA, VE	72	88	16	79	79	0
3077	VC, VP, AR	73	88	15	67	76	9
3050	AR, FA, VD	74	87	13	78	80	2
3008	AR, HP, FA	70	86	16	72	63	-9
3012	AR, FA, CU	79	86	7	77	86	9
3109	VP, AR, CU	75	85	10	71	80	9
3031	AR, VE, VP	76	85	9	70	79	9
3118	VE, AR, CU	77	85	8	71	68	-3
3100	VC, HP, AR	76	85	9	78	76	-2
3108	VP, AR, AP	71	84	13	64	77	13

3111	AR, FA, VA	77	84	7	57	77	20
3053	VD, AR, AP	75	81	6	82	77	-5
3013	AP, AR, CU	73	80	7	70	72	2
3043	AR, VE, VD	70	80	10	61	68	7
3091	VC, VA, AR	73	79	6	62	76	14
3104	VC, FA, CU	75	78	3	73	73	0
3002	AR, HP, VP	75	78	3	75	68	-7
3005	AR, FA, VP	79	77	-2	98	95	-3

9.4.2.4 VALIDATION EXTERNE DES MODELES

Les données des personnes âgés ont été testés dans les modèles montrant plus de 65% de réussite. Les modèles montrant plus de 65% de réussite à la validation externe sont présentés dans le tableau ci-dessous.

Model	Validation	% accuracy	Kappa	Right classification	Wrong classification
3121	4 elderly AR	75%	0	3 AR	1 V Contrast
3050	4 elderly AR	75%	0	3 AR	1VD
3008	4 elderly AR	75%	0	3AR	1 FA
3118	4 elderly AR	75%	0	3 AR	1 CU
3002	4 elderly AR	100%	0	4 AR	0
4027	4 elderly AR	75%	0	3AR	1 VP

Six des modèles montrent un haut pourcentage de réussite lors de la validation externe et concernent tous une dégradation de l'amplitude articulaire de la cheville.

9.5 CHAPITRE 5 DISCUSSION

Cette thèse inclue deux larges expériences avec chacune d'entre elle incluant six conditions séparées dont trois sous conditions (les différents aspects de vision et les différentes articulations testées). Lorsque toutes les conditions sont réunies, le total est de 14 conditions testées. Le nombre important de données de cette thèse a rendu l'analyse difficile. Le dernier chapitre expose la discussion de ces analyses.

9.5.1 POPULATION

Les personnes âgées testées dans cette étude ont réalisé le test de timed up and go qui permet de déterminer les chuteurs des non chuteurs selon la valeur obtenue au test. Parmi les personnes âgées testées, 20 d'entre elles performent au-delà du seuil indiquant que 80% des personnes âgées sont à risque de chute. Les tests cliniques des personnes âgées ont montré

qu'elles présentaient de multiples dégradations, seules peu de personnes âgées présentent une seule et principale dégradation.
En plus des personnes âgées, les jeunes adultes à Jodhpur et les jeunes adultes à Auckland ont été testé avant et après les dégradations temporaires Les deux populations jeunes de Jodhpur et Auckland sont équivalente en termes de nombres, poids, taille et activité physique.

Dans de futures études, il serait intéressant de recruter une population avec des dégradations uniques de manière à valider les modèles construits sur plus de cas. Par exemple, plutôt que de tester des personnes ayant subis un exercice de fatigue musculaire, tester une population atteinte de myopathie serait plus pertinent. De la même manière pour les autres dégradations, il serait plus pertinent de tester des personnes atteintes d'entorse de cheville, de névrite vestibulaire, des diabétiques pour la perte de proprioception cutanée plantaire, de maladie de la rétine, de cataracte ou de glaucome. Ces conditions ont été étudiées par certaines études, mais avec peu de paramètres de stabilogramme et des paramètres différents selon les études, il serait donc intéressant de regarder les effets de ces dégradations sur une large palette de paramètres de stabilogramme comme il a été présenté dans cette étude.

Le nombre de sujets testés conditionne la réussite des modèles. La proportion du nombre de paramètres inclus dans le modèle par rapport au nombre de cas utilisés pour construire ces modèles est un facteur important pour la performance des modèles. Le nombre total de paramètres est de 198 paramètres et le nombre de cas testés est de 200 le ratio est faible, cependant la sélection de paramètres a permis d'améliorer ce ratio. Il serait cependant intéressant d'augmenter le nombre total de cas à utiliser pour construire les modèles.

9.5.2 TESTS ET DEGRADATIONS

Les tests de vision ont montré que les dégradations effectuées étaient efficaces, cependant une différence d'amplitude de dégradation est remarquée entre les deux lieux de tests, cela peut être due à la différence de luminosité entre les deux laboratoires. L'utilisation de populations différentes permet d'avoir une population plus hétérogène.

Le test de mesure de la qualité vestibulaire a montré que les résultats varient selon les paramètres du test mesuré, le test de Fukuda n'est probablement pas le test le plus approprié pour montrer une réduction de la capacité vestibulaire mais c'est le plus approprié au contexte des expériences. Cependant une tendance à des scores plus élevés a tout de même été enregistrée pour les jeunes adultes après dégradation.

Les tests d'amplitude articulaire ont montré de larges différences entre les populations, cependant la dégradation appliquée était excessive puisque l'amplitude articulaire était totalement supprimée. Les personnes âgées ont montré une amplitude articulaire relativement similaire à celle des jeunes adultes, ce qui est contraire aux autres études sur le sujet, cela peut-être due à la large pratique du Yoga en Inde, pratique ancrée dans la culture est reconnue pour améliorer la flexibilité articulaire.

Les tests de proprioception articulaire ont été peu concluants. L'échec de repositionnements est probablement dû à la pression des vibrateurs sur la peau qui donnent des informations cutanées sur la position des vibrateurs alors que les vibrations sont supposées perturber la proprioception articulaire. Cependant le manque de résultats des tests n'est pas forcément

gage d'échec de dégradation, les résultats montrent tout de même une tendance de perte de proprioception après la dégradation temporaire imposée aux jeunes adultes.

La fatigue musculaire s'est montrée efficace pour réduire la force musculaire. L'expérience à Jodhpur a également mesuré la puissance musculaire mais l'exercice isométrique réduit principalement la force mais pas la puissance musculaire, et pour ne pas dégrader la proprioception articulaire la méthode isométrique était nécessaire. Le test a donc été abandonné à Auckland.

Les mesures de proprioception plantaire ont été différentes entre Jodhpur et Auckland il est donc impossible de comparer les résultats, cependant les résultats peuvent être comparés à la littérature. La dégradation de la proprioception cutanée plantaire s'est révélée efficace.

9.5.3 MESURES DE L'EQUILIBRE

De nombreux paramètres ont été utilisés dans la littérature pour l'évaluation de l'équilibre ou de la marche. La plupart des études n'utilisent que des paramètres simples cependant plusieurs études ont décrit des paramètres de stabilogramme complexe pouvant apporter plus de précision dans l'analyse du stabilogramme.
Cette thèse utilise 198 paramètres mesurés par une plateforme force lorsque les participants montent sur la plateforme, y restent de manière statique puis redescendent de la plateforme. Le nombre de paramètres étant élevés, une sélection de paramètres a été effectuée. Plusieurs paramètres reviennent régulièrement dans les sélections pour des modèles différents. Ces paramètres sont les mesures de distance et d'air du stabilogramme, la vitesse et l'accélération du centre de gravité, le taux de charge, les impulsions, les fréquences d'analyse, l'exposant de Hurst et les exposants de Lyapunov.

Les résultats de cette étude montrent qu'il est possible d'établir une discrimination entre différentes dégradation des facteurs de risques intrinsèques grâce à l'analyse des paramètres de stabilogramme. Une étude similaire a montré qu'il était possible de déterminer parmi plusieurs dégradations vestibulaires à partir de paramètres de stabilogramme. Dans cette thèse, il est montré qu'il est possible de discriminer parmi des conditions plus variées. Cependant bien qu'il ait été possible de produire des modèles efficaces pour 3, 4 ou 5 conditions, cette étude a montré que les modèles de 6 conditions et plus n'étaient pas performants.

9.5.4 CONSTRUCTION DES MODELES

9.5.4.1 SELECTION DES PARAMETRES

Dans cette thèse la sélection des paramètres a été utilisée pour ne conserver que les paramètres les plus pertinents dans la discrimination des conditions. Sur les 198 paramètres initialement calculé, le nombre de paramètres restant après sélection varie entre trois et une vingtaine de paramètres selon les modèles. Deux principales méthodes de sélection ont été utilisées : la régression logistique et le support vector machine. Etonnamment, les deux méthodes ont montré de grandes différences dans la sélection de paramètres pour les mêmes

modèles, non seulement le nombre de paramètres sélectionnés est différent mais également aucun paramètre n'est commun aux deux sélections pour le même modèle soumis à la sélection. Malgré ces différences, la précision des modèles avec les deux techniques s'est révélée quasiment identique. A notre connaissance, aucune étude ne rapporte ce genre de résultats et comparaison entre deux méthodes de sélection de paramètres.
Il été supposé que les sélections de paramètres mettraient en évidence un pattern de stabilogramme spécifique à une condition dégradée et que par conséquent l'identification de ce pattern lors d'évaluation posturale permettrait d'identifier les conditions dégradées. Ces différences reposent probablement dans les algorithmes utilisés par les méthodes de sélection de paramètres qui dépend de l'objectif et du nombre de données utilisées dans les modèles.
Dans cette étude, la sélection de paramètres a permis au modèle d'améliorer leur précision jusqu'à 16% ce qui est relativement une importante amélioration surtout que certains modèles présentaient déjà 90% de réussite avant la sélection de paramètres.

9.5.4.2 PRECISION DES MODELES

Selon la littérature, il semble qu'un modèle est efficace quand il atteint 70% de précision, des modèles allant jusque 94% ont été rapportés. Il est important de noter que dans cette présente thèse, les modèles avaient à classifier parmi un plus grand nombre de conditions que ce qui est rapporté dans la littérature. Plus il y a de conditions à classer plus il est difficile d'obtenir un % de réussite élevé. La construction des modèles donnent une précision entre 75 et 93% pour les modèles comportant 3 conditions. Le test de ces modèles à 3 conditions produit une précision comprise entre 65 et 86%. Les modèles incluant 4 conditions montrent un % de réussite pour la construction des modèles compris entre 60 et 77% et une réussite pour le test de ces modèles entre 63 et 76%. Les modèles testant plus de conditions ont montré un pourcentage de réussite trop faible pour être accepté comme efficace. Ces faibles % de réussite pour les modèles avec plus de 4 conditions est probablement dû au nombre insuffisant de cas utilisés pour construire les modèles. Cinquante cas ont été entrés dans les modèles, un plus grand nombre donnerait probablement un meilleur % de réussite.
Il est aussi à noter que la plupart des études dans la littérature ne donnent pas de détails sur les % de réussite, il n'est pas mentionné si ces % concernent la construction du modèle ou le test de ces modèles. Les précisions sur chaque modèle sont apportées dans cette thèse. Plus de 20 modèles se sont révélés efficace dans la classification de conditions.

Le coefficient de Kappa a également été utilisé pour évaluer la précision des modèles, cependant à notre connaissance, aucun modèle avec les mêmes objectifs que ceux exposés dans cette thèse utilise le coefficient de Kappa. Dans cette présente thèse, le coefficient de Kappa a été associé au % de précision. Un coefficient de Kappa de 0.50 ou plus a été considéré comme étant garant d'un modèle efficace. Certains modèles bien qu'ayant un % de précision au-delà des 65% montrent un coefficient de Kappa inférieur à 0.50. L'utilisation des deux mesures permet une meilleure évaluation de la précision des modèles.
Dans cette étude, seuls les modèles présentant une large validité (65% et 0.50 Kappa) ont été utilisés dans chacune des étapes de l'analyse.

9.5.4.3 VALIDITE DES MODELES

Cette thèse s'est appliquée à mettre une validation interne et une validation externe des modèles.

La validation interne des modèles a été faite par l'utilisation de méthode de data split et cross validation expliquée dans le chapitre de méthode. En plus de ces méthode, les expériences de cette thèse ont été réalisées dans deux pays différents avec les même critères d'inclusion mais avec des populations présentant des différences culturelles, par conséquent il est raisonnable d'assumer que la validité interne du modèle donne une bonne approximation de la validité externe du modèle pour la généralisation des modèles.
La validité externe des modèles a été réalisée par le test des données des personnes âgées sur les modèles montrant une haute précision. Peu de données des personnes âgées ont pu être utilisées pour la validation externe car peu de personnes âgées pouvaient être classés dans une unique dégradation des facteurs de risques de chute. Sept modèles ont été validés de manière externe par ces données des personnes âgées. Les personnes âgées présentaient des dégradations de plusieurs facteurs de chute, mais furent classées selon le facteur montrant la plus grosse dégradation. Il est donc possible que certains modèles ont détecté d'autres dégradations même si elles ont été classées mineures selon notre échelle de score. Il semble évident qu'un plus grand nombre de personne âgées est nécessaire pour la validation des modèles. Il semble important de tester les modèles avec une population montrant des dégradations équivalentes à celles présentes chez les personnes âgées.

9.5.5 PERTINENCE DE LA THESE

Le but de cette thèse était de créer un modèle pour les 6 risques facteurs de chute étudiés, qui ont chacun montré avoir un effet négatif sur l'équilibre postural. Les variables du modèle étaient les paramètres du stabilogramme, il était attendu de détecter un pattern de paramètres spécifiques à chaque condition. Le pattern de stabilogramme permettrait alors de détecter les dégradations des risques facteurs de chute responsable de la perte d'équilibre. Une plateforme de force a été utilisée dans cette étude mais les résultats sont transposables sur la Balance Quality Tester pour permettre l'évaluation clinique ou à domicile. Après l'identification de ces problèmes il serait alors possible de proposer de la rééducation ciblée pour améliorer l'équilibre et diminuer le risque de chute.

En réalité, cet objectif a été partiellement atteint mais pas complètement pour plusieurs raisons. Tout d'abord, le nombre de sujets et le type de sujets testés influence le résultat, un total de 50 jeunes participants sains ont été recrutés avec deux populations provenant de villes et pays différents. Pour une meilleure construction des modèles il aurait fallu un total avoisinant les 200 sujets qui est difficilement faisable avec les moyens et le temps disponible. Cependant même avec les 50 sujets, les modèles ont atteint des % de réussite élevés.
Le test des modèles a été effectué avec les données des personnes âgées, seulement peu de personnes âgées présentaient une unique dégradation des risques facteurs de chute probablement parce que la population âgée testée n'était pas une population âgée saine mais déjà très affectée par les effets du vieillissement sur les 6 facteurs de risques étudiés. L'échantillon de personnes âgées testése a montré à 80% faire partie d'une population fragile. De plus les personnes âgées provenaient toutes d'Inde qui montre des différences socio-culturelles importantes. Le % de personnes à risques de chute est plus élevé en Inde que dans les pays occidentaux, ces différences incluent la marche à pied nu et pratique très régulière du Yoga qui influent sur les risques facteurs de chute étudiés avec une proprioception cutanée plantaire plus faible et une flexibilité plus élevée.

Un des principaux points de cette thèse est l'utilisation de dégradations temporaires et artificielles de chacun des facteurs de risque de chute. Des tests ont été utilisés pour montrer

l'efficacité des dégradations. La plupart des dégradations se sont révélées efficaces cependant quelques tests ont montré une moins bonne sensibilité à détecter les changements après dégradation comme le test vestibulaire et le test de proprioception articulaire, cependant selon d'autres études ces dégradations ont été montrées efficaces, le test utilisé ici n'était pas approprié mais était le seul disponible ou réalisable dans le contexte de l'étude.
Un autre problème souligné par rapport aux dégradations et que certaines de ces dégradations étaient exagérées par rapport à la condition réelle des personnes âgées comme l'amplitude articulaire. Au contraire, les personnes âgées présentaient une amplitude articulaire similaire aux sujets jeunes et sains qui probablement due à la pratique de Yoga comme mentionné précédemment. La dégradation de la perception de la profondeur a également été totale pour les personnes jeunes et saines, aucun autre moyen de dégradation n'était possible. Il semble donc que plusieurs dégradations ne correspondaient pas à un niveau de dégradation d'une personne âgée comme il était initialement voulu.

Un autre point de discussion important concerne la différence entre les paramètres désignés par la méthode de sélection des paramètres. Les deux méthodes ont montré des paramètres complétement différents mais des résultats de précision relativement identiques. Cela est probablement due au fait que parmi les 198 paramètres calculés plusieurs sont hautement corrélés les uns avec les autres et donc possiblement interchangeables. Si ces paramètres mesurent d'une manière ou d'une autre la même chose ou le même genre de variables il est possible que choisir un paramètre ou l'autre soit en fait revient en fait à la même chose. Il serait intéressant de standardiser ces paramètres pour éviter la redondance.

Malgré les problèmes cités ci-dessus, le meilleur modèle détectant parmi 4 conditions montre une précision de 79% et un coefficient de Kappa de 0.77 ce qui est considéré être une large validité. Les meilleurs modèles avec 4 conditions incluent tous les conditions de fatigue (baisse de force musculaire) et diminution de l'amplitude articulaire de la cheville. Deux autres conditions sont présentes dans 5 des 9 modèles : la proprioception cutanée et la vision des contrastes. De même, pour les modèles avec 3 conditions, 95% incluent la condition d'amplitude articulaire de la cheville, ont été aussi fréquemment inclus : la fatigue, la vision des contrastes et la proprioception cutanée. La présence constante de l'amplitude articulaire de la cheville dans les modèles peut être due à plusieurs raisons. La première est que la dégradation de l'amplitude articulaire de la cheville était radicale car presque complète. Cependant dans l'expérience de Jodhpur, la hanche et le genou subissaient eux aussi une dégradation quasi complète mais n'apparaissait pourtant pas comme condition phare dans les modèles testés dans la pré –analyse sur les données indiennes, ces conditions étant même tellement peu concluantes qu'elles ont été abandonnées dans l'étude d'Auckland. Une autre raison serait alors que la stratégie d'utilisation de la cheville est la plus utilisée pour maintenir l'équilibre postural et donc une dégradation sévère de l'amplitude de cheville entraîne une baisse considérable de l'équilibre.

9.5.6 FUTURES RECHERCHES

Les résultats de cette thèse amènent plusieurs questions qui pourraient être étudiées par plusieurs études complémentaires. Tout d'abord, le fait que les personnes âgées présentaient de nombreuses dégradations qui ont rendu la validation externe du modèle compliquée. Il serait donc intéressant d'avoir une population avec une seule dégradation parmi les 6 facteurs testés. Il serait également nécessaire d'étudier les différences entre les personnes âgées provenant de différents pays. Le test de Timed up and Go ne semble pas fonctionner avec les mêmes valeurs normatives en Inde. Une étude est planifiée avec l'Institut médical de Jodphur

(AIIMS) et l'institut de technologies de Jodhpur (IITJ) afin de comparer les tests cliniques dans les zones rurales et urbaines. La collection des données pour cette étude va être effectuée avec des outils construits à l'université de technologies de Troyes (UTT).

L'autre perspective intéressante est la possibilité d'étudier les programmes de rééducation qui peuvent être mis en place pour pallier les dégradations identifiés grâce aux modèles développés dans cette thèse. La littérature a montré que les facteurs de risque de chute étudiés dans cette thèse peuvent être améliorés par la mise en place de programmes ciblés aux besoins de l'individu. Il serait intéressant de commencer par les trois conditions apparaissant le plus dans les meilleurs modèles à savoir l'amplitude de la cheville, la force musculaire et la proprioception cutanée.

9.5.7 CONCLUSION

Ce travail de thèse a montré la possibilité de créer des modèles des réseaux de neurones et de régression logistique capable de discerner avec une grande précision les dégradations des facteurs de risques de chute. Les modèles ont été construits en utilisant uniquement les paramètres de stabilogramme mesurés sur la plateforme de force lors de la montée et descente ainsi que la station debout. D'autres modèles de la littérature avaient déjà été construits pour diagnostiquer les chuteurs cependant ces modèles nécessitaient plusieurs évaluations tel que des tests cliniques et des questionnaires. Ces évaluations additionnelles demandent plus de temps tandis que le modèle présenté dans cette thèse nécessite uniquement une évaluation de stabilogramme d'une durée de 30 secondes. Même si une plateforme de force n'est pas un outil facilement accessible, il a été mentionné dans l'introduction que l'UTT a construit une balance de salle de bain capable de fournir les mêmes données stabilographiques qu'une plateforme de force. Cette balance de salle de bain est donc facilement transportable, peu coûteuse et une alternative très intéressante pour l'évaluation de l'équilibre postural d'autant plus que l'outil est utilisable de manière autonome.

D'autres études ont construit des modèles basés sur les paramètres de stabilogramme pour évaluer l'équilibre. Cependant ces modèles ont utilisé très peu de sujets, une des contributions de la thèse et qu'elle a inclu un grande nombre de sujets de populations variées. De plus un grand nombre de dégradations ont été étudiés dans cette thèse (10 facteurs de risque de chute). De même ces études dans la littérature ont utilisé très peu de paramètres, dans cette étude un panel de 198 paramètres du stabilogramme a été calculé.

Vingt-cinq modèles incluant différentes combinaisons de conditions ont montré une précision élevée aussi bien en entraînement du modèle que dans sa phase de test. Même si ces modèles ont montré leur validité et leur performance, plusieurs améliorations doivent être mises en place pour permettre la généralisation pour l'utilisation clinique. Les modèles efficaces incluent 3 ou 4 conditions, alors que les modèles avec plus de conditions ont montré des performances insuffisantes. D'autres études sont nécessaires pour déterminer s'il est possible d'utiliser une succession de modèles pour déterminer les dégradations présentes dans les populations testées ou s'il faut trouver une solution pour construire un modèle incluant toutes les conditions et montrant une performance et validité acceptables. Avec de tels modèles développés il serait alors possible de diagnostiquer les dégradations chez les personnes âgées et envisager des interventions ciblées ce qui serait un outil essentiel pour la prévention des chutes dans la pratique clinique quotidienne.