THE RISK OF FALLS IN ELDERLY, COMMUNITY-DWELLING WOMEN WITH EXUDATIVE AGE-RELATED MACULAR DEGENERATION

by

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE
in
THE FACULTY OF GRADUATE STUDIES
(Health Care & Epidemiology)

THE UNIVERSITY OF BRITISH COLUMBIA
October 2006

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Abstract

Purpose: To prospectively determine physiologic risk factors for falls, and falls incidence, among elderly, community-dwelling women with exudative age-related macular degeneration (AMD).

Design: 1) Cross-sectional, and 2) prospective longitudinal cohort study.

Methods: In our cross-sectional study, 115 community-dwelling women aged 70 or over with exudative AMD were assessed for fall risk by Physiological Profile Assessment (PPA). The PPA generates a personalized risk score by comparing participants' scores on fall risk factor measures to a healthy Australian population. A second comparison group consisted of 34 normally-sighted women aged 70 or older without exudative AMD. In our cohort study, we followed 115 community-dwelling women aged 70 or over with exudative AMD and 93 normally-sighted women without AMD for 6 months and compared the falls incidence per group. Falls were measured by monthly telephone follow up. Multivariate negative binomial regression was used to model the association between falls incidence, and exudative AMD.

Results: In our cross-sectional study, we measured mean overall fall risk scores of 3.26 in the AMD group and 0.96 in the non-AMD group (p<0.0001). The AMD group as a whole scored significantly lower on measures of vision, postural sway, and reaction time, compared to the Australian population, but not on proprioception or quadriceps strength. In contrast, the average for the non-AMD group was within one standard deviation of the mean of the Australian cohort on all PPA measures except reaction time (z=-1.07). The fall rate was 82 falls per 100 person years for women with AMD, and 28 falls per 100 person years for women without AMD. Although AMD, comorbidities, and self-reported 12 month fall history were significant univariate predictors of falls, on multivariate modeling only AMD remained significant. The adjusted relative risk for having a fall over 6 months, for women with AMD compared to the non-AMD cohort, was 3.15 (95% confidence interval = 1.47 – 6.74).

Conclusion: Elderly women with exudative AMD are at a significantly higher risk of falls than those without AMD, by falls risk profile as well as 6-month falls incidence.
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<th>Description</th>
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<tr>
<td>ABC</td>
<td>Activities-Specific Balance Confidence scale</td>
</tr>
<tr>
<td>ADL</td>
<td>activities of daily living</td>
</tr>
<tr>
<td>AMD</td>
<td>Age-related macular degeneration</td>
</tr>
<tr>
<td>AOR</td>
<td>adjusted odds ratio</td>
</tr>
<tr>
<td>BC</td>
<td>British Columbia</td>
</tr>
<tr>
<td>BDES</td>
<td>Beaver Dam Eye Study</td>
</tr>
<tr>
<td>BMES</td>
<td>Blue Mountains Eye Study</td>
</tr>
<tr>
<td>CI</td>
<td>confidence interval</td>
</tr>
<tr>
<td>CNIB</td>
<td>Canadian National Institute for the Blind</td>
</tr>
<tr>
<td>CNS</td>
<td>central nervous system</td>
</tr>
<tr>
<td>dB</td>
<td>decibels</td>
</tr>
<tr>
<td>ECC</td>
<td>Eye Care Centre</td>
</tr>
<tr>
<td>EPESE</td>
<td>Established Populations for the Epidemiologic Studies of the Elderly</td>
</tr>
<tr>
<td>FICSIT</td>
<td>Frailty and Injuries: Cooperative Studies of Intervention Techniques</td>
</tr>
<tr>
<td>HR</td>
<td>hazard ratio</td>
</tr>
<tr>
<td>ICS</td>
<td>integrated contrast sensitivity</td>
</tr>
<tr>
<td>IRR</td>
<td>incidence rate ratio</td>
</tr>
<tr>
<td>MAR</td>
<td>minimum angle resolvable</td>
</tr>
<tr>
<td>MET</td>
<td>Melbourne Edge Test</td>
</tr>
<tr>
<td>NPV</td>
<td>negative predictive value</td>
</tr>
<tr>
<td>OR</td>
<td>odds ratio</td>
</tr>
<tr>
<td>PASE</td>
<td>Physical Activities Scale for the Elderly</td>
</tr>
<tr>
<td>PPA</td>
<td>Physiological Profile Assessment</td>
</tr>
<tr>
<td>PPV</td>
<td>positive predictive value</td>
</tr>
<tr>
<td>RR</td>
<td>relative risk</td>
</tr>
<tr>
<td>SD</td>
<td>standard deviation</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>------------------------------------</td>
</tr>
<tr>
<td>SOF</td>
<td>Study of Osteoporotic Fractures</td>
</tr>
<tr>
<td>TSSA</td>
<td>Tree-structured survival analysis</td>
</tr>
<tr>
<td>UBC</td>
<td>University of British Columbia</td>
</tr>
<tr>
<td>VFQ25</td>
<td>Visual Function Questionnaire 25</td>
</tr>
<tr>
<td>VH</td>
<td>Vancouver Hospital</td>
</tr>
<tr>
<td>WCS</td>
<td>weighted comorbidity scale</td>
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</table>
CHAPTER 1: INTRODUCTION
1.0 OVERVIEW

Falls in the elderly are an important public health concern, and are associated with a high rate of injury, morbidity, and mortality.\(^1\) Falls are common in people over 65, with 1 in 3 elderly individuals falling each year.\(^2,3\) Multiple risk factors contribute to falls in older people and include behavioural factors such as fear of falling, and physiologic risk factors such as poor balance.\(^2-5\) Large, population-based studies of the community-dwelling elderly have also identified poor vision as an important physiologic risk factors for falls in the elderly.\(^6,7\) Impaired visual acuity, visual field, edge detection, and depth perception have been associated with an increased likelihood of falling, and falling frequently.\(^8,9\)

Age-related macular degeneration (AMD) is a disease that causes severe loss of central vision in the elderly. The mild, or "dry", form affects 1 in 3 people by 75 years of age, with 1 in 10 of these going on to the more severe, exudative, form of the disease.\(^10\) People with exudative AMD tend to score poorly on measures of visual risk factors for falls.\(^11,12\) However, the incidence of falls in this group, as well as how they perform on other measures of falls risk, is unknown.

To quantify individual fall risk, investigators have developed multidimensional fall risk assessments that include measures of vision and other known physiologic risk factors like strength, balance, reaction time, and proprioception.\(^\) The Physiological Profile Assessment (PPA) is one such fall risk screening tool that has high validity and reliability in predicting falls in the elderly.\(^5,13\) The PPA screening tool compares an individual's scores on several assessment variables to scores from a large cohort of normal individuals to determine an overall measure of fall risk for that individual. A screening tool like the PPA has never previously been used in a low vision population to examine fall risk.
Given their poor performance on measures of visual risk factors for falls, it seems likely that those with exudative AMD would be at high risk of falling. However, as most AMD patients remain relatively inactive due to poor vision, it is possible that those with AMD may actually fall less than healthy people. If those with AMD are frequent fallers, they would be a suitable target for intervention strategies to lower fall risk. The purpose of this study was to prospectively determine physiological and behavioural risk factors for falls, and the incidence of falls, in those with exudative AMD.
1.1 REVIEW OF THE LITERATURE

1.1.1 Falls epidemiology

Falls, defined as events resulting in an individual unintentionally coming to rest on the ground or lower level in the absence of overwhelming hazard,\textsuperscript{15} are a leading cause of morbidity and mortality in the elderly. About 30\% of those over 65 years of age experience one or more falls a year,\textsuperscript{2,3} with the incidence increasing with age. Serious injuries occur secondary to 11-15\% of falls in the elderly, with 2-6\% of all falls ending in fracture.\textsuperscript{3,16,17} Approximately 1\% of falls result in a hip fractures,\textsuperscript{16,17} and 90\% of all hip fractures in the elderly are attributable, at least in part, to falling.\textsuperscript{18} Among individuals who sustain a hip fracture, there is a 12-20\% excess mortality within the first year.\textsuperscript{19} One-year mortality rates following a hip fracture are approximately 36\% in men, and 21\% in women.\textsuperscript{20} However, women are more likely to fall and more likely to fracture than men of the same age,\textsuperscript{2,21,22} likely due to gender-related differences in mean physical activity levels or bone mass. Fifty percent of hip fracture patients never return to pre-fracture levels of function,\textsuperscript{23} with at least 20\% of patients requiring institutionalization after release from hospital.\textsuperscript{24}

In addition to fractures, falling is associated with a myriad of other negative health effects in those in which they occur. The development of fear of falling, and resultant risk-averse behavioural modification, is common.\textsuperscript{3,25} People who fall frequently report severely restricted physical and daily activities after a fall, which do not necessarily ever return to pre-fall levels.\textsuperscript{26,27} Individuals who fall report having been psychologically traumatized,\textsuperscript{25} experiencing a substantial loss of independence,\textsuperscript{28,29} reduced mobility, and social isolation.\textsuperscript{26} Multiple fallers have also been found to have significantly more difficulties with activities of daily living, and report a significantly lower quality of life, compared to non-fallers or one-time fallers.\textsuperscript{30}
Not only are falls a burden to the elderly in terms of morbidity, mortality, and reduced quality of life, they are also extremely costly to the health care system. The annual direct costs associated with osteoporotic fractures in Canada is estimated to be 1.3 billion dollars Canadian (CAD), including $437 million in hospitalization costs which in turn corresponds to 485,000 hospital days to treat 76,000 osteoporotic fractures. Falls are the largest contributor to hospitalization rates and length of hospital stay in the elderly in British Columbia (BC). Hip fracture patients alone occupy over 20% of available orthopedic beds, with an average hospital stay length of more than 20 days, at a cost of over $700 CAD per day. In BC, falls and related injuries have a direct cost of $128 million a year. The preceding studies did not estimate indirect costs, including caregiver time, fees for medical and assistive devices, or home care, but these are also substantial. As the mean age of the Canadian population is increasing, the total number of falls and fractures, and associated costs, is likely increasing as well.

1.1.2 Risk Factors for Falls in the Community-dwelling Elderly

Risk factors for falls in the elderly have been extensively investigated over the past few decades and these are reviewed in detail elsewhere. In this thesis that relates to visual impairment and falls, I will only briefly summarize the key literature relating to classification of fall risk factors. Large cohort studies in the community-dwelling elderly indicate that falls are multicausal, and represent a complex and individualized interaction between intrinsic (properties of the individual) and extrinsic (properties of the environment) risk factors. Single falls may typically be due to extrinsic causes, whereas in recurrent fallers, intrinsic risk factors may more often be implicated. Various models of the impact of intrinsic and extrinsic risk factors on the incidence of falls have been developed, based on the results of prospective cohort studies measuring risk factors and linking them to subsequent falls. One such model for fall risk, based in part on Tinetti and King’s groundbreaking study of risk factors for falls in the community-dwelling elderly, considers impaired mobility as a
prerequisite for having a fall, with falls incidence additionally influenced by attitudinal, social, and environmental factors. **Figure 1.1** provides an overview of falls risk, using this model.\textsuperscript{35}

**Figure 1.1**: Interactions among intrinsic, situational, and environmental factors that affect risk of falling in older people.

Extrinsic risk factors are those that create challenges to balance that must be overcome to avoid falls and injury. Such challenges can come in the form of regular daily activities (running for the bus, climbing stairs), environmental hazards (obstacles in the walking space in front of you, poor lighting), or position-changing activities (transfer from sitting to standing, for example). The degree to which these represent a risk for an individual depends on that person's vulnerability (based on intrinsic characteristics), as well as the frequency of
exposure. A fall would occur from extrinsic factors when the demands on an individual's postural control exceed his/her ability to manage them.\textsuperscript{35}

Intrinsic risk factors refer to properties of the individual that may predispose that person to having a fall. Numerous intrinsic fall risk factors have been identified, and include the recent history of an injurious fall,\textsuperscript{4} having multiple chronic illnesses,\textsuperscript{2, 3, 37} dementia,\textsuperscript{38} visual impairment,\textsuperscript{6, 9, 39-41} neurologic, musculoskeletal, or functional disabilities,\textsuperscript{36} postural hypotension, use of medications particularly psychotropic agents,\textsuperscript{3} benzodiazepines\textsuperscript{42} and some cardiac drugs,\textsuperscript{43} cognitive impairment, foot problems,\textsuperscript{3} and abnormalities of balance and gait, among others.\textsuperscript{3, 37, 44, 45} Decreased physical activity and mobility not only result from a fall, but can cause them as well.\textsuperscript{35, 46} In addition, the risk of experiencing a fall may increase linearly, associated with the number of risk factors present.\textsuperscript{3} Table 1.1 (reprinted from ref (1)) presents a summary of fall risk factors, and average relative risk calculated, from a recent review of fall risk factor studies.\textsuperscript{1, 47}

Table 1.1. Results of univariate analysis of most common risk factors for falls identified in 16\textsuperscript{1} studies that examined risk factors.

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Statistically Significant/Total*</th>
<th>Mean RR-OR</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle weakness</td>
<td>10/11</td>
<td>4.4</td>
<td>1.5 - 10.3</td>
</tr>
<tr>
<td>History of falls</td>
<td>12/13</td>
<td>3.0</td>
<td>1.7 - 7.0</td>
</tr>
<tr>
<td>Gait deficit</td>
<td>10/12</td>
<td>2.9</td>
<td>1.3 - 5.6</td>
</tr>
<tr>
<td>Balance deficit</td>
<td>8/11</td>
<td>2.9</td>
<td>1.6 - 5.4</td>
</tr>
<tr>
<td>Use assistive device</td>
<td>8/8</td>
<td>2.6</td>
<td>1.2 - 4.6</td>
</tr>
<tr>
<td>Visual deficit</td>
<td>6/12</td>
<td>2.5</td>
<td>1.6 - 3.5</td>
</tr>
<tr>
<td>Arthritis</td>
<td>3/7</td>
<td>2.4</td>
<td>1.9 - 2.9</td>
</tr>
<tr>
<td>Impaired ADL</td>
<td>8/9</td>
<td>2.3</td>
<td>1.5 - 3.1</td>
</tr>
<tr>
<td>Depression</td>
<td>3/6</td>
<td>2.2</td>
<td>1.7 - 2.5</td>
</tr>
<tr>
<td>Cognitive impairment</td>
<td>4/11</td>
<td>1.8</td>
<td>1.0 - 2.3</td>
</tr>
<tr>
<td>Age &gt; 80 years</td>
<td>5/8</td>
<td>1.7</td>
<td>1.1 - 2.5</td>
</tr>
</tbody>
</table>

*Number of studies with significant odds ratio or relative risk ratio in univariate analysis/total number of studies that included each factor.

\textsuperscript{1}References\textsuperscript{2, 3, 18, 37, 46-50}; ADL=Activities of daily living.
1.1.3 The Contribution of Visual Impairment to Falls

Impaired vision is an important risk factor for falls and warrants detailed review in this thesis. The concept of ‘vision’ is multifaceted, however the components of vision that are relevant with respect to falls are visual acuity, contrast sensitivity, visual field, and depth perception.

1.1.3.1 Elements that Contribute to Visual Function and Relation with Falls

Visual acuity is a measure of spatial resolution, and is the most frequently reported element of visual function. Specialized cells in the macula, or central retina, resolve fine detail and allow for the sensitive central vision useful for tasks like reading, watching television, or driving. Visual acuity is measured in the logarithm of the minimum angle resolvable (logMAR) using a chart of decreasing-sized letters, and is known to decline with age.\(^5\) Although over 5 years, the mean (standard deviation (SD)) change in visual acuity is only 0.4 (+4.9) letters in those aged 43 – 54, the mean (SD) change over the same time period in those over 75 is -5.2 (+5.4) letters.\(^6\) Measures of visual acuity may be important predictors of falls, as good visual acuity allows the detection of hazards that could cause trips and falls.

Contrast sensitivity is the ability to detect stimuli of varying brightness against a background of a given brightness. It is measured using a chart of figures of reducing contrast, and is quantified by the minimum contrast required to detect stimuli of varied frequencies, in decibels (dB). Contrast sensitivity, like visual acuity, also declines with age.\(^6\) Contrast sensitivity on the Melbourne Edge Test, for example, is stable until 50 years (23.8 ± 0.7 dB), after which time it decreases at a rate of 1.5 dB per decade, in healthy individuals.\(^6\) Contrast sensitivity may be related to falls in that a diminished ability to discriminate between objects in cluttered environments may predispose elderly individuals to tripping over obstacles.

Another element of visual function is visual field, which is a measure of one’s peripheral vision, and is defined as the spatial array of visual sensations available to observation.\(^6\)
Restricted visual fields may increase fall risk because of problems with the perception of obstacles located in an area of the visual field lacking sensory input. It is possible for an individual to have a very limited visual field with excellent central vision and acuity, as in those with glaucoma, or to have a full visual field with very poor central vision and acuity, as in age-related macular degeneration (AMD).

Finally, depth perception refers to the ability to perceive objects in three dimensions, and understand relative distance. Depth perception requires binocular input, and is measured in arcseconds. The ability to accurately judge distance and spatial relationships is required to avoid obstacles or safely negotiate threats to balance, like stairs, ramps, and curbs. Typically, in an individual, many or all of the preceding measures of visual function are highly correlated and this can complicate efforts to understand the relative contributions of each of these elements to risk of falling.

1.1.4 Clinical Conditions that Cause Visual Impairment in the Elderly

Several common visual disorders that occur predominantly in the elderly can cause impairments on measures of visual function that are associated with falls. Estimates of the burden of eye disease at the population-level are available from two large, population-based prospective cohort studies of visual function, the Beaver Dam Eye Study (BDES; Wisconsin, USA) and Blue Mountains Eye Study (BMES; Sydney, Australia).

The BDES is a prospective cohort study examining the prevalence, incidence, causes and effects of visual impairment. Between September 1987 to May 1988, a census was performed in Beaver Dam, Wisconsin, to enumerate all residents aged 43 to 84 years. Of the 5924 individuals identified, 4926 elected to participate and complete a baseline ophthalmic assessment. Study visits consisted of an interview to obtain demographic information, and then ophthalmic examinations including standardized measurements of visual acuity at near
and far, contrast sensitivity, visual sensitivity, visual field, and depth perception. Five year
follow up examinations were conducted on 3684 surviving willing participants in 1993 – 1995,
and a further 2783 surviving willing participants in 1998 – 2000. Although the goal of the
original studies was to estimate the burden of disease attributable to visual loss and various
visual impairments on a population level, subsequent interviews and analyses examined more diverse associations like those between cardiovascular disease, frailty, physical functioning, or falls, and visual impairment. The BDES found the three most common causes of visual impairment in the elderly to be cataract (clouding or blurring of vision resulting from opacification of the eye’s lens), glaucoma (constriction of the optic nerve from increased intraocular pressure), and age-related macular degeneration (AMD). Among all study participants, the prevalence of cataracts was 50%, glaucoma was 2.1%, any AMD was 20.9%, and exudative AMD was 1.9% at the initial assessment.

Estimates of the burden of eye disease from the BDES were confirmed and extended by the BMES, another population-based prospective cohort study of visual function and eye disease. The BMES was conducted among all willing residents from two urban postal codes in the Blue Mountains area west of Sydney, Australia. The study population consisted of all non-institutionalized residents 49 years of age or older, identified by door-to-door census during November to December 1991 (first postal code), and March to April 1993 (second postal code). Of the 4433 eligible residents, 3654 attended the eye examination. At the study visit, participants were queried on demographics, medications, and medical history. All participants then underwent an ophthalmic exam consisting of standardized measurements of best-corrected visual acuity, depth perception, contrast sensitivity, fundus photography, and visual field. As with the BDES, the associations examined by the BMES have expanded from simply a survey of visual impairments to include other factors such as cognitive impairment, dietary fatty acid intake, and falls. The BMES found the overall prevalence of any visual impairment (Snellen visual acuity <20/40) in at least one eye to be
20% amongst those aged 70-79 years, increasing to 50% in the over 80 age group. Approximately 5% of those aged 70-79 suffered from bilateral visual impairment, rising to 26% in those over 80. The three most common causes of visual impairment in the elderly were again found to be cataract, glaucoma, and AMD. Among participants over age 49, the prevalence of cataracts was approximately 50%, glaucoma was 3%, and early (dry) and late (exudative) AMD, 14% and 2%, respectively. The prevalence of each of these conditions also increased with age, most markedly for exudative AMD, where almost 20% of those over age 85 were affected.

AMD is the most frequent cause of largely untreatable visual impairment, and the leading cause of legal blindness, amongst the elderly in the Western world. Women have an approximately 3-fold increased risk of developing exudative AMD than men. Although no population-based estimates are available for Canada, the Canadian National Institute for the Blind (CNIB) registry indicates that in BC, about 14,000 people have exudative AMD, and more than 1,500 new cases are diagnosed annually. Given the prevalence of exudative AMD calculated in BDES and BMES, this is likely a substantial underestimate of the burden of disease in BC; one would expect over 25000 individuals to be affected. In the absence of the rigorous follow up occurring in the large prospective cohort studies, we cannot get accurate estimates of the burden of disease. However, it seems likely that many people with severe vision loss in exudative AMD in BC do not register with the CNIB.

Individuals with dry AMD develop pigmentary changes and whitish-yellow deposits (drusen) within the macula, typically causing mild to moderate decreases in visual acuity. The dry form affects 1 in 3 elderly people, with 10% of these going on to the more severe, exudative, form. Exudative AMD is characterized by the development of pigment epithelial detachments and choroidal neovascularization (i.e. new blood vessels that leak blood and fluid) that eventually lead to scarring and fibrosis under the macula. People with exudative
AMD experience a severe loss of central vision in the affected eye that is apparent as a black spot obliterating the central visual field. As a result, AMD patients have great difficulty with tasks requiring fine central vision, like reading, driving, or recognizing faces. Peripheral vision in AMD typically remains intact, although peripheral vision is always much poorer than central vision, due to the anatomy and function of the retina. It is not possible to train the peripheral retina to have sharp visual acuity, such as that needed for reading or driving. Those with exudative AMD are known to score poorly on measures of visual acuity, contrast sensitivity, depth perception, and sometimes visual field, known risk factors for falls. Exudative AMD has a substantial negative impact on quality of life; people with severe visual deficits also frequently report reductions in physical activities and functional limitations. Despite the development of novel therapies to treat exudative AMD of recent onset, little can be done at present for those who already have the condition. Visual deficits in AMD could therefore present a serious problem, not only in terms of reduced physical functioning, daily activities, and quality of life, but also potentially by increasing the risk of experiencing falls and injurious falls.

1.1.5 The Association Between Falls and Visual Function

Decreased visual function was a risk factor for falls in a large number of clinical, community-, and population-based observational studies. Tobis et al. were one of the first to report on visual function and falls. They conducted an experimental study on a convenience sample of 134 hospitalized elderly men and women in the United Kingdom in the late 1970's. They found that those hospitalized for falls were more likely to demonstrate errors in the visual perception of verticality and horizontality than non-faller controls, measured using lines of different orientations projected on a screen.

Mary Tinetti’s seminal 1988 longitudinal fall risk factor study was the first to begin to examine, in depth, the association between incidence of falls and putative physiological
predictors among community-dwelling individuals aged 75 and over. She recruited 336 willing participants of a random sample of 458 individuals (73%), measured a wide variety of risk factors for falls at baseline, and prospectively followed all participants for one year. Poor near visual acuity ($\leq 20/30$ Snellen), but not distance visual acuity, was associated with an increased risk of falls in her study (relative risk (RR) = 1.7, 95% confidence interval (95%CI) = 1.2-2.3)). Other elements of visual function, such as depth perception or visual field, were not measured. Nevitt et al. conducted a one-year prospective cohort study of falls in 325 community-dwelling fallers aged 60 years and above, recruited from senior centres and residences, churches, and university-affiliated outpatient clinics in San Francisco. All participants had fallen previously (reporting $\geq 1$ fall in the previous 12 months), and participated in a baseline assessment of fall risk factors prior to beginning prospective follow up. Impaired depth perception ($\geq 200$ arcseconds at 0.4m) was associated with an increased risk of having $\geq 3$ falls during follow up (adjusted odds ratio (AOR) = 2.1, 95%CI = 1.1-4.2) on multivariate analysis, and having poor visual acuity ($< 20/50$ Snellen) associated with at least 2 falls during follow up (unadjusted RR = 1.5 (1.1 - 2.1) on univariate analysis).

Campbell et al., in a longitudinal population-based study of 761 community-dwelling individuals aged 70 and older from one rural community in New Zealand, found that impaired visual acuity was not associated with the falls in either men (RR = 1.3, 95%CI (0.6-2.8) or women (RR = 1.3, (0.8-2.2)). However, participants in Campbell’s study were categorized into good and poor visual categories by one Snellen visual acuity cutoff ($< or > 20/40$), which may not reflect the visual cutoff point that actually discriminates fallers and non-fallers. The authors did not report sensitivity analyses according to different visual acuity cutoffs. Further, contrast sensitivity and peripheral vision, which are potentially important visual measures for falls, were not measured in this study. Self-reported poor visual function was examined in relation to falls as part of the Longitudinal Aging Study Amsterdam, a cohort study of a random sample of 1469 individuals over age 65, drawn from the population registers.
reported poor vision was a significant predictor of any falls (OR=1.8 (1.3-2.4)) and recurrent falls (OR=1.6 (1.1-2.3)) on univariate analysis, however, these associations did not remain significant when adjusted for other confounders such as impaired mobility or urinary incontinence.81 Lord et al. reported that having poorer contrast sensitivity, rather than visual acuity, was significantly associated with incidence of falls in a prospective study of a convenience sample of individuals aged 59 to 97, living in a hostel for the aged.41 Although provocative, contrast sensitivity and visual acuity were actually highly correlated in this study (r=-0.60), and other elements of visual function important in predicting falls, like depth perception, visual field, and dark adaptation, were unmeasured.

The Randwick Falls and Fractures study corroborated the importance of contrast sensitivity, perhaps even more than visual acuity, as a predictor of falls in the elderly. In a population-based random sample of 704 elderly women that retrospectively examined risk factors for falls, poor vision was again significantly associated with a fall in the past 12 months.13 However, the estimate of association in this study may be biased by problems with recall. Subjects were required to self-report all falls within the past 12 months, a measure that is known to be unreliable. In a prospective study of 304 men and women over 60, the incidence of falls calculated from in-home weekly follow up visits was compared to self-reported falls, collected by 3-, 6-, and 12-monthly phone calls. Thirteen to 32% of all falls were forgotten by those experiencing them, dependent upon the time window.82

The original Randwick Falls and Fractures Study was extended for a prospective one year follow up period in 341 of the original 704 women, to more accurately estimate the effect of various putative risk factors on fall incidence. Visual function, by high and low contrast visual acuity and contrast sensitivity, was measured, and only low contrast visual acuity and contrast sensitivity significantly discriminated between multiple fallers and non-fallers.5
Contrast sensitivity was found to be the best visual measure to predict falls over one year in Lord's study.

As controversy over the importance of visual measures as predictors of falls increased, more studies examining the effects of specific visual risk factors on the risk of falling were undertaken. Both the BDES and BMES cohort studies conducted analyses to determine the effect of visual function on risk of falls. The BDES compared the history of falls in the past year in 3722 participants, between those that scored well or poorly on measures of best-corrected visual acuity, habitual acuity, contrast sensitivity and visual sensitivity. Interestingly, contrast sensitivity was the only measure that did not differ significantly between those that fell and those that did not. In a 5-year follow-up study of 2783 of the original 3722 Beaver Dam participants, again, poor habitual visual acuity (OR=2.02 (1.13 – 3.63)), but not contrast sensitivity (OR=1.61 (0.99 – 2.62)), was significantly associated with one-year fall history when other potential confounders were controlled for. The BMES examined the relationship between poor visual acuity and specific visual impairments with one-year fall history in its 3654 participants. Visual acuity, contrast sensitivity, and to a lesser extent visual field loss, were significantly associated with falls, as were the diagnosis of posterior subcapsular cataract or use of nonmiotic glaucoma medication. Exudative age-related macular degeneration was not associated with falls, however this group (n=40) comprised only 1.2% of the study population. Further, the overall population was quite young (65% of the study population was ≤69 years), and had good vision. In both the Blue Mountains and Beaver Dam Studies, the visual measures were obtained after the fall had occurred, which is an important potential source of bias. In addition, both studies relied upon retrospective recall of falls, and, as noted previously, 12 month recall of falls in the elderly is poor. Despite the large size of both studies and standardized exposure measurement, the association of specific visual impairment with falls remains unclear due to poor
ascertainment of outcome, and the lack of established temporality between risk exposure and outcome.

Lord and Dayhew prospectively examined the predictive value of visual measures and other physiologic fall risk factors on falls over one year, in a sample of 156 community-dwelling individuals aged 63 to 90, randomly selected from electoral rolls. They found that those who experienced multiple falls during the follow-up period performed significantly worse on each test of visual function, as well as on physiologic measures of strength, reaction time, and sway, compared to those who did not experience multiple falls. They also determined, by comparing those in the best vision quartile to those in the worst and adjusting for confounders, that impaired depth perception was the best predictor of multiple falls (RR=2.51 (1.4-4.51)), followed by low contrast visual acuity (RR=2.33 (1.29-4.21)), edge detection (RR=2.24 (1.21-4.21)), and high contrast visual acuity (RR=1.85 (1.01-3.38)). Interestingly, individuals with good vision in one eye but moderate or poor vision in the other, experienced falls as frequently as those with poor vision in both eyes. An important consideration when interpreting the results of this study is that it is very likely that many of the visual measures for each individual are highly correlated. Inclusion of two or more highly collinear variables in a regression model can make it impossible to identify the specific effect of any variable, when you control for the effect of the others. This can result in either under- or overestimation of the associated odds ratio or relative risk.

Coleman et al. prospectively examined the risk of multiple falls over 12 months, associated with a decline in visual acuity over the preceding 5 year period, in a convenience sample of 2002 of the 6330 surviving female participants in the Study of Osteoporotic Fractures (SOF). The SOF recruited a volunteer sample by mailed invitation brochure from population-based listings of residents in Baltimore, Pittsburgh, Minneapolis, and Portland, USA. Enrollment was conducted between September 1986 and October 1988, and restricted
to white women aged 65 and older. Baseline assessment consisted of, among other measures, a best-corrected distance visual acuity measurement. A five year follow-up examination was conducted in August 1992 – July 1994, and included a repeat visual acuity examination. Coleman et al. found that the adjusted odds of having multiple falls was higher in women who lost visual acuity over the preceding 5 years compared with those who did not, with adjusted ORs ranging from 1.85 (95%CI=1.16-2.95) to 2.51 (95%CI=1.39-4.52) based on amount of vision lost (none, 1, 2, 3, or >3 lines lost of Snellen acuity). Curiously, the odds of having a fall did not increase linearly with increasing vision lost, suggesting an interaction between visual decline and some other, potentially unmeasured, variable. Also of interest, impairments in contrast sensitivity and depth perception, but not visual acuity, were found to be associated with an elevated risk of hip fracture in the larger, main, component of the SOF. Contrast sensitivity and depth perception were not measured in the smaller substudy looking at risk factors for multiple falls. Although the SOF enrolled only white women, and therefore may not be generalizable to other populations, it suggests a role for visual acuity modification as a mechanism to reduce fall risk in the elderly.

De Boer et al. prospectively examined visual risk factors for both falls and fractures over 3 years in a subsample of 1509 participants in the Longitudinal Aging Study Amsterdam who completed an additional medical interview. Visual function was defined using two measures of contrast sensitivity (integrated contrast sensitivity (ICS), and low frequency contrast sensitivity), and 3 questions that obliquely referred to visual acuity (ie., “Can you read small print in newspapers”). Visual acuity was never measured directly using an eye chart. Only ICS (hazard ratio (HR)=1.53 (1.03-2.29)) and low frequency contrast sensitivity (HR=2.66 (1.11-2.48)) were associated with recurrent falls. Again, as non-standard measures of visual acuity were used in this study, it did not help to clarify the relative contributions of visual acuity versus contrast sensitivity to the incidence of falls.
Developing accurate estimates of the risk of falls associated with specific visual deficits, based on the current evidence, is difficult. As different studies included different elements of visual function, it is hard to develop a hierarchy of the importance of the various elements in relation to falls. Even when the same visual function measure was included in different studies, measurements were not performed in the same, standardized fashion. Some studies looked retrospectively at previous falls and current measures of visual function, creating problems with understanding the temporality of the association between exposure and outcome. Despite these issues, the general consensus from published studies to date is that people aged 65 and older with visual impairments are at least at 1.5 times the risk of falls as those with normal vision. Alternate estimates of risk associated with vision problems that come from studies examining people with specific diagnoses of visual impairment, rather than varied measures of visual function, provide valuable confirmatory estimates of increased risk in those with vision problems.

1.1.6 Falls and Visual Impairment

A few investigators have examined falls incidence within the context of specific visual impairments, to further delineate potential high-risk populations. Glynn et al. examined the association between glaucoma and the risk of falls in the past 12 months, in a convenience sample of 489 patients with clinically-confirmed glaucoma from one tertiary care centre. Although visual field loss did not predict falls in this study (AOR=3.0 (0.94-9.8)), use of nonmiotic (AOR=5.4, (1.8-16.4)) or miotic (AOR=3.2, (1.0-10.1)) topical eye medications, gender and use of antihypertensive cardiac medications did predict falls. Non-differential misclassification may be a problem in this study as the measurements of visual function were performed after the occurrence of a fall, and participants may have inaccurately recalled the occurrence, or non-occurrence, of a fall. Only 9.6% of participants in this study reported a fall, far less than the approximately 30% rate of falls previously reported by Tinetti and colleagues. Further, individuals with glaucoma who had an injurious or fatal fall would not
have been available to be considered for inclusion, as this was a retrospective, clinic-based study. Falls were also examined in relation to cataracts by Brannan et al., in a prospective study of 84 willing subjects awaiting cataract surgery; 37% recorded having had a fall during 6 month pre-operative follow up period. Although the fall rate seems higher than that expected, the absence of an external comparison group makes inferences difficult. To date, no studies have examined the incidence of falls in those with AMD.

1.1.7 The Relationship between Visual Impairment and Other Fall Risk Factors

Impairments in vision in people at risk for falls do not occur in isolation. In most fallers, falls likely result from the synergistic interaction between many individual risk factors, even in people with one or more clear deficits. Many studies have investigated the association between visual impairment and other specific risk factors for falls.

Postural control is an important predictor of falls, and is undeniably related to vision – it represents the integration between visual, proprioceptive, and vestibular input to the central nervous system (CNS) and motor response. Vision is thought to stabilize posture by providing the CNS with constant feedback about the position and movement of the body in relation to itself and the environment. Closing one’s eyes alone can cause increases in postural sway of up to 70%. Artificially restricting the peripheral visual field also results in significantly poorer postural control. Poor visual acuity and contrast sensitivity are associated with increased postural sway on compliant, but not firm surfaces, confirmed in a study of postural sway in 16 men and women (mean age, 74 years) with AMD. Patients with AMD also demonstrate gait abnormalities on uneven or difficult surfaces. Increased blur (simulating cataractous changes) significantly increased postural instability in one experimental study of 13 normally-sighted elderly people without a previous history of falls. As the participants’ posture was more stable when they were presented with a low contrast visual target, and as cataracts cause decreased contrast, these changes would likely be
reflected in measures of contrast sensitivity. \(^9^7\) Contrast sensitivity has also been identified as a major determinant of postural stability discriminating between multiple fallers and those that fell once or not at all, \(^9^8\) or predicting sway on compliant surfaces. \(^8^9\) In a cross-sectional study of 156 community-dwelling men and women aged 63 to 90, those with poor postural stability, measured by lateral sway and tandem stability tests, were more likely to have poor visual acuity, as well as reduced proprioception, strength, reaction time and peripheral sensation, compared to those with better postural stability. \(^9^9\) Together, these findings suggest that a number of physiological systems are important in maintaining balance, and that there is more to falls in the visually impaired than simply not being able to see obstacles. Falls in this group may also be attributable to an individual's inability to accurately perceive the position and movement of their body in relation to their environment. \(^8^9\)

Functional limitations and disabilities are also related to visual dysfunction. Not only do the visually impaired demonstrate decreases in physical and regular daily activities, \(^1^4\) but visually impaired individuals have to use adaptive strategies to be able to perform regular daily activities. \(^1^0^0\) Visual impairment has been associated with functional disability in a number of studies. Salive et al. conducted a prospective cohort study in 3133 Americans who were part of the Established Populations for the Epidemiologic Studies of the Elderly (EPESE). The EPESE was a survey of over 65 year olds conducted at multiple centres in the United States, and Salive measured visual acuity, self-reported mobility and daily activities, and physical functioning (rising from a chair, balance, and walking) in these participants over 15 months. They found that participants with severe visual impairment had 3-fold higher odds of incident mobility and activity limitations compared to those with good vision (≥20/40 Snellen). \(^1^0^1\) In a study of 1210 non-randomly sampled community-dwelling French women aged 75 and over, women with low visual acuity and contrast sensitivity were significantly more likely to report being physically dependent than women who scored highly on the visual measures. \(^1^0^2\) In another cross-sectional study of physical functioning and visual impairment, a random
sample of men and women aged 65 to 84 from Maryland were questioned on physical function and activities of daily living. Binocular visual acuity was also measured. Individuals with a presenting visual acuity of <20/40 Snellen reported significantly more difficulties with physical functioning and activities of daily living.\(^{103}\)

As tasks take longer and are more difficult to negotiate in the visually impaired, it is not surprising that people with visual problems frequently report functional limitations.\(^{104}\) Functional limitations, like difficulties with stair climbing, using public transportation, or cutting one's own toenails, are independent predictors of falls and fractures.\(^{105,106}\) Although it seems likely that visual impairment would be the cause of the functional decline, most of the preceding studies were cross-sectional and precluded inference of causality or prediction of future outcomes. Longitudinal data from approximately one quarter of the 5345 original SOF participants was used to evaluate the relationship between visual impairment and subsequent functional decline.\(^{107}\) The adjusted odds ratio for experiencing subsequent functional decline based on previous visual impairment was found to be 1.79 (1.15-2.79), further supporting the strength of association between visual impairment and falling and fractures.

Falls in the elderly have many contributory causes, and represent a complex interplay between many fall risk factors. Visual risk factors for falls, including specific visual impairments, are one potential contributory cause but do not develop in isolation. They are frequently reported in association with other independent risk factors for falls. It is possible that among individuals with more than one risk factor for falls, risk may be compounded.\(^3\) Effective strategies to reduce fall incidence in those at high risk would be valuable in decreasing the burden of morbidity on the individual as well as the high economic burden on the health care system. Prior to intervening, however, those at high risk of falling must first be identified.
1.1.8 Falls Risk Assessments

Assessing fall risk factors is necessary for the development of broad primary preventative strategies for falls and also to identify those patients who are at particularly high risk. Although the proportion of community-dwelling elderly individuals who fall remains high, interventions that target those who are at higher than normal risk of falling are more likely to be cost-effective.

A number of strategies have been attempted to achieve the dual aims of developing preventative strategies and clinically identifying high risk individuals. Tinetti et al. were the first to develop a fall risk index in 1986 to distinguish elderly individuals at an elevated risk of falling, based on an individual’s scores on 9 physiologic and self-reported measures. Since that time, efforts have been made to develop screening tests with increased predictive accuracy, while balancing simplicity in interpretation and implementation.

Comprehensive geriatric assessment, as the name suggests, provides the most complete information about an individual’s fall risk. Typically performed in the setting of a falls prevention or geriatrics clinic, the comprehensive geriatric assessment generally includes measurement of physiologic risk factors, interview for measures relying on self-report, health history and physical examination. Such highly time- and resource-consuming assessments may involve one or many health care professionals.

Another approach is to measure single fall risk parameters (e.g., single leg stance) to provide a proxy for a more comprehensive assessment. Falls assessments based on measures of only one or two risk factors, however, do not capture the interaction between risk factors within an individual. Many investigators have developed indices and risk scores that integrate the contribution of several putative fall risk factors, to better identify high-risk individuals.
Stel et al. developed a classification tree based on tree structured survival analysis (TSSA) to look at 11 predictive factors, and the relationships between them, in generating likelihoods of experiencing recurrent falls in the community-dwelling elderly.\textsuperscript{112} The classification tree has the advantage that not all predictors need to be measured, because specific combinations of predictors identify the probability of distinct outcomes. However, TSSA involves a high degree of data fitting,\textsuperscript{113} and some of the statistical relationships discovered could be spurious, as can occur when the model generated is too specific to the data set on which it is based. Further, this tool has not been validated in a population different from the one in which it was developed.

Other investigators have developed fall risk indices with the purpose of predicting falls, rather than identifying fall risk factors, based on the results of multivariate modeling. Stalenhoef et al. developed a predictive risk model for recurrent fallers based on 6 easily-measured fall risk factors as variables,\textsuperscript{114} including age, gender, pain, balance, presence of a chronic neurologic disorder, and antidepressant use. However, Stalenhoef’s model has a relatively low predictive accuracy (sensitivity=64%, specificity=71%, positive predictive value (PPV)=42%, negative predictive value (NPV)=86%). Tromp et al., in the Longitudinal Aging Study Amsterdam, developed a risk model that included history or a fall, urinary incontinence, visual impairment, and benzodiazepine use as the 4 predictors of falls, but again, the predictive value at the recommended scale cut off was relatively low (sensitivity=54%, specificity=79%, PPV=25%, NPV=93%).\textsuperscript{106} Covinsky et al. included having an abnormal mobility exam, a history of balance difficulties, and a fall in the past year as potential explanatory variables in their risk model, but the index had similarly low predictive values (sensitivity=59%, specificity=73%, PPV=38%, NPV=86%).\textsuperscript{115} These indices have several limitations. Although the goal in using an index rather than comprehensive assessment is parsimony, the length of assessment can remain prohibitive for both the participant and clinician. In addition, variability in assessment between measurers has the
potential to bias results, and these indices frequently include self-report measures which can be subject to recall or reporting bias. Further, most of these indices have not been validated in populations other than those in which they were developed. Thus, by the year 2000, despite over a decade of research focused on fall prevention, there was no instrument that provided a valid fall risk profile.

1.1.8.1 Physiological Profile Assessment (PPA)

In an attempt to overcome this major limitation in the field – to better identify those at high risk of falling – Dr Stephen Lord developed the Physiological Profile Assessment (PPA).\textsuperscript{116} The PPA is a valid and reliable falls risk assessment tool with a high predictive accuracy for falls (sensitivity=75%; specificity=75%; PPV=44.2%; NPV=91.9%).\textsuperscript{5,98} The PPA screening tool compares an individual’s scores on each of the physiologic assessment variables to scores from a large cohort of normal individuals from the Randwick Falls and Fractures Study, to determine an overall measure of fall risk for that individual. Fall risk is reported in standard deviations from the mean value for that measure, for normal 65-year old men and women.

The physiologic risk factors included in the PPA were those that displayed the highest predictive value for falls amongst the 341 elderly individuals that participated in the Randwick Falls and Fractures Study (see Section 1.1.5).\textsuperscript{5} The long-form PPA measures vision (high- and low-contrast visual acuity, and contrast sensitivity), vestibular function (visual field dependence), peripheral sensation (tactile sensitivity, vibration sense, proprioception), strength (quadriceps flexion, extension, and ankle dorsiflexion), reaction time (hand and foot), and postural sway (with eyes open or closed, on a firm or pliant surface). A weighted combination of the scores measured for these physiologic tests of function generates the overall individualized fall risk score.
A short-form PPA has been developed to further facilitate the rapid and reliable screening of potentially at risk individuals, particularly for settings where there are time constraints. Both the long- and short-form PPA tests generate the same overall fall risk score. The short-form PPA is composed of the elements of the long-form PPA that were identified on discriminant function analyses as being the most important discriminants between people who fall and those who do not. It is composed of the following measures:

- **Vision** - Contrast sensitivity (the Melbourne edge detection test); wherein the participant must identify the orientation of a line that divides a circle into a shaded and non-shaded half, with the contrast (in decibels) between the two sections decreasing on each successive test.

- **Proprioception** – uses a limb-matching task, where the participant must, with their eyes closed, align the position of their elevated big toes through a 1 cm plastic sheet, with an average of 5 trials being recorded (in degrees).

- **Quadriceps strength** – wherein the participant must displace as much weight (in kilograms) as possible by pulling against a strap attached around their calf, with the best of 3 trials recorded.

- **Reaction time** – wherein the participant is required to press a button in response to a variably-timed light cue, with the speed (in milliseconds) being recorded on 10 experimental trials.

- **Postural sway** – wherein the participant must stand as still as possible on a piece of foam for 30 seconds, and total sway (number of square millimeters) measured using a vertically mounted pen affixed to the participants back.

The five components of the short-form PPA are further outlined in Appendix A.

The PPA has a number of strengths as a fall risk assessment tool, particularly for widespread clinical use. Each component of the PPA is quick and simple to administer and measure. The assessments are non-invasive, easy to perform and comprehend. It is mobile.
and easily portable, allowing its use in participants' homes, or by multiuser teams. The PPA is readily accepted by most of those assessed, a valuable quality in an assessment of fall risk factors in the elderly. The PPA has been validated in a number of different populations, and is inexpensive. A final critical issue is the ability of the PPA to generate continuous, quantitative measures, allowing the use of parametric statistics for analysis of measurements. The PPA has now been used in a number of clinical settings outside of the ones in which it was developed, to successfully identify individuals at high risk of future falls.

1.1.9 Interventions to Prevent Falls in those at Risk

Once individuals at high risk of falls have been identified, they can receive targeted interventions to prevent falls. Although information is typically collected on both modifiable (i.e. balance) and non-modifiable (i.e. blindness) risk factors for falls, interventions to prevent falls in the elderly aim at decreasing the effect of one or more modifiable risk factors. For the purposes of this thesis, I will only briefly review relevant interventional studies reporting falls as an outcome, to provide some background to interventional strategies currently being investigated.

Some interventional studies to date have focused on the modification of a single risk factor to reduce falls in high-risk populations. Decreasing the number of prescription medications significantly decreased the odds of a subsequent fall in three studies. A comprehensive medical assessment followed by intervention for unmet medical needs has prevented falls in two studies, but not in a third. Many investigators have examined exercise programs alone as a means of preventing falls in the elderly. Neither a regular exercise program implemented as part of the Randwick Falls and Fractures Study, nor a low-impact weight bearing exercise program with calcium supplementation in the young elderly (mean age of 65, range 60 – 73), decreased fall incidence among participants.
However, poor compliance in these studies may be affecting the perceived effectiveness of exercise programs; in Lord's study, those who attended at least 75% of their classes were significantly less likely to have a subsequent fall. Although the mean attendance rate in McMurdo’s study was 76%, some participants attended as few as 46% of the classes. In contrast, an intensive strength and endurance training program decreased both health resource use and fall risk by up to 50% in a separate study in the community-dwelling elderly. Campbell et al. conducted a series of large randomized trials in the community-dwelling elderly, and found that individualized strength and balance retraining programs were beneficial in reducing both falls, again by up to 50%, and injuries. A pre-planned meta-analysis of the FICSIT (Frailty and Injuries: Cooperative Studies of Intervention Techniques) Trials, a series of 8 large controlled trials of falls prevention in the elderly, suggested that when the results are considered in aggregate, exercise interventions may be even more effective than evident from the individual studies. Finally, Tai Chi reduced the risk of recurrent falling by 47.5% in a study of 200 community-dwelling participants who had fallen previously. However, a recent systematic review suggested that Tai Chi is of only limited effectiveness, when smaller studies are also considered. The authors of that systematic review are presently planning a large randomized controlled trial to provide definitive proof of the efficacy, if it exists, of Tai Chi as a falls prevention strategy.

Multifactorial interventions in community-dwelling individuals simultaneously target two or more modifiable fall risk factor systems to decrease falls in those at risk. Home modification was found to be of equivocal benefit in preventing falls and no benefit in preventing fractures amongst the community-dwelling elderly in multifactorial intervention programs. Exercise programs as part of multifactorial interventions can reduce fall incidence, if compliance with the program is high. The majority of these studies were conducted using community-dwelling, healthy elderly individuals. It is only very recently that fall intervention efforts have included and focused on those with visual impairment.
Interventions to Prevent Falls in the Visually Impaired

Interventions to decrease the risk of falls in the visually impaired are beginning to be investigated. The most obvious suggestion, and that originally made in many of the studies first examining vision as a risk factor for falls, is to improve visual function. Anand et al. examined the effect of simulated refractive blur on postural sway in normally-sighted elderly volunteers, and suggested that correction of refractive error and removal of cataracts could successfully reduce fall risk in affected elderly individuals. In a study of 23 consecutive patients with cataract, cataract surgery was associated with a significant increase in postoperative postural stability. Brannan et al. determined in a prospective observational study of 97 patients that the rate of falls was less following cataract surgery, than in the 6-month pre-operative period. The power of the study was limited by the small sample size and short follow up time that resulted in a low event rate; nonetheless, it suggested that valuable gains in individual and public health through falls avoidance could be gained by timely vision-restoring intervention. Harwood et al. randomized 306 women over 70 with cataracts to expedited (within 4 weeks) or routine (within 12 months) wait to cataract surgery for the first eye, to examine its effect on incidence of falls. Although no difference was seen in the risk of having a first fall within this period, after adjustment for differences in baseline variables between groups, a 40% reduction in risk of recurrent falls between groups and a 34% reduction in the overall rate of falls was seen.

Only one study to date has examined the effect of a multifactorial, non-visual-specific, fall prevention program in the visually impaired. Campbell et al. randomized 391 elderly men and women with poor vision (<20/80 on the Snellen chart), with 12 month follow up, to one of 4 programs: 1) home hazards assessment and modification, 2) physiotherapist-led home-based exercise program with vitamin D supplementation, 3) both interventions, or 4) social visits as a control. Participants randomized to the home hazards group experienced a reduction in falls incidence (incidence rate ratio (IRR) = 0.59 (95%CI 0.42 – 0.83), but no
benefit was seen in those randomized to exercise (IRR=1.15 (95%CI=0.82-1.61). However, the falls rate in the exercise group was 77% lower among those with good compliance (p=0.001). Exercise interventions may still have utility in the visually impaired, if enrollment were restricted to those able to adequately participate.

The renowned New Zealand geriatrician and falls researcher, Professor John Campbell, stated that 'in community-based programmes for prevention of falls one size does not fit all' (138). This statement could equally be applied to screening programs. Particularly in a potentially high-risk population such as the visually impaired, where distinct visual deficits will limit the types of interventions that could be applied, tailored programs may be required to both identify and treat those visually impaired fallers. On the one hand, the performance of patients with AMD on tests of visual function would suggest increased risk of falling, but on the other hand, their decreased physical activity and mobility combined with increased caution may reduce risk. This is the first study to examine whether those with exudative AMD are truly at a higher risk of falls than those without.
1.2 REFERENCES


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1.3 THESIS THEMES

Thesis: The Risk of Falls in Elderly Community-dwelling Women with Exudative Age-related Macular Degeneration

**Topic 1:** Physiological Risk Factors for Falls in Elderly, Community-dwelling Women with Age-related Macular Degeneration

**Objective:** To determine, through the use of a multidimensional falls risk assessment, if the risk of falls is higher in those with exudative AMD than in those without exudative AMD.

**Topic 2:** The Incidence of Falls in Elderly, Community-dwelling Women with Exudative Age-Related Macular Degeneration

**Objective:** To prospectively determine the 6-month incidence of falls in those with AMD.
CHAPTER 2: PHYSIOLOGICAL RISK FACTORS FOR FALLS IN ELDERLY,
COMMUNITY-DWELLING WOMEN WITH AGE-RELATED MACULAR DEGENERATION
INTRODUCTION

Falls are a leading cause of morbidity and mortality in the elderly. Approximately 30% of those over 65 years experience at least one fall each year.\textsuperscript{1,2} Ninety percent of all hip fractures in the elderly are attributable to falling,\textsuperscript{3} which in turn is associated with a 12-20% excess in mortality within the first year.\textsuperscript{4} Those that fall typically report a reduction in physical and daily activities,\textsuperscript{5,6} increased fear of falling,\textsuperscript{1,7} a loss of independence,\textsuperscript{8,6} and increased social isolation.\textsuperscript{5} Women are both more likely to fall and more likely to fracture than men of the same age.\textsuperscript{2,10,11} Falls and related injuries have a direct cost of $128 million a year in British Columbia (BC) alone,\textsuperscript{12} in a population of approximately 4.3 million persons,\textsuperscript{13} and are the largest contributor to hospitalization rates and stay lengths in the elderly in this province.\textsuperscript{12} The annual direct costs associated with osteoporotic fractures in Canada as a whole is estimated to be 1.3 billion dollars, including 437 million in hospitalization costs corresponding in turn to 485,000 hospital days to treat 76,000 osteoporotic fractures.\textsuperscript{14} As the mean age of the population is increasing, the prevalence of falls and fractures, and associated economic burdens to the health care system, are increasing as well.\textsuperscript{15}

Large prospective cohort studies of falls in the community-dwelling elderly have shown that most falls have multiple causes,\textsuperscript{1-3} and represent a complex and individualized interaction between intrinsic and extrinsic risk factors. Intrinsic risk factors refer to specific properties of the individual that may predispose that person to having a fall. Numerous intrinsic fall risk factors have been identified, and include the history of a fall within one year,\textsuperscript{3} multiple chronic illnesses,\textsuperscript{1,2,16} dementia,\textsuperscript{17} neurologic, musculoskeletal, or functional disabilities,\textsuperscript{18} postural hypotension, use of psychotropic medications,\textsuperscript{19,20} cognitive impairment, foot problems,\textsuperscript{1} abnormalities of balance and gait,\textsuperscript{1,16,21} and visual impairment.\textsuperscript{22-26} Studies of visual risk factors for falls in the elderly have identified impairments in contrast sensitivity,\textsuperscript{24,25,27,28} visual acuity,\textsuperscript{1,25,26,29} and depth perception\textsuperscript{3,25} as independent contributors. The identification of modifiable risk factors for falls in older people may be useful to reduce fall
incidence.\(^3\) Measurement of these factors is the first step in designing appropriate intervention strategies. Multidimensional fall risk assessments have been developed that include measures of vision and other known physiologic risk factors like strength, balance, reaction time, and proprioception. One standardized tool, the Physiological Profile Assessment (PPA),\(^3\) has been developed to quantify an individual's fall risk,\(^2\),\(^3\) but has never previously been used in a population with visual impairment or specifically in those with exudative age-related macular degeneration (AMD).

AMD is the most frequent cause of untreatable visual impairment,\(^3\) and the leading cause of legal blindness, amongst the elderly in the Western world. The mild, dry, form of AMD affects 1 in 3 elderly people, with 10% of these going on to the more severe, exudative, form.\(^3\) Women have an approximately 3-fold increased risk of developing exudative AMD than men.\(^3\) People with exudative AMD experience a partial or complete loss of central vision in the affected eye, score poorly on measures of visual acuity and contrast sensitivity,\(^3\) and report a substantially decreased quality of life.\(^3\) Data on fall risk in this group is limited. No comprehensive fall risk assessments have been conducted and enrollment of participants with exudative AMD in the large cohort studies of visual impairment and falls\(^2\),\(^3\) was low. As people with AMD score poorly on measures of visual risk factors for falling, it is likely that they are at high risk of falling. Conversely, most AMD patients have reduced levels of physical activity due to poor vision\(^3\) and may actually fall less than healthy people. Little is known about how those with AMD score on other, non-visual, fall risk factors. At present, visual changes in AMD are non-reversible and reducing fall risk in this group will require modification of other risk factors (e.g. proprioception, reaction time). The purpose of this study is to determine, through the use of a multidimensional falls risk assessment, if the risk of falls is higher in those with exudative AMD than in those without exudative AMD.
METHODS

Design

We conducted a cross-sectional study examining physiologic risk factors for falls, by PPA, among 115 elderly, community-dwelling women with exudative AMD (AMD cohort). We compared our measurements to data from two comparison populations; the first was a locally-recruited sample of 34 elderly community-dwelling women without exudative AMD (non-AMD cohort), and the second consisted of normalized data on PPA measures (in z scores and standard deviations (SDs)) from 341 participants in the Randwick Falls and Fractures Study (the Randwick cohort), on which the PPA screening tool is based.

Participants

Our study cohort was composed of elderly (aged 70 years and older) community-dwelling women with exudative AMD (AMD cohort). Eligible participants had exudative AMD diagnosed by the presence of geographic atrophy or choroidal neovascularization on clinical exam and/or fluorescein angiography, were community-dwelling, English-speaking, and capable of giving information consent. Individuals were excluded if they self-identified as having a neuromuscular disease (ie. Parkinson's), used a wheelchair, or had other causes of poor vision including glaucoma or diabetic retinopathy. Recruitment took place from the specialty retinal practice of Dr. M. Potter at the University of British Columbia (UBC)/Vancouver Hospital (VH) Eye Care Centre (ECC) between August 1, 2004 and August 31, 2005.

Our comparison cohort was composed of elderly (aged 70 years and older) community-dwelling women without exudative AMD (non-AMD cohort). Eligible non-AMD participants reported good vision and had a recent (within 6 months) normal eye exam according to their regular ophthalmologist or optometrist. Participants may have had cataract surgery, have early lens changes, or features of dry AMD but no evidence of exudative changes, and had
to have a Snellen visual acuity of at least 20/40 bilaterally. All participants were community-dwelling, English-speaking, and capable of giving informed consent. Exclusion criteria also included use of a wheelchair, neuromuscular disease, or other causes of poor vision including glaucoma or diabetic retinopathy. Non-AMD group participants were recruited from the UBC/VH Eye Care Centre, where they were in attendance as a companion to a clinic patient.

The second comparison cohort (Randwick cohort) included 341 women aged 65 and over who participated in the Randwick Falls and Fractures Study,\textsuperscript{28} in Sydney, Australia, between 1988 and 1991. This population-based cohort study measured physiologic, health, and lifestyle factors associated with falls and fractures over 1 year. All recorded scores were compared by discriminant function analysis to determine which risk factors maximally discriminated fallers from non-fallers over one year, for inclusion in the PPA. The PPA generates an overall fall risk score for each individual based on performance on tests of fall risk factors. Available data on the Randwick cohort include demographics, and mean age-specific (in 5-year intervals) normal scores (z scores with SD) for each PPA measure and overall fall risk score. The PPA is a valid\textsuperscript{28, 32} and reliable\textsuperscript{40} tool for assessing fall risk in community-dwelling elderly populations. The fall risk score calculated by the PPA has a sensitivity and specificity of 75% for predicting falls in the elderly.\textsuperscript{28, 32} It has been used to objectively quantify fall risk in a number of recent studies,\textsuperscript{41-45} including in BC.\textsuperscript{41-43}

**Primary Outcome Measure**

All participants in the AMD and non-AMD cohorts completed the short form of Lord's Physiological Profile Assessment (PPA; Prince of Wales Medical Research Institute, Sydney NSW, Australia).\textsuperscript{31} All participants also completed additional tests of vision (high- and low-contrast visual acuity) and postural sway (with eyes closed on a compliant surface).
The PPA measurement consists of tests of vision, proprioception, reaction time, strength, and balance. Binocular visual acuity was measured at three meters using a high-contrast and low-contrast (10%) modified Snellen visual acuity chart, in the minimum angle resolvable (MAR) in minutes of an arc, using habitual correction. Contrast sensitivity was measured in decibels (dB), where dB = 10log_{10} contrast by the Melbourne Edge Test (MET), a non-grating test consisting of a series of 20 circles containing an edge with reducing contrast. Lower limb proprioception was assessed using a seated lower limb matching task, where discrepancy between the angle of limbs was measured in degrees. Hand reaction time was measured in milliseconds using a hand-held electronic timer, after the participant pushed a button in response to either a visual (light) or aural (tone) cue. Quadriceps strength was measured by weight displacement against a strain gauge, to the nearest 0.5 kg. Finally, postural sway was calculated using a swaymeter (40 cm long rod with a vertically mounted pen at the end) that measured displacement of the body at the waist on a sheet of paper; sway was measured in millimeters and testing performed with the participants' eyes open, then closed, on a piece of high density foam.

Individual standardized fall risk scores (z scores) were computed based on a summation of participant scores for each of the PPA measures. A score of zero on each test indicates average performance for those aged ≥65 years. Negative scores indicate below average performances on each measure, and positive scores, above average performances, with each unit representing one SD away from the mean. Weightings for each fall risk factor were calculated on the basis of a discriminant function analysis for predicting multiple falls conducted as part of the Randwick Falls and Fractures Study. Correlation coefficients used to generate the fall risk score were -0.33 for contrast sensitivity, 0.20 for lower limb proprioception, 0.47 for hand reaction time to a visual cue, -0.16 for quadriceps strength, and 0.51 for postural sway with eyes open on a compliant surface. In a clinical setting, fall risk scores of <1 can be interpreted as being at a low to mild risk of falling, 1 to 2 as being at a
moderate risk of falling, and scores above 2, being at a markedly increased risk of falling. Positive fall risk scores indicate a decreased risk of falls, compared to normal. 

**Fall Risk Factors/Potential Confounders**

In addition to the PPA, all participants in the AMD and non-AMD cohorts completed an interview to evaluate behavioral risk factors for falling. We measured these risk factors to assess the effect of potential confounders or effect modifiers on the relationship between visual impairment and falls. The impact of visual function on daily living was measured using the National Eye Institute's Visual Function Questionnaire 25, a 25-item scale covering 12 domains including general health, difficulties with near vision activities, driving, and mood. Participants were queried about demographics, one-year fall history, and the presence of stairs in the home. Current level of physical activity was assessed using the Physical Activities Scale for the Elderly (PASE). The PASE is a brief, reliable and valid 10-item scale for measuring physical activity in the community-dwelling elderly, specifically one's rate of participation in daily, sporting, and recreational activities. It correlates well with objective measures of physical activity, and physiologic measures such as hand grip strength, leg strength, and balance. We quantified fear of falling using the Activities-specific Balance Confidence (ABC) scale, a 16-item scale rating an individual's confidence with their balance in a variety of indoor and outdoor situations. Independent activities of daily living were measured using the Barthel Index, a 10-item index rating daily functioning, activities of daily living and mobility. Items include feeding, bathing, transferring from a bed to a chair, and mobility ascending or descending stairs. The effect of medical comorbidities were measured using a 25-item weighted comorbidity scale (WCS) quantifying medical problems and their impact on daily activities. The WCS has been used previously in those with AMD, and was measured both considering and then ignoring the effects of visual impairment, by removing the question on vision from the overall score.
**Sampling**

I approached potentially eligible participants, identified by daily clinic appointment schedule, upon their check-in at the UBC/VH ECC. The purpose of the study and inclusion criteria were reviewed verbally with potential participants, and if the individual was eligible and willing to participate, written consent was obtained.

**Sample Size**

We chose to test a two sided hypothesis as, although those with AMD have impairments on measures of visual function that are known risk factors for falls, low physical activity levels in this group may actually contribute to decreased time at risk and opportunity to fall. The annual falls rate among community-dwelling women over the age of 65 is between 30-40%. Tinetti found that 30% of elderly individuals fall each year, in her 1988 study of falls in community-dwelling individuals over 65 in the United States. As our study group is well-matched to Tinetti’s in age and gender (but not in visual impairment), we based our sample size calculation on her 30% annual fall rate. We chose to detect a 20% absolute difference (or, that up to 50% of women with AMD could fall once or more per year) as we felt that this difference in fall rates would be clinically meaningful. To detect an absolute difference of 20% in rates between the AMD and normal groups, using a 2-sided alpha error of 0.05 and power of 80%, we required 93 participants per group. We are assuming that the PPA fall risk score will reflect actual fall risk in the AMD and non-AMD cohorts. By agreement with members of the committee, I will present PPA data on the entire AMD cohort and the first 34 members of the non-AMD cohort, while the remainder of the non-AMD cohort are presently being recruited and undergoing assessment.
Analysis

Descriptive statistics (including the mean, range, SD, and proportions, as appropriate) were calculated for all dependent variables considered. Continuous data was examined for outliers (more than 3 SDs from the mean) using box plots. The mean of the distribution of ages was compared between groups using t-tests. The chi-square test was used to evaluate differences in proportions for categorical variables (1 year history of any falls, stairs in the home, history of hypertension or osteoporosis). Fisher's exact test was used to compare the proportions of categorical variables (history of multiple falls or fracture in the past year, use of a cane, joint replacement, or diagnosis of diabetes mellitus) if there were <5 counts per variable. A p value of $\alpha \leq 0.05$ was considered statistically significant. All calculations were performed using SPLUS 6.2 for Windows, Lucent Technologies Inc.53

Ethics

This study was approved by the University of British Columbia and Vancouver Hospital Clinical Research Ethics Review Boards (see Appendix B). As our target population was visually impaired, consent forms were read aloud to potential participants in both the AMD and non-AMD groups to ensure that both groups were equally informed prior to consenting.

RESULTS

I identified 131 potential participants for the AMD cohort, 115 of whom agreed to participate (87.8%). Sixteen women declined participation for varying reasons, the most common of which (n=10, 62.5%) was that the one hour assessment was viewed as too much of a time burden. Therefore, our AMD cohort was made up of 115 community-dwelling women 70 years of age or older with exudative AMD in one or both eyes. To the best of our knowledge, we approached all eligible participants, however a small number (<10) may have been missed while the researcher was already conducting an assessment. Sixty-five women
(57%) had exudative AMD in one eye only; 50 (43%) had bilateral exudative AMD. The mean time since diagnosis of AMD in the first eye was 26 months (range, 1 – 120 months).

Thirty-six potential participants were identified for the non-AMD cohort, two of whom declined participation. Our non-exposed group therefore was comprised of 34 women aged 70 or over, without exudative AMD. Eleven of the 34 non-AMD participants (32%) reported having a visual problem; 10 of these had the dry form of AMD, and 5 had early cataracts. Nonetheless, the mean and median habitual logMAR visual acuity among those without AMD were both 0.0 (Snellen equivalent=20/20; range,20/10 to 20/40). Baseline characteristics of the two groups are presented in Table 2.1. A significant difference was noted in VFQ-25 score, reflecting the difference in severity of visual impairment between the AMD and non-AMD cohorts. A higher proportion of AMD participants reported a history of a stroke in the past, or any fall in the previous year. Mean scores on WCS were significantly different between the groups at baseline, however when the impact of visual dysfunction was discounted from the WCS, no difference remained, by t test. Mean scores on the PASE scale were significantly different between the AMD and non-AMD cohorts, although this difference is likely not clinically meaningful. Mean scores on the ABC scale and Barthel Index were not significantly different between the AMD and non-AMD cohorts at baseline.

I performed the PPA falls risk profile assessment on all 115 AMD cohort participants and 34 non-AMD cohort participants. The mean overall fall risk scores of 3.26 (SD=1.26) in the AMD cohort and 0.96 (SD=0.79) in the non-AMD cohort were significantly different (p<0.0001). When each component contributing to the overall fall risk score (sway with eyes open, reaction time to light, contrast sensitivity, quadriceps strength, and proprioception) was examined separately, the mean for each measure was significantly different (p<0.05) between the two groups. Table 2.2 shows baseline overall mean fall risk scores, mean
scores for selected PPA components, and SDs of participants in the AMD, non-AMD and Randwick cohorts.

The AMD cohort, but not the non-AMD cohort, were at a substantially elevated fall risk over the Randwick cohort, by overall PPA fall risk score. The AMD group as a whole scored significantly lower on measures of vision, postural sway, and reaction time, compared with the Randwick cohort. However, scores on measures of proprioception and quadriceps strength approached normal (were within one SD of the mean). In contrast, the average for the non-AMD cohort was within one SD of the mean on all of the main PPA measures, except reaction time (z=-1.07). Postural sway with eyes closed, a test not included in the overall fall risk score, was markedly departed from the norm (z=-1.97) in the non-AMD cohort. Even so, the non-AMD cohort was still at a low risk of falls by PPA fall risk score, compared to the Randwick cohort. Figure 2.1 presents the physiologic falls profile based on the average responses of participants in the AMD and non-AMD group, in SDs from the mean (z scores) for each PPA component.

Overall fall risk in the AMD group increases with increasing age, when PPA fall risk score results are stratified by 5-year age category. In all age groups, AMD participants were at least at a moderately increased risk of falling over the normal 65 year old population. Within 5 year age categories, the overall fall risk score in the AMD cohort ranges from moderately elevated (2.39) in the lowest age range (70 – 75), to substantially elevated (3.79) in the highest age category (85+), compared to the average responses from a 65-year old from the Randwick cohort. The non-AMD cohort displays a similar age-dependent trend for 5 year age categories, with risk scores increasing from no elevated risk (0.18) among those aged 70 – 75 to moderate risk (1.50) among those over 85, compared to the average responses of a 65-year old from the Randwick cohort. The magnitude of the risk is less in the non-AMD
cohort than the AMD cohort. The age ranges with overall fall risk scores and SDs for participants in the AMD and non-AMD groups are presented in Table 2.3.

Compared to our second comparison group of age-matched participants from the Randwick Falls and Fractures Study, the AMD group is also at an elevated risk of falls by PPA fall risk score. Within each age stratification category, AMD group participants consistently demonstrate scores that are normal on measures of proprioception and strength, but beyond normal limits on all other PPA measures. In contrast, participants in the non-AMD group fall within the range of expected values for each PPA component in each age stratum, except for postural sway with eyes closed. Table 2.4 presents average PPA measure scores for participants in the AMD and non-AMD groups, and normal women from the Randwick Falls and Fractures Study, for the representative age stratum of individuals aged 70 – 74 years.

DISCUSSION

We performed a cross-sectional study to measure physiologic risk factors for falls, and calculate an overall fall risk score using the PPA, in elderly, community-dwelling women with exudative AMD. In our study, we found that women with exudative AMD were at a significantly higher risk of falling, by both PPA fall risk score and performance on measures of physiological risk factors for falls, than women without exudative AMD. On average, women with exudative AMD were more than three standard deviations above the mean in fall risk score compared to normal 65-year old women, with the average fall risk score increasing with age. Women with exudative AMD demonstrated substantial deficits on the PPA components of vision, postural sway, and reaction time, while measures of proprioception and strength approached normal.

Ours is the first study to prospectively measure physiologic risk factors for falls in those with exudative AMD, and the first use of the PPA in a low vision population. This quantifies that
women with AMD are at a high risk of falls, by a valid and reliable fall risk score, compared to a non-AMD population. The visual measures on which those with AMD frequently score poorly, such as visual acuity, contrast sensitivity, visual field, and depth perception, are known fall risk factors among the normal community-dwelling elderly. The exudative AMD cohort displayed poor postural control, with eyes open and particularly so with eyes closed. These data extend upon a similar finding of poor standing balance reported in 16 individuals with AMD. Maintaining postural control requires the effective integration of visual, proprioceptive, and vestibular input; deficits in any one of these systems can cause severe problems with balance. The non-AMD group also demonstrated problems with balance with eyes closed, though to a lesser extent than the AMD group, compared to the normalized Australian population. The results obtained for sway with eyes closed may be explained by the older ages of both our AMD and non-AMD groups compared to the 65-year old normative population, as standing balance decreases with age, especially with the eyes closed.

Participants with AMD had a slow reaction time to a light cue but normal reaction time when reacting to a tone. Thus, their actual 'reaction time' was normal; vision alone limited their perception of the light cue. Two other PPA dimensions -- strength and proprioception -- were normal. As proprioception is a key determinant of balance, it suggests that the poor postural sway scores in the AMD group may reflect more the severity of AMD rather than the deterioration of the proprioceptive or vestibular systems. Campbell and colleagues recently reported results of the first interventional trial that targeted falls amongst the visually impaired including some patients with exudative AMD. An intention to treat analysis revealed that this strength and balance retraining program did not reduce falls. Our present study suggests that focusing on improving postural sway, rather than strength, may be of more value in preventing falls in those with exudative AMD.
Our study was strengthened by the use of two well-matched comparison groups. Comparing our AMD cohort to our two non-AMD cohorts consistently showed that those with AMD are at an increased risk of falling. In addition, our non-AMD cohort was at a low risk of falls, in line with the fall risk from the Randwick cohort. We measured baseline characteristics such as balance confidence (ABC) and physical activity levels (PASE) because these are relevant risk factors for falls. However, although these are independent risk factors for falls in studies of the community-dwelling elderly, both poor balance and low physical activity would occur in the AMD cohort secondary to the AMD disease process itself. In our study, balance, but not balance confidence, was significantly worse in the AMD cohort than the non-AMD cohort. Balance confidence may be poor overall in elderly individuals, indicated by the similarly poor ABC scores measured in both the AMD and non-AMD cohorts. Physical activity, by PASE, was significantly worse in our AMD group. Our findings of significantly poorer balance and physical activity scores in the AMD cohort compared to the non-AMD cohort and our PPA measurements support this hypothesis. No difference was noted in the Barthel Index, measuring independent activities of daily living, which is not surprising as both study groups are composed of healthy, community-dwelling individuals.

Participants in the AMD and non-AMD cohorts differed significantly in their visual impairment (by VFQ25 and WCS), our variable of interest. A significant difference was also noted between the AMD and non-AMD cohorts in the proportion of individuals with a history of a fall in the previous year. The proportion of individuals reporting a fall within the past 12 months in the non-AMD group was substantially less than previously reported, and it is possible that there was a reporting bias due to problems with recall. Self-reported fall history is not a reliable measure as up to 30% of fallers forgot to report a fall in a one year study of falls in the elderly. The number of participants with stroke in both groups was small but significantly higher amongst those with AMD. This is unlikely to be a major confounder,
however, as a key strength of the PPA is that it is a physiologic-, not disease-oriented approach that focuses on the effects of impairment irrespective of the cause.31

A strength of our study is the use of a well-matched comparison group, who were companions of people attending medical appointments at the VH/UBC Eye Care Centre as a comparison group. The non-AMD cohort, however, may be a particularly healthy one as they are companions or drivers to other elderly individuals. This could bias our results towards increasing the apparent magnitude of the difference between our non-AMD and AMD cohorts. Nonetheless, the non-AMD cohort is a reasonable comparison group because the target AMD population is community-dwelling, and the groups were well-matched on baseline characteristics when the effects of visual impairment were disregarded.

The generalizability of our results may be limited by our study's restriction to women. We chose to include only women because of their higher incidence of exudative AMD, and fall and fracture rate2,10,11 compared to men of the same age. In addition, due to the cross-sectional design of this study, it is not possible to infer causality between the incidence of AMD and poor performance on fall risk factor measures. Nonetheless, it seems likely that reduced physical activity secondary to poor vision contributes to functional decline and poor balance, rather than the opposite. Indeed, that visual impairment is associated with subsequent functional decline has been demonstrated in other prospective studies of falls in the elderly.61,62

In summary, we found that women with exudative AMD were at a significant and dramatically elevated risk of falls, based on measured fall risk factors. However, the use of the PPA has not yet been validated in a visually impaired population. Prospective follow up studies of the visually impaired with respect to falls will help to further illuminate the problem. Information on any specific deficit in fall risk profile in those with AMD (for example, postural sway), could
provide an important target for intervention strategies to reduce fall risk. Numerous studies have demonstrated that effective intervention can reduce the risk of falls by 40-60%, in elderly community-dwelling populations. Our data indicate that women with exudative AMD perform poorly on measures of physiologic risk factors for falls, and should stimulate the development of intervention strategies focusing on improving modifiable risk factors such as postural sway.
Table 2.1: Baseline characteristics of the study groups (self-reported)

<table>
<thead>
<tr>
<th></th>
<th>AMD cohort (n=115)</th>
<th>Non-AMD cohort (n=34)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age (range)</td>
<td>81.3 years (70 – 92)</td>
<td>78.6 years (72 – 89)</td>
</tr>
<tr>
<td>70 – 74</td>
<td>17 (15%)</td>
<td>5 (15%)</td>
</tr>
<tr>
<td>75 – 79</td>
<td>21 (18%)</td>
<td>16 (47%)</td>
</tr>
<tr>
<td>80 – 84</td>
<td>47 (41%)</td>
<td>8 (24%)</td>
</tr>
<tr>
<td>85 – 89</td>
<td>30 (26%)</td>
<td>5 (15%)</td>
</tr>
<tr>
<td>Mean (SD) VFQ-25 score</td>
<td>282.54 (61.38)</td>
<td>360.2 (25.5)</td>
</tr>
<tr>
<td>One year fall history</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any</td>
<td>32 (28%)</td>
<td>8 (24%)</td>
</tr>
<tr>
<td>Two or more</td>
<td>9 (8%)</td>
<td>1 (3%)</td>
</tr>
<tr>
<td>One year fracture history</td>
<td>7 (6%)</td>
<td>3 (9%)</td>
</tr>
<tr>
<td>Occasional cane use</td>
<td>18 (16%)</td>
<td>3 (9%)</td>
</tr>
<tr>
<td>Joint replacement</td>
<td>4 (3%)</td>
<td>4 (11.8%)</td>
</tr>
<tr>
<td>Stairs in home</td>
<td>89 (77%)</td>
<td>23 (68%)</td>
</tr>
<tr>
<td>Medication use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium/Vitamin D</td>
<td>23 (20%)</td>
<td>9 (26.5%)</td>
</tr>
<tr>
<td>Benzodiazepines</td>
<td>7 (6%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Other sedatives</td>
<td>5 (4%)</td>
<td>2 (5.9%)</td>
</tr>
<tr>
<td>Antidepressants</td>
<td>10 (9%)</td>
<td>2 (5.9%)</td>
</tr>
<tr>
<td>Diuretics</td>
<td>17 (15%)</td>
<td>6 (17.6%)</td>
</tr>
<tr>
<td>Medical Comorbidities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>9 (8%)</td>
<td>4 (11.8%)</td>
</tr>
<tr>
<td>Osteoporosis</td>
<td>42 (37%)</td>
<td>7 (20.6%)</td>
</tr>
<tr>
<td>History of Stroke</td>
<td>9 (8%)</td>
<td>1 (3%)</td>
</tr>
<tr>
<td>Arthritis</td>
<td>53 (46%)</td>
<td>19 (55.9%)</td>
</tr>
<tr>
<td>Any of the above</td>
<td>78 (67.8%)</td>
<td>26 (76%)</td>
</tr>
<tr>
<td>Mean (SD) PASE score</td>
<td>94.26 (48.27)</td>
<td>104.6 (42.4)</td>
</tr>
<tr>
<td>Mean (SD) Barthel score</td>
<td>98.13 (9.90)</td>
<td>99.1 (2.3)</td>
</tr>
<tr>
<td>Mean (SD) ABC score</td>
<td>85.91 (16.27)</td>
<td>87.2 (11.4)</td>
</tr>
<tr>
<td>Mean (SD) WCS score</td>
<td>8.40 (4.7)</td>
<td>4.29 (3.3)</td>
</tr>
<tr>
<td>Mean (SD) WCS score, without visual impairment</td>
<td>5.61 (4.5)</td>
<td>4.29 (3.3)</td>
</tr>
</tbody>
</table>
Table 2.2: Mean (SD) PPA fall risk score, and scores for select PPA components, by group.

<table>
<thead>
<tr>
<th></th>
<th>AMD cohort (n=115)</th>
<th>Non-AMD cohort (n=34)</th>
<th>Randwick cohort (n=341)†</th>
<th>p value‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall Risk Score</td>
<td>3.26 (1.26)</td>
<td>0.96 (0.79)</td>
<td>0.0 (1.0)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>High Contrast Visual Acuity</td>
<td>3.93 (4.50)</td>
<td>1.05 (0.38)</td>
<td>1.48 (1.03)</td>
<td>0.00024</td>
</tr>
<tr>
<td>Low Contrast Visual Acuity</td>
<td>10.1 (7.09)</td>
<td>2.40 (0.85)</td>
<td>2.59 (1.76)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Edge Contrast Sensitivity*</td>
<td>12.5 (4.16)</td>
<td>20.4 (2.82)</td>
<td>21.0 (3.4)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Proprioception*</td>
<td>2.13 (0.99)</td>
<td>1.27 (0.97)</td>
<td>1.92 (1.58)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Quadriceps Strength*</td>
<td>16.8 (6.25)</td>
<td>20.3 (7.7)</td>
<td>12.6 (4.6)</td>
<td>0.0092</td>
</tr>
<tr>
<td>Reaction Time – Light*</td>
<td>343.0 (95.1)</td>
<td>301.5 (50.6)</td>
<td>249.0 (53.0)</td>
<td>0.0154</td>
</tr>
<tr>
<td>Reaction Time – Tone</td>
<td>282.4 (113.5)</td>
<td>251.9 (74.1)</td>
<td>NA</td>
<td>0.1636</td>
</tr>
<tr>
<td>Sway – Eyes Open*</td>
<td>312.6 (177.5)</td>
<td>141.0 (82.2)</td>
<td>131.0 (63)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Sway – Eyes Closed</td>
<td>867.1 (630.6)</td>
<td>588.5 (196.7)</td>
<td>230 (111.0)</td>
<td>0.0131</td>
</tr>
</tbody>
</table>

*Measures that are incorporated into overall fall risk score; † from Lord JAGS 1994 Ref 28; ‡ for the difference between mean measures for the AMD and non-AMD cohorts.
Table 2.3: Overall fall risk scores by age category

<table>
<thead>
<tr>
<th>Age category</th>
<th>AMD cohort</th>
<th>Non-AMD cohort</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fall Risk Score (SD, n)</td>
<td>Fall Risk Score (SD, n)</td>
</tr>
<tr>
<td>70 – 74</td>
<td>2.39 (1.11; n=17)</td>
<td>0.18 (0.59; n=5)</td>
</tr>
<tr>
<td>75 – 79</td>
<td>2.96 (1.14; n=21)</td>
<td>1.02 (0.65; n=16)</td>
</tr>
<tr>
<td>80 – 84</td>
<td>3.44 (1.25; n=47)</td>
<td>1.01 (0.78; n=8)</td>
</tr>
<tr>
<td>≥85</td>
<td>3.79 (1.23; n=30)</td>
<td>1.50 (1.01; n=5)</td>
</tr>
</tbody>
</table>
Table 2.4: Age-specific (age 70 – 74 years) PPA measures for participants age 70 – 74 in the AMD, non-AMD, and Randwick age-matched normal cohorts.

<table>
<thead>
<tr>
<th>Fall Risk Measure</th>
<th>AMD Group (n=17)</th>
<th>Non-AMD Group (n=5)</th>
<th>Age-matched Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Contrast Visual Acuity</td>
<td>2.84 (3.91)</td>
<td>1.01 (0.26)</td>
<td>0.83 – 1.58</td>
</tr>
<tr>
<td>Low Contrast Visual Acuity</td>
<td>6.18 (5.84)</td>
<td>2.46 (1.06)</td>
<td>1.32 – 2.65</td>
</tr>
<tr>
<td>Melbourne Edge Test</td>
<td>14.53 (4.56)</td>
<td>23 (1.58)</td>
<td>23 – 24</td>
</tr>
<tr>
<td>Proprioception</td>
<td>1.96 (0.93)</td>
<td>0.64 (0.55)</td>
<td>0.4 – 2.4</td>
</tr>
<tr>
<td>Quadricep Strength</td>
<td>18.47 (7.77)</td>
<td>24.8 (7.82)</td>
<td>15 – 29</td>
</tr>
<tr>
<td>Visual Reaction Time</td>
<td>296.69 (76.92)</td>
<td>265.1 (11.63)</td>
<td>197 – 267</td>
</tr>
<tr>
<td>Sway – Eyes Open</td>
<td>248.94 (132.41)</td>
<td>113.4 (55.92)</td>
<td>65 – 163</td>
</tr>
<tr>
<td>Sway – Eyes Closed</td>
<td>625.11 (331.41)</td>
<td>582 (103.69)</td>
<td>108 - 285</td>
</tr>
</tbody>
</table>
Figure 2.1: Falls Risk Profile in the AMD and non-AMD cohorts.

The bars indicate average performance on each measure in relation to norms for persons aged 60 years and over. Scores above zero show above average performances and scores below zero show below average performances. Scores below -1 indicate significant impairments. Sway EC=Sway with Eyes Closed; Sway EO=Sway with Eyes Open; RT=Reaction Time to Visual Cue; KES=Knee Extension (Quadriiceps) Strength; Prop=Proprioception; ECS=Edge Contrast Sensitivity; VALC=Low-Contrast Visual Acuity; VAHC=High-Contrast Visual Acuity.
References


CHAPTER 3: THE INCIDENCE OF FALLS IN ELDERLY, COMMUNITY-DWELLING WOMEN WITH EXUDATIVE AGE-RELATED MACULAR DEGENERATION
Age-related macular degeneration (AMD) is the leading cause of severe vision loss and legal blindness amongst elderly people throughout the developed world.\(^1\) The exudative form of AMD is characterized by the development of choroidal neovascularization (CNV), and is associated with severe, and at present, irreversible, central visual loss.\(^2\) Women have a 2-3 fold increased risk of developing AMD than men.\(^1\) Affected individuals may be unable to read, write, recognize faces, or drive due to loss of central visual function. However, peripheral vision, useful for orientation, identifying motion, and mobility, is typically unaffected. Nonetheless, people with severe vision loss in exudative AMD report restricted mobility,\(^3\) reductions in physical activity and functional limitations.\(^4\) It is presently unknown whether the visual impairment, alone or in combination with reduced physical activity and mobility, is associated with a higher rate of falling and fractures amongst those with AMD.

Falls are a major cause of morbidity, disability, and mortality in the elderly. Approximately one in three community-dwelling people over the age of 70 fall each year, and the incidence increases with age.\(^5,6\) Women are both more likely to fall and more likely to fracture than men of the same age.\(^6-8\) Risk factors for falls are numerous, and include deficits in visual measures such as contrast sensitivity, visual acuity, and depth perception.\(^5,9-16\) Although poor vision is a known risk factor for falls, and AMD is the leading cause of poor vision among the elderly in the Western world, no prospective study has examined the incidence of falls after the diagnosis of exudative AMD. Two large prospective population-based cohort studies of visual impairment, the Beaver Dam and Blue Mountains Eye Studies, examined the risk of falls and fractures as secondary outcomes, but included only a small number of people with exudative AMD.\(^16,17\) These secondary studies only looked retrospectively at falls history, and it was never shown that the onset of visual impairment actually preceded the fall. Further, the outcome measure relied upon 12-month recall of falls; up to 32% of fallers forget having experienced a fall, when 12-month recall is compared to weekly individualized follow up.\(^18\) Although falls and exudative AMD have not yet been studied directly, people with
exudative AMD score poorly on measures of visual risk factors for falls, including visual acuity, contrast sensitivity,\textsuperscript{19} depth perception, and sometimes visual field.\textsuperscript{20} In addition, associations have also been found between exudative AMD and other fall risk factors, such as postural sway,\textsuperscript{21} gait,\textsuperscript{22} and cognition.\textsuperscript{23}

These data raise the question of whether or not people with exudative AMD suffer more falls than their age-matched counterparts. On the one hand, it could be argued that the visual and physiologic changes that are part of the condition expose those with exudative AMD to a higher risk of falling compared with the general elderly population. On the other hand, as most AMD patients have reduced levels of physical activity due to poor vision,\textsuperscript{4} it is possible that those with AMD may actually fall less than healthy people. If those with AMD are frequent fallers, they would be a suitable target for intervention strategies to lower fall risk. At present, longstanding visual changes in AMD are irreversible and reducing fall risk in this group would require modification of other fall risk factors. Therefore, as there have been no studies that comprehensively examined fall risk in people with exudative AMD, the purpose of this study was to prospectively determine the incidence of falls in those with AMD.

METHODS

Design

I conducted a 6-month cohort study examining the association of behavioural, medical, and demographic risk factors with subsequent incidence of falls, in 115 community-dwelling women aged 70 years or older with exudative AMD (AMD cohort). We compared the incidence of falls in the AMD cohort to the incidence of falls in our non-AMD cohort, comprised of 93 community-dwelling women aged 70 years or older without exudative AMD.
**Participants**

Our study cohort group was composed of elderly (aged 70 years and older) community-dwelling women with exudative AMD (AMD cohort). Eligible participants had exudative AMD diagnosed by the presence of disciform scars or choroidal neovascularization on clinical exam and/or fluorescein angiography, were community-dwelling, English-speaking, and capable of giving information consent. Individuals were excluded if they self-identified as having a neuromuscular disease (i.e. Parkinson’s), used a wheelchair, or had other causes of poor vision including glaucoma or diabetic retinopathy. Recruitment took place from the specialty retinal practice of Dr. M. Potter at the University of British Columbia (UBC)/Vancouver Hospital (VH) Eye Care Centre (ECC) between August 1, 2004 and August 31, 2005.

Our comparison cohort (non-AMD cohort) was composed of elderly (aged 70 years and older) community-dwelling women without exudative AMD. Eligible non-AMD participants reported good vision and had no exudative AMD on a recent (within 6 months) eye exam according to their regular ophthalmologist or optometrist. Participants may have had cataract surgery, have early lens changes, or features of dry AMD but no evidence of exudative changes, and had to have a Snellen visual acuity of at least 20/40 bilaterally. All participants were community-dwelling, English-speaking, and capable of giving informed consent. Exclusion criteria included use of a wheelchair, neuromuscular disease, or other causes of poor vision including glaucoma or diabetic retinopathy. Non-AMD group participants were recruited from the UBC/VH Eye Care Centre, where they were in attendance as a companion to a patient.

**Primary Outcome Measure**

Falls were defined as an event resulting in an individual unintentionally coming to rest on the ground or a lower level, in the absence of overwhelming hazard. Fall events were
classified, based on the system proposed by Robertson and Campbell,\textsuperscript{26} as causing 1) serious injury if a fracture or hospital admission followed, 2) moderate injury if bruising, sprains, cuts, abrasions, or a 3-day reduction in physical function resulted, or the participant consulted medical care, and 3) no injury. All participants were provided with a 6-month daily fall diary in which to record falls and the circumstances surrounding them. As retrospective recall of falls is poor in the elderly,\textsuperscript{18} with up to 32% of fallers forgetting having a fall within one year, all participants were followed monthly over the telephone. Monthly follow up, especially in combination with a falls calendar, is accepted as the gold standard in falls research, compared to 3-, 6-, or 12-month follow up intervals.\textsuperscript{27} After 6 months of follow up per patient, the incidence of falls in the AMD cohort was compared to that of the non-AMD comparison cohort.

**Falls Risk Factors/Potential Confounders**

All participants were interviewed to measure baseline risk factors for falling, to allow us to assess the roles of other potential confounders or effect modifiers of the relationship between visual impairment and falls. The interview consisted of questions on demographics, one-year fall history, and medication use. Binocular visual acuity was then measured at three meters using a high-contrast and low-contrast (10\%) modified Snellen visual acuity chart, in the logarithm of the minimum angle resolvable (logMAR) in minutes of an arc, using habitual correction. Independent activities of daily living were measured using the Barthel Index,\textsuperscript{28} a 10-item index rating daily functioning, activities of daily living and mobility. Items include feeding, bathing, transferring from a bed to a chair, and mobility ascending or descending stairs. The impact of visual function on daily living was measured using the National Eye Institute’s Visual Function Questionnaire 25,\textsuperscript{29} a 25-item scale covering 12 domains including general health, difficulties with near vision activities, driving, and mood. The effect of medical comorbidities were measured using a 25-item weighted comorbidity scale (WCS) quantifying medical problems and their impact on daily activities. The WCS scale has been used
previously in those with AMD,\textsuperscript{30} and was measured both considering, and then disregarding, the effects of visual impairment, by removing the question on vision from the overall score.

**Sampling**

I approached potentially eligible participants, identified by daily clinic appointment schedule, upon their check-in at the UBC/VH ECC. The purpose of the study and inclusion criteria were reviewed verbally with potential participants, and if the individual was eligible and willing to participate, written consent was obtained.

**Sample Size**

We chose to test a two sided hypothesis as, although those with AMD have impairments on measures of visual function that are known risk factors for falls,\textsuperscript{12} low physical activity levels\textsuperscript{4} in this group may actually contribute to decreased time at risk and opportunity to fall. The annual falls rate among community-dwelling women over the age of 65 is between 30-40\%.\textsuperscript{5,6} Tinetti found that 30\% of elderly individuals fall each year, in her 1988 study of falls in community-dwelling individuals over 65 in the United States.\textsuperscript{5} As our study group is well-matched to Tinetti’s in age and gender (but not in visual impairment), we based our sample size calculation on her 30\% annual fall rate. We chose to detect a 20\% absolute difference (or, that up to 50\% of women with AMD could fall once or more per year) as we felt that this difference in fall rates would be clinically meaningful. To detect an absolute difference of 20\% in rates between the AMD and normal groups, using a 2-sided alpha error of 0.05 and power of 80\%, we required 93 participants per group.
Analysis

Descriptive statistics (including the mean, range, standard deviation (SD), and proportions, as appropriate) were calculated for all dependent variables considered. The means and SDs of continuous variables were compared between groups using t tests. The Chi-square test was used to compare differences in proportions for categorical variables. Fisher’s exact test was used to compare the proportions of categorical variables where there were <5 counts per variable.

We compared the number of falls between those in the AMD cohort and those in the non-AMD cohort using negative binomial regression models. These models measure the rates of recurrent rare events, like falls, by estimating the number of occurrences for each participant over a constant (6-month) period of follow up. Falls are not normally distributed, and therefore models which assume a normal distribution, like linear regression, are not appropriate. Rather than viewing falls as a binary outcome, as in logistic regression, we chose to view falls as potentially recurrent events, which is particularly important as frequent fallers are an especially high risk population for future falls. The negative binomial regression model is useful for counts data, and for recurrent events. It is a generalization of Poisson regression, which is also used for counts data, and which assumes that the variance of the sample is equal to its mean. Negative binomial regression however allows for more variation in the sample (overdispersion) so that the mean and variance do not have to be equal. The Poisson distribution is therefore a special case of the negative binomial distribution, in which overdispersion equals zero. As we are dealing with an unknown population with unknown sample variability, we chose to use the negative binomial model to allow us the most flexibility and make fewer assumptions about the dispersion of our study data. Should the dispersion in our sample actually be very low, and the variance equal the mean, our negative binomial distribution will be equivalent to the Poisson. The amount of variability accounted for by our model in the sample is determined by calculating $R^2$. 

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equivalent to $1 - (K/K_{\text{max}})$, where $K$ ($K=1/\theta$) is the overdispersion parameter for the fitted model and $K_{\text{max}}$ ($K_{\text{max}} = 1/\theta$) is the overdispersion parameter for a model without covariates.

Adjusted relative risks for falling, with 95% confidence intervals, based on AMD were calculated. All calculations were performed using SPLUS 6.2 for Windows, Lucent Technologies Inc. A $p$ value of $\alpha \leq 0.05$ was considered significant.

**Ethics**

This study was approved by the University of British Columbia and Vancouver Hospital Clinical Research Ethics Review Boards (see Appendix B). All participants were required to be independent and community-dwelling, as well as English speaking, to minimize any potential problems with obtaining informed consent in the elderly. As our target population was visually impaired, consent forms were read aloud to potential participants in both the AMD and non-AMD groups to ensure that both groups were equally informed prior to consenting.

**RESULTS**

I identified 131 potential participants for the AMD cohort, 115 of whom agreed to participate (87.8%). Sixteen women declined participation for varying reasons, the most common of which ($n=10$, 62.5%) was that the one hour assessment was viewed as too much of a time burden. Therefore, our AMD cohort was made up of 115 community-dwelling women 70 years of age or older with exudative AMD in one or both eyes. Sixty-five women (57%) had exudative AMD in one eye only; 50 (43%) had bilateral exudative AMD. The mean time since diagnosis of exudative AMD in the first eye was 26 months (range, 1 – 120 months). I approached 97 potential non-AMD cohort participants aged 70 or over without exudative AMD in either eye, 93 (96%) of whom agreed to participate. Thirty-three women (35%) had
mild, dry AMD and 9 women (10%) had evidence of mild cataracts in one or both eyes. Nonetheless, the mean and median habitual logMAR visual acuity among those without AMD were both 0.0 (Snellen equivalent=20/20; range, 20/10 to 20/40). No participants in the non-AMD cohort developed exudative AMD during the course of the study. To the best of our knowledge, all eligible participants were approached although a small number (<10) may have been missed while S. Szabo was already performing an assessment. Baseline characteristics of the two groups are presented in Table 3.1. Only mean age ($p<0.0001$), VFQ-25 score ($p<0.0001$), and WCS score ($p=0.0005$) differed significantly between the groups at baseline. When the effect of visual impairment on comorbidity was disregarded by removing the question on vision from the total score, the difference in means was no longer significant ($p=0.3803$)

Over 6 months of follow up, 32 women in the AMD group (27.8%) and 13 women in the non-AMD group (13.7%) reported at least one fall during the 6-month follow up period ($p=0.03$). Repeated falls were reported by 9 of the 32 fallers in the AMD group, and 0 of the 13 fallers in the non AMD group ($p<0.001$). The odds of being a faller, for AMD vs. non-AMD, was 2.40 (95%CI = 1.18 – 4.87), and 2.55 (95%CI = 1.14 – 5.74) after age adjustment.

In terms of total number of falls, 47 were recorded in the AMD group and 13 in the non-AMD group ($p=0.004$) over the 6 month follow up period. An average of 0.41 falls per person were experienced in the AMD group, and 0.14 falls per person were experienced in the non-AMD group over 6 months ($p<0.001$). The fall rate per group was therefore 82 falls per 100 person years for those with AMD, and 28 falls per 100 person years for those without AMD. As our outcome of interest was the total number of falls per participant for the AMD vs. non-AMD groups, we developed univariate negative binomial regression models to examine the effect of our putative explanatory variables on falls incidence. Table 3.2 lists regression coefficients, standard errors, unadjusted relative risks, and 95% confidence intervals for
measured putative explanatory variables in our study. Although AMD, WCS score, and self-reported 12 month fall history were significant predictors of falls on univariate analysis, only AMD and self-reported fall history remained significant in the multivariate model (Table 3.3). The adjusted relative risk of an individual having a fall over 6 months, for exudative AMD versus no exudative AMD, is 3.15 (95% CI=1.47 – 6.74). The $R^2$ of the fitted model was 0.662.

Of the 60 total falls recorded over the 6 month time period, 34 falls caused at least moderate injury. Twenty-eight injurious falls occurred in the AMD group and 6 in the non-AMD group ($p=0.07$). We also developed univariate negative binomial regression models to measure the effect of putative explanatory variables on the number of injurious falls experienced in 6 months (Table 3.4). Although AMD and WCS score were significantly associated with falls on univariate analysis, again only AMD score remained significant in the multivariate model (Table 3.5). The adjusted relative risk for having an injurious fall over six months, for exudative AMD versus no exudative AMD, was 3.75 (95%CI=1.28 – 10.9). The $R^2$ of the fitted model was 0.29.

**DISCUSSION**

We performed a prospective 6-month cohort study to determine whether elderly community-dwelling women with exudative AMD were at a higher risk of falls and injurious falls, than similar women without exudative AMD. The relative risk for women with exudative AMD to experience a fall compared to those without exudative AMD, adjusted for age, was 3.15. Even more remarkably, the relative risk for a women with exudative AMD to experience an injurious fall, compared to one without exudative AMD, over the 6 month study period was 3.75.
Our AMD group cohort of 115 participants, followed for 6 months, experienced 47 falls over 690 person-months of follow up, corresponding to a rate of 84 falls per 100 person-years. Campbell and colleagues reported a rate of 113 falls per 100 person-years in the control arm of their interventional study of falls in the visually impaired. The control arm included 163 (83%) people with either dry or wet AMD, with a best-corrected best-eye Snellen visual acuity \(\leq 20/80\), but participants may have had coexisting eye problems such as glaucoma or diabetic retinopathy. Our falls rate is also in line with rates from other high-risk groups, such as recurrent fallers presenting to the Emergency Department at tertiary care centres. The rate in our AMD group was also much higher than the observed 28 falls per 100 person years in our control population.

Our study is the first to prospectively examine the risk and risk factors for falls specifically in those with exudative AMD. Our observations are consistent with previous studies examining the association of visual function and visual impairments with falls. Estimates of risk for falling associated with measures of poor visual function from other studies in the community-dwelling elderly consistently show that impaired vision is an important predictor of falls. Tinetti et al. reported a relative risk for falls of 1.7 associated with near-vision loss, and Nevitt et al., a relative risk of 2.1 for recurrent falls associated with poor depth perception. Poor visual acuity was associated with a prevalence ratio of 1.9 for recurrent falls in a retrospective analysis of data from the Blue Mountains Eye Study. In the Beaver Dam Eye Study, poor habitual visual acuity was also significantly associated with a recent history of falls and fractures. Lord et al. found that impairments in depth perception and edge contrast sensitivity were predictive of falls in a sample of community-dwelling elderly people without specific visual impairments. Deficits in depth perception, visual acuity, and contrast sensitivity occur with varying severity in patients with exudative AMD.
Although those with exudative AMD have known visual function deficits that would put them at a higher risk of falls, there was a suspicion among clinical colleagues that those with AMD may restrict their activity and be aware of their visual limitations to limit their opportunity to fall. Individuals with exudative AMD report decreased quality of life, physical activities, and physical functioning. Our data indicate a high rate of falling among participants with AMD. Physical functioning (by the Barthel Index) was not significantly associated with falls in our sample. The mean scores for both the AMD and non-AMD cohorts were very high on this scale, reflecting that participants in both groups are independent community-dwellers. As expected, the VFQ-25 score was also significantly different between the AMD and non-AMD cohorts, but did not predict falls in our sample. The type of visual function measured by the VFQ-25 is therefore not likely to be a major cause of falls amongst those with AMD. Self-reported fall history was a significant predictor of any falls in our negative binomial regression, however we chose not to adjust for this, as we believe that recent fall history would be a consequence of having exudative AMD.

Our study clearly shows that community-dwelling women with exudative AMD have significantly more falls, and more injurious falls, than women without exudative AMD. The rigorous exposure and monthly outcome assessment, as well as the inclusion of a well-matched control group strengthen our conclusion. We used the companions of people attending medical appointments at the VH/UBC Eye Care Centre as our non-AMD comparison group. The non-AMD cohort, however, may be a particularly healthy one as they are companions or drivers to other elderly individuals, which could bias our results towards increasing the magnitude of the difference between our non-AMD and AMD cohorts, and resulting in an apparently higher relative risk. Nonetheless, the non-AMD cohort is a reasonable comparison group because the target AMD population is community-dwelling, and the groups were well-matched on baseline characteristics when the effects of visual impairment were disregarded.
A potential limitation involves our use of 6-month data; the large cohort studies of falls and fractures typically use 12 month follow up. The assumption that fall rates are equal throughout the year, and that a doubling of six months of follow up approximates the rate that would be seen over twelve, is likely flawed. Fall rates in the elderly are subject to seasonal variation\textsuperscript{39} so the doubling of a 6 month fall rate for an individual could over- or underestimate the actual rate, depending on the months included. In addition, as recurrent fallers are more likely to fall again\textsuperscript{9} shortening the follow up period to 6 months would underestimate the number of falls that could occur over 12. Still, as both groups were followed in the same fashion and recruited over the same time period, we believe that the difference in rates between the groups calculated reflects the actual effect of visual impairment on the risk of falls. We chose to restrict our sample to women only as women are more likely to fall, with associated fractures\textsuperscript{6-8} and more likely to have exudative AMD\textsuperscript{1} than men of the same age. Nevertheless, our results may not be generalizable to men, or women with exudative AMD who are not community-dwelling. In non-community-dwelling individuals with or without exudative AMD, the reported annual falls rate is much higher than our reported 84 falls per 100 person years; one prospective study reported a falls rate of 258 per 100 person years among institutionalized men and women, with a mean age of 84 years.\textsuperscript{40}

This study has demonstrated that the adjusted relative risk for falls among community-dwelling women aged over 70 years with exudative AMD is 3.15 (95%CI=1.47 – 6.74) for any fall, and 3.75 (1.28 – 10.9) for an injurious fall, compared to women aged over 70 years without exudative AMD. This is the first study to examine the rate of falls specifically in those with exudative AMD. Clinicians caring for elderly women with exudative AMD would be well advised to measure risk factors for falls as part of a comprehensive health assessment. In addition, clinicians should be aware of the high risk of falls in those with AMD, as the common clinical perception that such patients are not truly at risk of experiencing falls\textsuperscript{41} is
false. Our work should encourage intervention studies focusing on potentially modifiable non-vision-related risk factors for falls among those with exudative AMD, to help decrease the morbidity and mortality associated with falls in this population.
### Table 3.1: Baseline characteristics

<table>
<thead>
<tr>
<th></th>
<th>AMD Group (n=115)</th>
<th>Non-AMD Group (n=93)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age (range)</td>
<td>81.3 years (70 – 92)</td>
<td>75.6 years (70 – 92)</td>
</tr>
<tr>
<td>70 – 74</td>
<td>17 (15%)</td>
<td>41 (44%)</td>
</tr>
<tr>
<td>75 – 79</td>
<td>21 (18%)</td>
<td>37 (40%)</td>
</tr>
<tr>
<td>80 – 84</td>
<td>47 (41%)</td>
<td>11 (12%)</td>
</tr>
<tr>
<td>85 – 89</td>
<td>30 (26%)</td>
<td>4 (4%)</td>
</tr>
<tr>
<td>Mean Best Eye Visual Acuity</td>
<td>20/80</td>
<td>20/16</td>
</tr>
<tr>
<td>One year fall history</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any</td>
<td>32 (28%)</td>
<td>12 (12.9%)</td>
</tr>
<tr>
<td>Two or more</td>
<td>9 (8%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>One year fracture history</td>
<td>7 (6%)</td>
<td>2 (2%)</td>
</tr>
<tr>
<td>Occasional cane use</td>
<td>18 (16%)</td>
<td>2 (8.3%)</td>
</tr>
<tr>
<td>Joint replacement</td>
<td>4 (3%)</td>
<td>2 (2%)</td>
</tr>
<tr>
<td>Stairs in home</td>
<td>89 (77%)</td>
<td>70 (75%)</td>
</tr>
<tr>
<td>Medication use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium/Vitamin D</td>
<td>23 (20%)</td>
<td>25 (27%)</td>
</tr>
<tr>
<td>Benzodiazepines</td>
<td>7 (6%)</td>
<td>3 (3%)</td>
</tr>
<tr>
<td>Other sedatives</td>
<td>5 (4%)</td>
<td>5 (5%)</td>
</tr>
<tr>
<td>Antidepressants</td>
<td>10 (9%)</td>
<td>4 (4%)</td>
</tr>
<tr>
<td>Diuretics</td>
<td>17 (15%)</td>
<td>18 (19%)</td>
</tr>
<tr>
<td>WCS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With Visual Impairment</td>
<td>8.40 (4.7)</td>
<td>6.16 (4.5)</td>
</tr>
<tr>
<td>Without Visual Impairment</td>
<td>5.61 (4.5)</td>
<td>6.16 (4.5)</td>
</tr>
<tr>
<td>Medical Comorbidities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>9 (8%)</td>
<td>7 (8%)</td>
</tr>
<tr>
<td>Osteoporosis</td>
<td>42 (37%)</td>
<td>30 (32%)</td>
</tr>
<tr>
<td>Stroke</td>
<td>9 (8%)</td>
<td>6 (6%)</td>
</tr>
<tr>
<td>Arthritis</td>
<td>53 (46%)</td>
<td>55 (59%)</td>
</tr>
<tr>
<td>Mean (SD) Barthel score</td>
<td>98.13 (9.90)</td>
<td>99.10 (1.7)</td>
</tr>
<tr>
<td>Mean (SD) VFQ-25 score</td>
<td>282.54 (61.38)</td>
<td>361.07 (37.3)</td>
</tr>
</tbody>
</table>
Table 3.2: Regression coefficients, standard errors (SE), unadjusted relative risks (RR), and 95% confidence intervals (CI) for selected univariate associations between independent fall risk factors, and 6 month fall incidence

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>SE</th>
<th>RR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMD</td>
<td>1.08</td>
<td>0.346</td>
<td>2.95</td>
<td>1.50 - 5.82</td>
</tr>
<tr>
<td>Age</td>
<td>0.035</td>
<td>0.027</td>
<td>1.04</td>
<td>0.98 - 1.09</td>
</tr>
<tr>
<td>12 Month History of a Fall</td>
<td>0.933</td>
<td>0.321</td>
<td>2.54</td>
<td>1.35 - 4.77</td>
</tr>
<tr>
<td>History of Repeated Falls</td>
<td>0.894</td>
<td>0.589</td>
<td>2.44</td>
<td>0.771 - 7.75</td>
</tr>
<tr>
<td>VFQ25</td>
<td>-0.004</td>
<td>0.002</td>
<td>0.996</td>
<td>0.99 - 1.00</td>
</tr>
<tr>
<td>Barthel</td>
<td>-0.006</td>
<td>0.017</td>
<td>0.994</td>
<td>0.96 - 1.03</td>
</tr>
<tr>
<td>Ca/Vit D</td>
<td>-0.412</td>
<td>0.400</td>
<td>0.663</td>
<td>0.303 - 1.45</td>
</tr>
<tr>
<td>Benzodiazepine</td>
<td>-0.153</td>
<td>0.844</td>
<td>0.858</td>
<td>0.164 - 4.49</td>
</tr>
<tr>
<td>Other Sedatives</td>
<td>0.956</td>
<td>0.551</td>
<td>2.60</td>
<td>0.883 - 7.67</td>
</tr>
<tr>
<td>Anti-depressant</td>
<td>-0.321</td>
<td>0.682</td>
<td>0.726</td>
<td>0.190 - 2.76</td>
</tr>
<tr>
<td>Any Psychotropic</td>
<td>0.469</td>
<td>0.405</td>
<td>1.60</td>
<td>0.723 - 3.53</td>
</tr>
<tr>
<td>Diuretic</td>
<td>-0.017</td>
<td>0.415</td>
<td>0.983</td>
<td>0.436 - 2.21</td>
</tr>
<tr>
<td>Diabetes Mellitus</td>
<td>0.082</td>
<td>0.566</td>
<td>1.09</td>
<td>0.358 - 3.29</td>
</tr>
<tr>
<td>Osteoporosis</td>
<td>-0.15</td>
<td>0.335</td>
<td>0.857</td>
<td>0.445 - 1.65</td>
</tr>
<tr>
<td>Stroke</td>
<td>0.678</td>
<td>0.490</td>
<td>1.97</td>
<td>0.745 - 5.21</td>
</tr>
<tr>
<td>Arthritis</td>
<td>0.162</td>
<td>0.311</td>
<td>1.18</td>
<td>0.639 - 2.16</td>
</tr>
<tr>
<td>WCS</td>
<td>0.083</td>
<td>0.028</td>
<td>1.09</td>
<td>1.03 - 1.15</td>
</tr>
<tr>
<td>WCS without visual impairment</td>
<td>0.060</td>
<td>0.031</td>
<td>1.06</td>
<td>0.99 - 1.13</td>
</tr>
</tbody>
</table>
Table 3.3: Multivariate negative binomial regression model examining the association between 6 month fall incidence and AMD, adjusted for age.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>SE</th>
<th>RR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-1.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMD</td>
<td>1.15</td>
<td>0.389</td>
<td>3.15</td>
<td>1.47 – 6.74</td>
</tr>
<tr>
<td>Age</td>
<td>-0.01</td>
<td>0.031</td>
<td>0.989</td>
<td>0.931 – 1.05</td>
</tr>
</tbody>
</table>
Table 3.4: Regression coefficients, standard errors (SE), unadjusted relative risks (RR), and 95% confidence intervals (CI) for selected univariate associations between independent fall risk factors, and 6 month injurious fall incidence

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>SE</th>
<th>RR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMD</td>
<td>1.34</td>
<td>0.494</td>
<td>3.81</td>
<td>1.45 – 10.0</td>
</tr>
<tr>
<td>Age</td>
<td>0.053</td>
<td>0.037</td>
<td>1.05</td>
<td>0.981 – 1.13</td>
</tr>
<tr>
<td>12 Month History of a Fall</td>
<td>0.859</td>
<td>0.444</td>
<td>2.36</td>
<td>0.989 – 5.64</td>
</tr>
<tr>
<td>History of Repeated Falls</td>
<td>0.318</td>
<td>0.935</td>
<td>1.38</td>
<td>0.220 – 8.59</td>
</tr>
<tr>
<td>VFQ25</td>
<td>-0.005</td>
<td>0.003</td>
<td>0.995</td>
<td>0.990 – 1.00</td>
</tr>
<tr>
<td>Barthel</td>
<td>-0.003</td>
<td>0.026</td>
<td>0.997</td>
<td>0.948 – 1.05</td>
</tr>
<tr>
<td>Ca/Vit D</td>
<td>0.019</td>
<td>0.494</td>
<td>1.02</td>
<td>0.387 – 2.68</td>
</tr>
<tr>
<td>Benzodiazepine</td>
<td>0.441</td>
<td>0.956</td>
<td>1.55</td>
<td>0.239 – 10.1</td>
</tr>
<tr>
<td>Other Sedatives</td>
<td>0.966</td>
<td>0.754</td>
<td>2.63</td>
<td>0.599 – 11.5</td>
</tr>
<tr>
<td>Anti-depressant use</td>
<td>-0.873</td>
<td>1.19</td>
<td>0.418</td>
<td>0.047 – 3.74</td>
</tr>
<tr>
<td>Any Psychotropic</td>
<td>0.505</td>
<td>0.545</td>
<td>1.66</td>
<td>0.569 – 4.83</td>
</tr>
<tr>
<td>Diuretic</td>
<td>-0.166</td>
<td>0.580</td>
<td>0.847</td>
<td>0.272 – 2.64</td>
</tr>
<tr>
<td>Diabetes Mellitus</td>
<td>0.465</td>
<td>0.693</td>
<td>1.59</td>
<td>0.409 – 6.19</td>
</tr>
<tr>
<td>Osteoporosis</td>
<td>0.087</td>
<td>0.440</td>
<td>1.09</td>
<td>0.461 – 2.58</td>
</tr>
<tr>
<td>Stroke</td>
<td>0.792</td>
<td>0.658</td>
<td>2.21</td>
<td>0.608 – 8.01</td>
</tr>
<tr>
<td>Arthritis</td>
<td>-0.106</td>
<td>0.418</td>
<td>0.899</td>
<td>0.396 – 2.04</td>
</tr>
<tr>
<td>WCS</td>
<td>0.094</td>
<td>0.038</td>
<td>1.10</td>
<td>1.02 – 1.18</td>
</tr>
<tr>
<td>WCS without visual impairment</td>
<td>0.072</td>
<td>0.041</td>
<td>1.07</td>
<td>0.991 – 1.16</td>
</tr>
</tbody>
</table>
Table 3.5: Multivariate negative binomial regression model examining the association between 6 month injurious fall incidence and AMD, adjusted for age.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>SE</th>
<th>RR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-2.93</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMD</td>
<td>1.32</td>
<td>0.548</td>
<td>3.75</td>
<td>1.28 – 10.9</td>
</tr>
<tr>
<td>Age</td>
<td>0.003</td>
<td>0.041</td>
<td>1.00</td>
<td>0.925 – 1.09</td>
</tr>
</tbody>
</table>
References

CHAPTER 4: DISCUSSION
In summary, I examined risk factors for, and the incidence of, falls among elderly, community-dwelling women with exudative AMD. The cross-sectional study (Chapter 2) showed that women with exudative AMD were at a significantly elevated risk of falls by Physiological Profile Assessment risk score. The AMD cohort had significant impairments on measures of key fall risk factors including postural sway, reaction time, and vision, compared to the Randwick cohort. The AMD cohort performed significantly more poorly on all risk factor measures of vision, balance, strength, proprioception and reaction time, compared to our non-AMD comparison cohort. These results were substantiated in our six-month prospective cohort study of the incidence of falls (Chapter 3), as women with exudative AMD were at approximately three times the risk of experiencing a fall, or an injurious fall, than women without exudative AMD.

These studies are the first to examine falls specifically amongst those with exudative AMD. Other population-based cohort studies examining the association between visual impairment and falls have reported odds ratios of 1.6 – 2.0, over 12 months.\textsuperscript{1,2} However, few AMD participants were included. Further, they did not prospectively measure either physiological risk factors or subsequent incidence of falls. As such, my thesis provides novel data on the risk factors and the rate of falls among those with AMD, a population we now know is at high fall risk.

I used a detailed risk measure which has been standardized and validated to obtain an accurate picture of risk factors for falls among those with exudative AMD. Another strength in this study is the use of monthly follow up phone calls, which greatly improves accuracy of recall over 3-, 6-, or 12-month follow up intervals.\textsuperscript{3} Again, the generalizability of these results is limited to community-dwelling women with exudative AMD, although we have no reason to believe that the results would change, should both genders be included.
Our findings that strength and proprioception are normal, but balance and reaction time are impaired in women with exudative AMD will inform the development of interventional studies. Strength and balance re-training by themselves are not sufficient to reduce falls risk and incidence among the visually impaired. Given that the AMD group had normal strength, our results suggest that focusing on balance may improve fall-related outcomes. That people with visual impairments have difficulties accessing resources in fitness centres and health clubs, and that the majority of our study sample no longer drives a car, are concerns in planning and tailoring an appropriate intervention to decrease fall risk. Although home-based programs may seem easier to implement, the value of group activities in decreasing the loneliness and social isolation common in exudative AMD may also be worth considering.

These studies serve as a starting point for further work on falls prevention in the visually-impaired elderly. A study to measure physiological risk factors for falls, followed by 12 months of prospective follow up is indicated. Linking information on physiological risk factors to an individual’s actual falls incidence in a prospective study would allow better modeling of the association between exudative AMD and the incidence of falls. One year prospective follow up of these individuals would also allow the validation of the PPA against actual falls incidence in a visually impaired population, a key step if this measure is to be used as a fall risk screening tool in those with low vision. Finally, given that we have determined that those with exudative AMD, overall, are at a higher than average risk of falls, testing an appropriate intervention strategy would be indicated.

In summary, my thesis shows that women with exudative AMD are at a significantly elevated risk of falls compared to community-dwelling locally-recruited age-matched women without exudative AMD, and a second cohort of healthy women from Australia. Our prospective cohort study demonstrated that women with exudative AMD are at approximately three times the risk of any falls, and injurious falls, compared to those without exudative AMD. We
believe that this data is important given the general impression that falls are not a concern for those with severe visual impairments, and the lack of counseling or intervention programs in BC that focus on falls prevention in the visually impaired. The development of appropriate intervention strategies has the potential to reduce the burden of falls and related injuries, given the substantially elevated risk of falls measured in those with exudative AMD in this study, and the high prevalence of exudative AMD among the community-dwelling elderly in British Columbia.
References

APPENDICES
Appendix A: Short-form PPA
EDGE CONTRAST SENSITIVITY - THE MELBOURNE EDGE TEST (MET)

In this test the subject is seated at a desk/table. Position the MET transparency on the white acrylic board at an angle of approximately 45 degrees with the bottom edge resting on a desk/table top at a usual reading distance (about 50-60cm). Position it so that the transparency is at right angles to the subject's line-of-sight (i.e. as you would hold a book) – see figure 1a. Keep the transparency still. Start the subject at the top row and then proceed to rows 2 and 3. Subjects can indicate their response by pointing to one of the four edge options on their response card. Subjects often hesitate but they can usually perceive many edges after they fixate the circle stimuli for a short time. Give subjects plenty of time and force a choice. Continue to force a choice until an error is made. Record the lowest contrast patch (highest number) correctly identified. The test should be performed in a room with fluorescent lighting, with blinds drawn to standardize lighting conditions. Subjects perform the test binocularly (with both eyes together) wearing their near-distance correction lenses (reading glasses, bi/multifocals) if applicable.

**Subject instructions**

"This test measures how well you can see edges under low contrast conditions. I want you to look at this transparency, but please try not to touch it. Look at the circles one at a time and tell me which way the line goes through the circle, that is, point to the correct match for each on this (response) card."

**PERFORMANCE (dB)**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>24</td>
</tr>
<tr>
<td>Good</td>
<td>20-23</td>
</tr>
<tr>
<td>Fair</td>
<td>16-19</td>
</tr>
<tr>
<td>Poor</td>
<td>1-15</td>
</tr>
</tbody>
</table>

Figure 1a: Melbourne Edge Test position.

Figure 1b: The Melbourne Edge Test chart- sample only.
PROPRIOCEPTION

This test measures the ability of subjects to align their lower limbs either side of a clear acrylic (Perspex) sheet. Performance is assessed by measuring how closely subjects can align their two great toes. However, subjects with severe Hallux valgus (bunions) cannot achieve this, so these subjects are asked to align the first metatarsal joints (bunions). Mark the center of the medial aspect of great toes or the medial point of the first metatarsal joint with a marker pen to mark the matching reference points.

Subject Instructions

“This test measures joint position sense – a test to see how well you can judge position and movement of your legs and feet. For this test I will place this Perspex sheet between your legs. Now, raise both your legs together, (in a pigeon-toed action) and attempt to match the position of your big toes, so that if the Perspex sheet were not there, your toes would be touching. OK, match them again a bit lower down. Now, a bit higher up. Now I want you to do the same thing again five times, but with your eyes closed. When you match them, keep your feet still so I can measure how accurate you are and don’t move them until I tell you.”

The lines on the protractor are two degrees apart, so that matching can be made to an accuracy of one degree. Record only the radial disparity, ignoring any errors of distance along the lines. Administer the test as quickly as possible so that the test results are not influenced by lower limb weakness.

PERFORMANCE (degrees error)

<table>
<thead>
<tr>
<th>Good</th>
<th>&lt; 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fair</td>
<td>2-4</td>
</tr>
<tr>
<td>Poor</td>
<td>&gt; 4</td>
</tr>
</tbody>
</table>

Figure 2: Proprioception Test
KNEE EXTENSION (QUADRICEPS) STRENGTH

Unless contraindicated, assess the dominant limb (for example, ask with which foot the subject would kick a ball). Attach the hook connected to the spring gauge over the horizontal bar at the back of the tall test chair, and slide the metal peak detector to the zero point. With the patient seated on the chair with the hips at 90° and knees at 70-80° (so that at maximum contraction the knee joint will be approximately 90 degrees), position the centre of the strap approximately 10cm above the lateral malleolus. Place the foam pad under the strap and make sure the strap is taught.

Subject instructions

"This test measures the strength of the quadriceps muscles of the leg. I'm going to place a strap around your shin. Hold on to the chair for support. Now at a moderate pace forcefully push against the strap as strongly as you can. Rest". [Encourage the patient as they attempt to extend the knee and tell them the score (by reading from the metal peak detector on the spring gauge) when they are rested] "Now, again - as strongly as you can. See if you can do even better". [Allow rest periods of 10-20 seconds between trials. Make sure the subject does not get support from the other leg (should be in a relaxed position) and be sure they do not push too hard if they have a knee condition that might be aggravated.]

Record the best of three attempts.

<table>
<thead>
<tr>
<th>PERFORMANCE (kg)</th>
<th>Women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>&gt; 35</td>
<td>&gt; 45</td>
</tr>
<tr>
<td>Good</td>
<td>20-35</td>
<td>30-45</td>
</tr>
<tr>
<td>Fair</td>
<td>15-20</td>
<td>15-30</td>
</tr>
<tr>
<td>Poor</td>
<td>&lt; 15</td>
<td>&lt; 15</td>
</tr>
</tbody>
</table>

Figure 3: Knee extension strength
REACTION TIME – HAND

Subject Instructions

"This test is a test of your reaction time. When this red light on the mouse comes on I want you to press the right mouse button as fast as you can. So that you don't waste any time you can rest your finger lightly on the surface of the mouse button." [Make sure the subject does not depress the switch, otherwise the timer will not start. Ensure that the mouse is positioned comfortably for the subject and give 5 pre-practice trials to make sure they understand the procedure and get a feel for the mouse button.] "OK, the emphasis is on speed so just concentrate on the light and press the button as quickly as possible. We are going to do this 15 times - the first five will be practice, then there will be 10 more after that".

Perform the test with the ceiling lights dimmed to ensure subjects can detect the light stimulus. In the 10 test trials, repeat and do not record reaction times that are notably slow, i.e. more than 150-200 milliseconds above their usual times recorded in the practice trials or notably fast, i.e. if they "jump the gun" and record scores less than 150 ms.

<table>
<thead>
<tr>
<th>PERFORMANCE (ms)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>&lt; 200</td>
</tr>
<tr>
<td>Good</td>
<td>200-250</td>
</tr>
<tr>
<td>Fair</td>
<td>250-300</td>
</tr>
<tr>
<td>Poor</td>
<td>&gt; 300</td>
</tr>
</tbody>
</table>

Figure 4: Reaction Time - Hand
SWAY ON FOAM WITH EYES OPEN

Subjects perform the sway test barefoot. Place the swaymeter webbing strap very firmly around the waist for women and the level of the belt for men so that the aluminium plate of the swaymeter is positioned in the small of the back and the rod is extending behind the subject. Secure with the Velcro fastener. Position the table behind the subject and adjust its height so that the swaymeter rod is horizontal (the tip of the pen should be 4cm below the rod). Position the pen over a sheet of 2 cm² graph paper. Do not tell the subject that the test is a sway test as this can induce increased sway.

Ensure that there is no sideways pressure on the rod as you place the pen onto the paper - this results in pen initially darting across the paper and erroneously large lateral measurements. When the subject is performing the test, place your hand over the fulcrum of the swaymeter so that you can grasp it quickly to support the subject if he/she loses balance. Use a stopwatch or watch/clock second hand to measure the 30-second test period. Lift the pen immediately at the end of the test period, again ensuring you avoid sideways pressure on the rod.

Subject instructions

"This is a balance test. I'm going to put a strap around your waist". [Provide support as the subject steps onto the foam rubber mat and establishes the stance position, i.e. feet positioned at hip width]. "Firstly walk in place so we can standardize your standing position. [Reassure the subject that you will not let them fall whilst undertaking the test. Place the pen over the graph paper sheet on the adjustable height table positioned behind the subject]. "Now stand as still as possible for 30 seconds. Look slightly down and do not talk. I am standing right here beside you and can support you if you lose balance". Record the maximal anterior-posterior and medio-lateral sway excursions in mm for the test.

PERFORMANCE (sway area = AP x lateral)

<table>
<thead>
<tr>
<th>Performance</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>&lt;400</td>
</tr>
<tr>
<td>Good</td>
<td>400-800</td>
</tr>
<tr>
<td>Fair</td>
<td>800-1300</td>
</tr>
<tr>
<td>Poor</td>
<td>&gt;1300</td>
</tr>
</tbody>
</table>

Figure 5: Sway on the foam with eyes open
Appendix B: University of British Columbia Institutional Review Board Certificates