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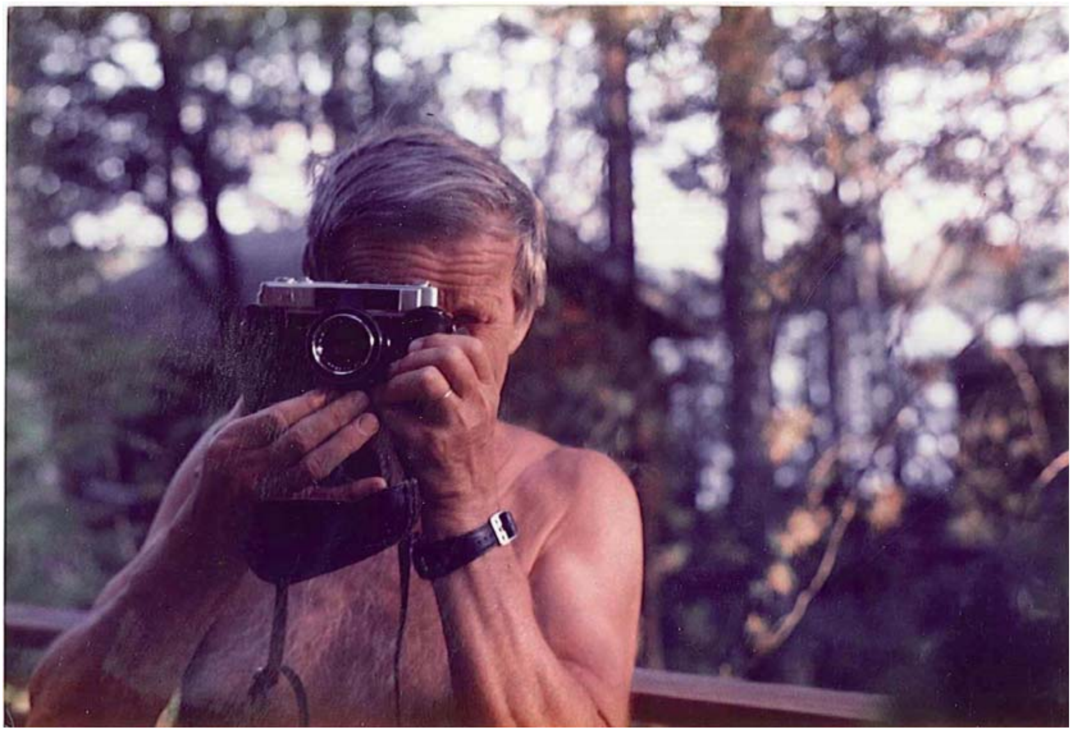
Jenni Kulmala

Visual Acuity in Relation to Functional Performance, Falls and Mortality in Old Age



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ABSTRACT

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Visual impairment is one of the leading causes of functional disability in old age. With increasing life expectancy, it is predicted that the number of people with visual impairment will increase significantly in the near future. This study was conducted to assess visual acuity in older people and to estimate whether possible visual acuity loss is associated with loss of functional capacity or disability. Furthermore, visual impairment as a risk factor for falls, other injurious accidents and mortality was examined.

This study was conducted with three existing data sets. Two data sets came from the Evergreen project, which is a multi-disciplinary, longitudinal follow-up study on the health and functional status of residents in Jyväskylä, Finland. The first study population comprised all persons aged 75 years in 1989 and the second all persons aged 80 years in 1990. Both populations were followed-up for 10 years after the baseline measurements. The third data set came from the Finnish Twin Study on Aging (FITSA), which investigates the role of genetic and environmental factors in the disablement process in old age. FITSA is a 3-year longitudinal study consisting of 434 women aged 63 to 76 years at baseline, with post baseline fall surveillance for one year and follow-up measurements at three years.

We found that among relatively healthy women aged 63-76, visual impairment correlated with decreased knee extension strength, leg extension power, maximal walking speed and standing balance. In addition, visual impairment increased the risk of falls (including injurious falls) when accompanied with hearing and balance impairments. Furthermore, we found that among persons aged 75 and 80 at the baseline, lowered vision was a risk factor for injurious accidents in the 10-year follow-up. Poor vision also predicted mortality in the 75-year-old population.

Visual impairment has a profound effect on multiple health outcomes and functional disability, and therefore should be taken into consideration when aiming to slow down the progression of the disablement process in old age.

Keywords: aging, coimpairment, disability, fall risk, functional capacity, mobility, mortality, visual acuity, visual impairment

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Jenni Kulmala

LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following papers, which will be referred to by their Roman numbers. Additionally, some unpublished data are included in the thesis.

I Kulmala J, Sipilä S, Tiainen K, Pärssinen O, Koskenvuo M, Kaprio J, Rantanen T. Vision in relation to lower extremity impairment in older women: cross-sectional and longitudinal study. Submitted for publication.

II Kulmala J, Era P, Pärssinen O, Sakari R, Sipilä S, Rantanen T, Heikkinen E. 2008. Lowered vision as a risk factor for injurious accidents in older people. Aging Clinical and Experimental Research 20, 25-30.

III Kulmala J, Viljanen A, Sipilä S, Pajala S, Pärssinen O, Kauppinen M, Koskenvuo M, Kaprio J, Rantanen T. 2009. Poor vision accompanied with other sensory impairments as a predictor of falls in older women. Age and Ageing 38, 162–167.

IV Kulmala J, Era P, Törmäkangas T, Pärssinen O, Rantanen T, Heikkinen E. 2008. Visual acuity and mortality in older people and factors on the pathway. Ophthalmic Epidemiology 15, 128–134.

ABBREVIATIONS

ADL	Activities of daily living
ANOVA	Analysis of variance
BMI	Body mass index
CES-D	Center for Epidemiologic Studies Depression Scale
CI	Confidence interval
COP	Center of pressure
FITSA	Finnish Twin Study on Aging
FOF	Fear of falling
HR	Hazard ratio
IADL	Instrumental activities of daily living
IR	Incidence rate
IRR	Incidence rate ratio
LV	Lowered vision
MMSE	Mini-Mental State Examination
N	Newton; expression on muscle force
NV	Normal vision
OR	Odds ratio
SD	Standard deviation
SE	Standard error
VA	Visual acuity
VEL	Velocity moment
VI	Visual impairment
W	Watt; expression of muscle power
WHO	World Health Organization

CONTENTS

1 INTRODUCTION

Visual acuity declines with age and this deterioration is faster at higher ages (Gerson et al. 1989, Klein et al. 2006). With increasing life expectancy, it is predicted that the number of people with visual impairment will increase significantly in the near future. A previous study has reported that in Finland, among persons aged 65 or over, the best corrected visual acuity is 0.8 (1.0 is considered normal) in 73%, with a gradual decline with age to 20%, among persons aged 85 years or over. A visual acuity less than 0.1 is found in 1% of persons aged 65 and over and in 7% of those aged 85 or over. Ninety-one percent of persons aged 65 or over are able to read newspaper-size print by using conventional presbyopic lenses. For those aged 85 years or over the rate is 50% (Häkkinen 1984). Globally, visual impairment is a major problem, with about 40 million individuals with blindness and almost 300 million estimated to have visual impairment worldwide (Resnikoff et al. 2004, Sommer 2004).

In the aging eye, pupil size, loss of accommodation and clouding of the lens diminish the amount of light that can reach the retina. Due to these changes seeing properly requires a greater amount of light. Colour vision and contrast sensitivity are also affected by aging (Coeckelbergh et al. 2004). Along with aging, the lens becomes less elastic and consequently less able to accommodate to focus on near objects. This condition, called presbyopia, is considered a universal age-related change (Newell 1969). Loss of visual field sensitivity is also a consequence of age-related changes in visual functions (Coeckelbergh et al. 2004). In addition to normal age-related changes in vision, many diseases are the causes of visual deficits. The major causes of blindness and visual impairment are related to cataracts, glaucoma, age-related macular degeneration and diabetic retinopathy –all of which recognize aging as the major risk factor (Fotouhi et al. 2004, Tsai et al. 2005, Cerulli 2008). Also cardiovascular and several other systemic diseases are associated with visual impairment (Saari 2001).

When decrements in vision exceed normal age-related changes, they may begin to compromise the ability to carry out the routine activities of daily living. Vision impairment can affect the most common and simple tasks. It is one of the leading causes of functional disability in old age (Rovner & Ganguli 1998, Reuben et al. 1999). Being dependent on others to carry out normal daily activities is over two times greater among older people with impaired vision when compared to persons with good vision (Keller et al. 1999, Haymes et al. 2002). The impact of visual impairment on quality of life includes loss of independent living, subjective well-being, loss of confidence and depression (Bergman & Sjostrand 2002, McDonnall 2009). It has also been suggested that visual impairment in old age could be a marker of frailty (Klein et al. 2003a), which is often defined as decreased resistance to stressors, resulting from declines across multiple physiologic systems (Fried et al. 2004).

Vision has an important role in balance control, while it provides the nervous system with continuously updated information regarding the position as well as the movements of body segments in relation to the environment. Previous studies have shown that when people with normal vision stand with their eyes closed, postural sway increases markedly, indicating difficulty in balance control in the absence of visual feedback (Brooke-Wavell et al. 2002). People with visual impairment have impaired functional balance more often than those with better vision (Lee & Scudds 2003). Poor vision therefore increases fall risk among older people (Ivers et al. 2000, de Boer et al. 2004, Sihvonen et al. 2004a). The risk of hip fracture is also increased among older people with impaired vision (Ivers et al. 2000). In addition to poor visual acuity, poor contrast sensitivity (Lord et al. 1991) and poor depth perception (Lord & Dayhew 2001) are also major risk factors for fall-related injuries in older people. Fall-related injuries have adverse effects on health and independent functioning, especially among older people. Approximately 20% of falls lead to injury that requires medical attention (Tinetti et al. 1995a). In addition, falling may easily lead to the vicious circle of fear and activity restriction, which further increases the risk of disability. Previous studies have observed increased mortality rates among older people with visual impairment (Cacciatore et al. 2004, Freeman et al. 2005, Jacobs et al. 2005, Pedula et al. 2006), which could be in part a consequence of increased injury rates (Lee et al. 2003b).

The main pathway in the disablement process as described by Nagi (1976) and later expanded by Verbrugge & Jette (1994) is that pathology (i.e. the presence of diseases) causes impairments (which are abnormalities at the physiological or anatomical level), which in turn lead to functional limitations (i.e. limitations in basic physical actions) and finally to disability (i.e. difficulties in activities relevant to daily living). The strong association between visual impairment and disability, such as self-reported difficulties in activities of daily living (ADLs) and instrumental activities of daily living (IADLs) has been reported in several recent cross-sectional and longitudinal studies (Reuben et al. 1999, Lin et al. 2004, Sloan et al. 2005a, Laitinen et al. 2007). Understandably, poor vision may directly lead to disability, i.e. through not receiving visual information about the environment or task being performed. However, it is also possible that other factors mediate the association of visual impairment and disability.

The consequences of visual impairment in old age have not been extensively studied. Definitions of visual impairment also vary between studies as do sample size and sample selection. Moreover, a wide range of assessment measures have been used to identify vision impairment. Therefore more information is needed about the consequences of sensory deficits on the disablement process, which in many cases also cause other adverse outcomes such as loss of independence.

In old age, sensory impairments often coincide. Thus far, the combined effects of poor vision and other sensory impairments on health and functioning are not well known. Most of the previous studies have focused on the independent effects of sensory functions, while only a few studies have investigated the combined effects (Keller et al. 1999, Reuben et al. 1999, Lupsakko et al. 2002, Crews & Campbell 2004, Lee et al. 2005b). In this study, in addition to visual acuity, we studied the effect of co-existing sensory deficits on fall-risk among older people.

Examining vision in relation to impairments and functional limitations as well as to disability-related outcomes, such as falls, provides new knowledge about the factors on the pathway from visual impairment to disability and mortality. This study provides new knowledge about the role of vision in the multifactorial disablement process in older people.

2 REVIEW OF THE LITERATURE

2.1 Basic anatomy of the eye

The tough, outermost layer of the eye is the sclera. It maintains the shape of the eye. The front sixth of this layer is transparent cornea. The light passes through the cornea when it enters the eye. The cornea is the chief refracting surface of the eye. The choroid is the second layer of the eye. It contains the blood vessels that supply blood to structures of the eye. The coloured part of the eye is the iris, which is an adjustable diaphragm around the pupil. The pupil controls the amount of light admitted to the eye (Newell 1969).

The lens is a transparent structure located immediately behind the iris and the papillary aperture and in front of the vitreous body. The lens along with the cornea helps to refract light to be focused on the retina. The vitreous body is a transparent gel having the shape of a sphere. Light rays pass through the vitreous before reaching the retina. The innermost layer is the retina, which is the light-sensing portion of the eye. It contains rod cells, which are responsible for vision in low light, and cone cells, which are responsible for colour vision and seeing details. In the back of the eye, in the centre of the retina, is the macula. In the centre of the macula is an area called the fovea centralis. This area contains only cones and is responsible for seeing fine detail clearly. The retinal nerve fibres collect at the back of the eye and form the optic nerve, which conducts the electrical impulses to the brain. The spot where the optic nerve and blood vessels exit the retina is called the optic disk (Figure 1) (Newell 1969).

2.2 Vision in old age

2.2.1 Age-related changes in visual system

There are a number of structural and physiological changes which are associated with aging and have an effect on vision. These changes may occur in the cornea, the pupil, the lens and the retina, and singly or in combination affect visual functions. Some of these changes, especially changes in the lens, can be adapted to because the deterioration is often gradual and slow. Therefore older persons may be unaware of or underreport impaired vision. Some of these changes are normal and do not signify any disease process. Age-related changes in the visual functions often concern the quality or sharpness of the picture (Haegerstrom-Portnoy et al. 1999, Ball 2003, Bonnel et al. 2003).

The changes in the cornea due to aging are mostly asymptomatic and do not usually affect vision, hence they not require treatment. However, the aged cornea becomes more susceptible to infections (Cerulli & Missiroli 2008). In the aging eye, the pupil decreases in size and loses its mobility. This causes the pupil to become less responsive to changes in ambient lighting. When the maximum size of the pupil decreases, less light reaches the retina, resulting in poorer vision, especially in low light situations. That is one reason for older people needing more light for comfortable reading and functioning than younger adults (Artal 2008).

The principle function of the eye's crystalline lens is to focus the image on the retina and enable accommodation, which is the process by which the eye changes optical power to maintain a clear image on an object as its distance changes (Alio et al. 2008). From young adulthood, the lens gradually becomes less flexible. The collagen content of the lens becomes thicker and harder. As a result, the lens becomes less elastic and consequently less able to change shape (accommodate) to focus on near objects. This condition, called presbyopia (old-age sightedness) is considered a universal age-related change. Presbyopia results in the need to hold reading material further away in order to focus clearly on the print. Usually reading glasses help to focus on reading. Presbyopia usually becomes noticeable in the early to mid-40s. It is not a disease, and it cannot be prevented (Newell 1969, Lim & Constable 1995, Saari 2001). Besides the physiological changes in the lens, the additional effects caused by exposure to external physical and chemical factors, e.g. medications, lead to modifications in the quality of the optic lens (Alio et al. 2008).

Aging causes the retina, which is responsible for the reception and transmission of visual stimuli, to become less sensitive. The cone cells in the retina are responsible for color vision. Therefore decline in sensitivity along with aging, causes colors to become less bright and the contrast between different colors to be less noticeable (Bonnel et al. 2003, Binder & Falkner-Radler 2008). The rod cells are situated more in the peripheral retina and are responsible for peripheral and dark vision. Dark adaptation is affected by age-related changes in these cells as well as changes in visual pathway. This may lead to difficulties e.g. when walking about or toileting during nighttime. Also, older people are more likely to be dazzled by bright sunlight. When walking from a dimly lit room into bright lighting, older people often experience temporary blindness until the eyes adjust to this dramatic change in illumination (Fotiou et al. 2007, Radhakrishnan & Charman 2007).

Aging also causes a loss of visual field (Taylor et al. 1997). The visual field refers to the space or range within which objects are visible to the immobile eye at a given time. Changes in the visual field are due, for example, to decreased pupil size as well as opacities in the lens. Previous studies have reported a prevalence of visual field loss ranging from 5.6% to 17% in adults aged 40 and older (Taylor et al. 1997, Ramrattan et al. 2001). Restriction of a person's visual field increases the likelihood of slips and trips.

Some older people experience a decrease in tear secretion accompanied by a sense of dry eyes. This is usually caused by a problem with the quality of the tear film that lubricates the eyes (Obata 2008). For this reason, eyes may feel irritated. This condition can be relieved with the application of artificial tears. Also the eye lid's elevator muscle function declines with age. This decline results in a decreased ability to look upward, making it more difficult to see objects that are above eye level. This may lead to narrowed vertical visual field (Feher & Olah 2008). It has been suggested that age-related changes in the orbicular muscles of the eye may generally be related to muscle aging (Feher & Olah 2008). However, in the absence of disease, vision should be correctable to normal level in even very old individuals, despite of these age-related changes. The sudden or even gradual weakening of vision is a sign of illness and needs immediate medical attention.

2.2.2 Diseases affecting vision in old age

In addition to normal age-related changes in vision, many primary ocular diseases as well as systemic diseases affect visual functions (Figure 1). Age-related macular degeneration (AMD) is an ocular disease that causes damage to the retinal macula, mostly in the older people. AMD is a disease that gradually destroys sharp, central vision, ultimately leaving the affected individual with only orienting vision and the peripheral visual field (van Leeuwen et al. 2003, Binder & Falkner-Radler 2008). Central vision is needed for seeing objects clearly and for common daily tasks. AMD occurs in two main forms: wet and dry. Wet AMD occurs when abnormal blood vessels behind the retina start to grow under the macula. These new blood vessels tend to be very fragile and leak blood and fluid. The blood and fluid raise the macula from its normal place. Damage to the macula and consequently loss of central vision may occur rapidly in days or weeks. Dry AMD occurs when the light-sensitive cells in the macula slowly break down, gradually blurring central vision (Kanski 1989, Saari 2001). Normal aging processes can lead to structural and blood flow changes that can predispose patients to AMD, although advanced age does not inevitably cause AMD. However, age as well as family history, smoking and hypertension are considered risk factors for age-related macular degeneration (van Leeuwen et al. 2003, Klein et al. 2004, Jager et al. 2008, Ting et al. 2009). AMD is the leading cause of visual deterioration and legal blindness in patients over 60 years of age in the Western World (Kanski 1989, Klein et al. 1997, Congdon et al. 2004). A previous nationally representative population-based study in Finland reported that the estimated prevalence of AMD increased from 1% in those aged 30–64 to 27% among persons aged 85 and over (Laitinen et al. 2009).

Cataract is a common cause of visual loss in older population (Congdon et al. 2004). Cataract occurs as the lens becomes cloudy and yellowish with aging. The normal lens is clear, but because of protein aggregation in cataract, the lens loses transparency (Newell 1969, Kalina 1997). Cataract reduces visual acuity and the loss of transparency in the lens may also contribute to a decrease in the ability to discriminate colors. In addition to advanced age, smoking, diabetes, and exposure to UVB light have consistently been identified as risk factors for cataract development (Abraham et al. 2006). In the Finnish population among persons 30 and older, the estimated prevalence of cataract (including operated cases) is about 9.5%. The prevalence increases significantly with age from 2% in persons under 65 to 67% in those aged 85 or older (Laitinen et al. 2009).

Glaucoma is considered one of the leading causes of visual impairment worldwide. Glaucoma is the name given to a group of diseases in which typically the intraocular pressure is sufficiently elevated to damage vision. However, the degree of increased intraocular pressure causing damage is not the same in every individual. Some persons may tolerate high pressure for a long time, while others with the same intraocular pressure rapidly go blind. Increased intraocular pressure damages the optic disc and nerve (Newell 1969, Kanski 1989). In Finland glaucoma is considered the main cause of visual deterioration in 1.5% of cases among persons aged 70 years or older (Hirvelä & Laatikainen 1995).

In addition to eye-related diseases, many systemic diseases may affect vision. Diabetes is one of the leading causes of visual loss in older people. The risk of blindness is about 25 times as great in diabetics than in persons without diabetes. Diabetic retinopathy is the result of microvascular retinal changes. Retinal vessels leak blood and other fluids that cause swelling of retinal tissue and clouding of vision. The incidence of diabetic retinopathy is related to the duration of diabetes (Kanski 1989). The estimated total prevalence of diabetic retinopathy in the Finnish population aged 30 years and older is 1% (Laitinen et al. 2009). Nearly all persons with type 1 diabetes and more than 60% of persons with type 2 diabetes have some retinopathy after 20 years (Mohamed et al. 2007). It is known that optimal management of blood glucose levels and hypertension reduces the incidence and progression of retinopathy (Mohamed et al. 2007, Paulus & Gariano 2009). Cataract also develops more often in diabetic individuals and at a younger age (Lim & Constable 1995).

Other systemic diseases, especially cardiovascular diseases, hypertension, thyroid and rheumatoid diseases, may affect the eye. Genetic and infectious diseases, as well as cancers and endocrinological diseases may also reduce visual acuity (Saari 2001). In some developing countries, keratomalacia (vitamin A deficiency) is a major cause of blindness (Lim & Constable 1995, Setälä 1995).

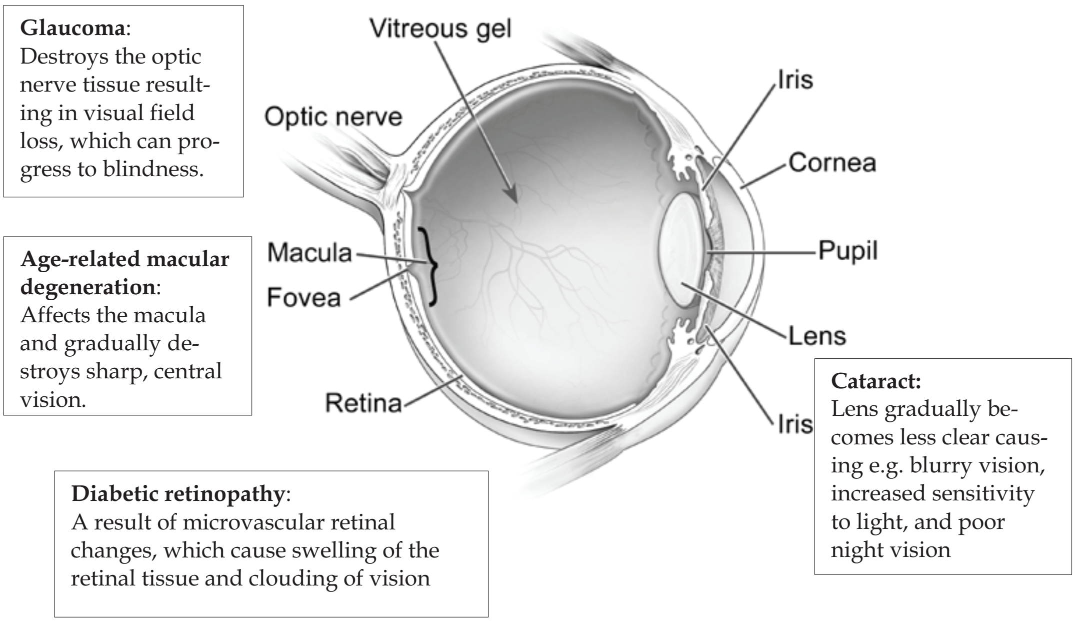


FIGURE 1 The basic anatomy of the eye and the most common age-related diseases. Figure modified from: National Eye Institute, National Institutes of Health, Bethesda, MD.

2.2.3 Prevalence of visual impairment in older populations

Visual acuity

Visual acuity (VA) is the most common measurement of visual function. It is the spatial resolving capacity of the visual system. VA refers to the ability to see details on which the gaze is fixed. Most of the optotypes used in visual acuity charts are based on the idea of ophthalmologist Herman Snellen (1834-1908), who invented a chart containing square shaped letters. The letters on the chart are drawn making the maximal dimension, usually the height, five times the thickness of the elementary line. According to Snellen, visual acuity is normal when a person recognizes a figure in which the elementary line is seen in an angle of one arc minute, which is equal to one sixtieth (1/60) of one degree, and the maximal dimension of the letter is seen in an angle of five minutes (Voipio 1995). The visual acuity (V) of the person is characterized by the Snellen fraction: $V=d/D$, in which d is the distance used and D is the distance on which the optotype fulfills the demand of one minute of arc visual angle (Voipio 1995).

In Finland, visual acuity is usually expressed as a decimal number. In many other countries, for example in the USA, the vulgar fraction is used. A decimal value of 1.0 is equal to the fractional visual acuity of 20/20, where the foot is used as a unit of measurement. When using meters, the standard visual acuity of 1.0 is equal to 6/6 (6 meters) or 5/5 (5 meters). In Finland, vision charts are usually designed for distance of five meters between the face of the examinee and the chart. VA is typically measured monocularly. It is measured according to the size of letters or other symbols, such as Landolt rings, Tumbling E, alphabets and numeral figures (Voipio 1995). The room used for measuring visual acuity has to be sufficiently large with light colored walls (Voipio 1995). VA is commonly measured with best refraction correction. Habitual visual acuity, which refers to VA measured with the person’s own spectacles, is also used. The correlation between habitual vision and VA with best refraction correction has been shown to be high (Klein et al. 1999a).

However, VA measures only the smallest detail we can see; it does not represent the quality of vision in general. In addition to visual acuity, several other aspects of vision can also be clinically assessed, such as visual field, contrast sensitivity and colour vision. Contrast sensitivity refers to the ability to differentiate between two objects of different light intensity, for example the ability to see a black object against a gray wall.

Refractive errors

A common cause of decreased visual acuity is refractive error. This is a physiological condition where the refracting system of the eye fails to focus objects sharply on the retina. It is usually corrected with glasses. *Myopia* (short sightedness) is an optical condition where images of distant objects are focused in front of the retina so that vision for distance is blurred, but near vision is normal. *Hypertropia* (long sightedness) is a condition where a distant object is focused behind the retina (Lim & Constable 1995). Attebo et al. (1999) found that the prevalence of hyperopia is age-related, increasing from 36% of persons aged <60 years to 71% of persons aged 80 and over, whereas prevalence of myopia decreases with age, from 21% of persons aged <60 years to 10% of persons over 80 years of age (Attebo et al. 1999). *Astigmatism* refers to an optical defect in which vision is blurred mainly due to an irregular curvature of the cornea or lens. In an eye with astigmatism, light rays are skewed and do not come to focus at a single point only, but instead are focused at two separate points (Newell 1969). Age is one of the most important predisposing factors of undercorrected refractive error. It has been reported that the risk for undercorrected refractive error increases by 1.8 times for every decade of life starting at 40 years of age. However, it should be noted that, for example, education modifies this risk (Liou et al. 1999).

Definitions of visual acuity impairment

Vision impairment usually means that a person's eyesight cannot be corrected to a normal level. The World Health Organization (WHO 1992) uses the following classifications of visual impairment (vision in the better eye with best possible glasses correction):

- 0.67-0.33 (20/30 to 20/60) = mild vision loss
- 0.29-0.13 (20/70 to 20/160) = moderate visual impairment, or moderate low vision
- 0.10-0.05 (20/200 to 20/400) = severe visual impairment, or severe low vision
- 0.04-0.02 (20/500 to 20/1,000) = profound visual impairment, or profound low vision
- Less than 0.02 (20/1,000) = near-total visual impairment, or near total blindness
- No light perception = total visual impairment, or total blindness.

The Unites States criterion for visual impairment is also commonly used in the previous literature. Accordingly, blindness is defined as best-corrected visual acuity of ≤0.1 in the better eye and low vision as a best-corrected visual acuity of <0.5 but >0.1 in the better eye. Visual impairment is defined as a best-corrected visual acuity of <0.5 in the better eye (Tielsch et al. 1990, Munoz et al. 2000).

Prevalence of age-related visual acuity loss

It has been estimated that the loss of best corrected visual acuity is approximately two lines in the visual acuity chart for each decade after age 50 (Ferrer-Blasco et al. 2008). With increasing life expectancy, it is predicted that the number of people with visual impairment due to age-related changes as well as diseases will increase significantly in the near future (Lee et al. 2003). Studies of the prevalence of visual impairment are numerous. Recent data from the Copenhagen City Eye Study assessed the cause-specific prevalence of visual impairment in an urban Scandinavian population aged 60 to 80 years. In their study visual impairment was defined according to the World Health Organization criterion (VA of 0.33–0.05 in the better eye) and the criterion most commonly used in the United States (VA worse than 0.5 but better than 0.1 in the better eye). They found the prevalence of low vision according to the WHO definition ranged from 2.6% in subjects aged 70 to 74 years to 5% in subjects 75 to 80 years of age. Using the U.S. definition, the overall age-adjusted prevalence of visual impairment was 3%. In comparison with other studies, these prevalence rates are rather low. A study by Munoz et al. (2000) reported that in older Americans aged 65-84 years visual acuity worse than 0.5 increased from 4% in the 65- to 74-year age group to 16% in the 80- to 84-year group. The overall percentage in this study population was 5% (Munoz et al. 2000). It has also been estimated that almost 40% of persons aged 75, who survive 15 years, develop visual impairment (VA < 0.5) during that time (Klein et al. 2006). The prevalence rates among some ethnic minorities are even higher, indicating that socioeconomic factors are strongly associated with visual loss, especially uncorrected refractive errors (Munoz et al. 2000, Munoz et al. 2002).

In the developed countries the number of blind people was estimated to be 3.5 million in 1990 and 3.8 million in 2002, an increase of almost 9%. During the same period the size of the population aged 50 years and older in these countries had increased by 16%. More significantly, it is estimated that about 18 million people had visual impairment in 2002, compared to 10 million in 1990. These figures represent an increase in unavoidable causes of visual impairment linked to an increase in the size of the population over 60 years of age. Globally, visual impairment is a major problem, with about 40 million individuals with blindness and over 120 million estimated to have severe visual deficits worldwide (Resnikoff et al. 2004). See Table 1.

TABLE 1 Global estimates of visual impairment, by WHO region, 2002. (Resnikoff et al. 2004)

	Afr	**Amr**	**Emr**	**Eur**	**Sear**	**Wpr**
Population	672 238	852 551	502 823	877 886	1 590 832	1 717 536
No. of blind people	6 782	2 419	4 026	2 732	11 587	9 312
No. with very low vision (VA of 0.05-0.3)	19 996	13 116	12 444	12 789	33 496	32 481
No. with visual impairment*	**26 778**	**15 535**	**16 469**	**15 521**	**45 083**	**41 793**

*includes low vision as well as blindness
Afr, WHO African Region; Amr, WHO Region of the America; Emr, WHO Eastern Mediterranean Region; Eur, WHO European Region; Sear, WHO South-East Asia Region; Wpr, WHO Western Pacific Region.

Häkkinen et al. (1984) reported that in Finland among persons aged 65 or over the best corrected visual acuity was 0.8 in 73%, with a gradual decline with age to 20% in late senescence (85 years or over). The poorest acuity level of less than 0.1 was found in 1% of persons aged 65 and over and in 7% of those aged 85 or over. 91% of persons aged 65 or over were capable of reading newspaper-size print with conventional presbyopic lenses. For those aged 85 years or over the rate was 50% (Häkkinen 1984). A recent large population-based study among adults aged 30 and over showed that the prevalence of visual acuity of 0.5 or more (measured with current spectacles) declined with increasing age from 99% in the youngest age group to 46% in people aged 85 and over. The prevalence of visual acuity of ≤ 0.25 increased significantly, especially in the age group of 65 to 74 years and upward (Laitinen et al. 2005). Among older nursing home residents in Finland, the prevalence of uncorrected distant visual acuity in the better eye has been shown to be less than 0.4 in 76% of men and 68% of women (Rifaat & Kivelä 1989).

2.3 Vision in relation to functional capacity and health in old age

2.3.1 Vision in relation to muscle strength, mobility and functional independence

Age-related changes in muscle strength and power

Age-related decreases in muscular strength and power have been well documented (Lexell 1995, Rantanen et al. 1997, Bemben 1998, Rantanen et al. 1998, Lauretani et al. 2003, Faulkner et al. 2007). These decreases are associated with age-related muscular and neural changes (Lexell 1995, Lamoureux et al. 2001). It has been estimated that by 80 years of age, approximately 50% of the fibers are lost from the muscle that have been studied (Lexell et al. 1988, Faulkner et al. 2007). Loss of muscle mass subsequently leads to reduced muscle strength. The annual decline in isometric strength is about 1-2% (Rantanen et al. 1997, Rantanen et al. 1998) and the deterioration in muscle power is even faster at 2-4% per year (Skelton et al. 1994). The age-related reduction in muscle mass and strength is widely considered one of the major causes of disability in older persons (Roubenoff 2003, Rolland et al. 2008). However, it is known that a number of modifiable factors, including a low level of physical activity and poor diet, are associated with increased decline in muscle strength among people (Forrest et al. 2007). In addition, previous studies have suggested that some people may be more prone to decreases in muscular strength and power in old age due to their genetic disposition. It has been estimated that approximately 20-30% of the interindividual differences in isometric muscle strength and muscle power are accounted for by genetic effects (Tiainen et al. 2004, Tiainen et al. 2005, Tiainen et al. 2008).

Vision and muscle function

In the previous literature, only a few studies have examined the association between visual functions and muscle strength or power in older people. A strong cross-sectional correlation between visual acuity and hand grip strength is found among persons aged 43 and older (Klein et al. 2003). In the same study population, cataract was associated with weaker hand-grip strength (Klein et al. 2006). The study by Uusi-Rasi et al. (2001) compared muscle performance among 40-year-old women with normal vision and with visual impairment (VA < 0.3). They found that the muscle strength of the upper-limb flexors and trunk flexors was significantly better in the group with normal vision, while there were no differences in mean values for leg extensor strength between the groups (Uusi-Rasi et al. 2001). It has been suggested that the association between poor vision and muscle weakness may be due to structural protein similarities in the lens and skeletal muscles. Another possible explanation is that aging processes may affect both functions at the same time (Klein et al. 2006). Since previous studies have shown that visual deficits are associated with avoidance of physical activity (Kempen et al. 2009), it is also possible that the low level of physical activity among visually impaired persons may compromise their muscle performance.

Mobility in old age

Mobility is defined as the self-reported or observed ability of a person to move safely and efficiently from one position to another within the environment. Limited mobility is a condition in which an individual has limitations in independent physical movement (Shumway-Cook et al. 2005). In this study mobility refers to a person's ability to move around independently, with or without walking aids. When measuring mobility, the spectrum of available procedures encompasses self-report measures, such as difficulties in walking, chair-rising or negotiating stairs and performance-based measures, which evaluate mobility directly. Performance-based measurements provide standardized information and therefore more attention is now paid to them.

Mobility function declines with age. However, it is difficult to know whether the changes observed are attributable to the aging process or some underlying pathological process. Cross-sectional studies have found clear differences between healthy older adults and younger adults. It has been reported that gait speed remains comparatively stable until the seventh decade and thereafter slows 15% per decade (Wolfson 2001). Diminished gait speed is associated with decreased stride length and single support time (single foot on the floor) as well as increased double support time (both feet on the floor) (Wolfson 2001). Maximal walking speed is more affected by aging than habitual walking speed (Bohannon 1997). Difficulties in walking 0.5 km, walking indoors and walking up 10 stairs increase in frequency with advancing age (Tilvis et al. 1997). Steffen et al. (1992) reported that mean test scores show a trend of age-related declines for the Six-Minute Walk Test, Timed Up and Go Test as well as for the comfortable- and fast-speed walking test for both men and women (Steffen et al. 2002). Data from longitudinal studies on mobility and changes with aging are limited. In the study by Onder et al. (2002) among women aged 65 or older, walking speed declined and time in the chair stand test increased by approximately 16%-27% over a 3-year follow-up (Onder et al. 2002). Maintaining mobility is a major goal for maintaining independence in older people (Rubenstein et al. 2001). Impaired mobility decreases quality of life (Netuveli et al. 2006), increases the chance of institutionalization (von Bonsdorff et al. 2006) and is associated with higher risk of mortality (Tilvis et al. 1997, Hirvensalo et al. 2000).

Vision and mobility

Worse visual function is strongly associated with limitations in mobility and poorer physical performance. A few studies have investigated the cross-sectional association between vision and performance-based physical functions, such as walking ability, the chair stand test and stair climbing (Salive et al. 1994, Sakari-Rantala et al. 1998, West et al. 2002, West et al. 2002, Laitinen et al. 2007). Performance-based mobility limitations have been shown to increase when distance visual acuity declines below 0.8 (Laitinen et al. 2007). Salive et al. (1994) showed that performance-based measure of rising from a chair was cross-sectionally associated with worse visual acuity, and in prospective analyses participants with severe visual impairment had a 3-fold higher risk of incident mobility limitation than those with visual acuity of 0.5 or better (Salive et al. 1994). West et at. (2002) found that poor visual acuity was associated with failure on the maximum walking speed test (nine or fewer 3-meter lengths completed in one minute), as well as inability to rise from a chair with arms crossed over the chest at least four times in one minute among adults aged 55 and over (West et al. 2002). A large population-based data from Finland showed that among older people at same age, inability to walk 6.1 meters at a speed of 1,2m/s or faster is three times more likely in visually impaired persons than among those with good visual acuity (Laitinen et al. 2007).

As well as decreased visual acuity, also other aspects of vision correlate with poor mobility. Impaired contrast sensitivity is associated with slower walking velocity, increased step width, and reduced stride length (Wood et al. 2009). Impairments in contrast sensitivity and visual fields are also associated with increased double-support time (time spent with both feet in contact with the ground) (Wood et al. 2009). Having a normal lower visual field has been shown to be important especially when walking in a multi-surface terrain (Marigold & Patla 2008). Also a sudden reduction from normal to marginal lighting when older persons are walking on an uneven surface reduces walking speed (Moe-Nilssen et al. 2006). Furthermore, Helbostad et al. (2009) reported that manipulating older persons' vision in simple conditions (walking straight ahead without obstacles) leads to a decrease in walking speed, cadence (steps/minute) and step length. Simulated tunnel and double vision in particular had the greatest effects (Helbostad et al. 2009).

Vision plays an important role in balance, gait and orientation and therefore its implications for mobility are readily apparent. Visual impairment and mobility difficulties may also arise from background factors in common, for example diseases. In addition, it is possible that decreased mobility among visually impaired older people may be due to fear of falling, since poor visual acuity has been identified as a one of the risk factors for fear of falling (Arfken et al. 1994, Murphy et al. 2003).

Vision and disability

Disability refers to reported difficulties in or an inability to perform activities of daily living (ADL) and instrumental activities of daily living (IADL) due to a health or physical problem. It is considered as a gap between a person's abilities and environmental demands (Verbrugge & Jette 1994). It is known that visual impairment is one of the leading causes of self-reported functional disability in old age (Rovner & Ganguli 1998, Reuben et al. 1999). Poor vision can affect even the most common and simple tasks. Cross-sectional studies have shown that visually impaired persons aged 55 and above have limitations in eating, going to the toilet, washing oneself, moving about in own apartment, dressing, getting in and out of bed and in IADLs, such as using the phone, cooking, shopping, laundering, banking four to five times more likely than persons with good visual acuity (Laitinen et al. 2007). They have also more difficulties in managing medications (Crews & Campbell 2004). The proportion of the older people dependent on others to carry out daily activities is over two times greater among older people with impaired vision (Keller et al. 1999, Haymes et al. 2002). According to self-reports, older people with visual loss have 3 times more likely difficulties in walking and in getting outside than persons without sensory problems (Crews & Campbell 2004). A strong association between visual impairment and self-reported functional status, especially in ADLs and IADLs and self-reported mobility has been established in many recent studies (Laukkanen et al. 1994, West et al. 1997, Keller et al. 1999, Reuben et al. 1999, Haymes et al. 2002, Swanson & McGwin 2004, Bibby et al. 2007, Laitinen et al. 2007). Objectively measured visual impairment increases the risk for ADL, IADL and mobility limitations three to five-fold and the association between self-reported visual loss and functional limitation is quite similar (Laitinen et al. 2007). Furthermore, among older people the presence of visual impairment increases the risk of developing future ADL- and IADL limitations (Dunlop et al. 2002).

2.3.2 Visual acuity, health and mortality

Visual impairment correlates strongly with self-rated health (Wang et al. 2000, Jacobs et al. 2005, Wang et al. 2006). Persons aged 18 and over who report visual impairment are two times more likely to report poor self-rated health compared to persons with good visual acuity (Lam et al. 2008). Visual impairment is also strongly associated with more frequent visits to a physician or hospital among adults 18-64 years of age, and restricted activity and bed rest days among males aged 45 years and older (Lee et al. 2005a). Reduced mobility in visually impaired older people may contribute to obesity, which is associated with various diseases such as diabetes, hypertension and cardiovascular diseases (Meigs 2003, Evangelista & McLaughlin 2009). Among older persons with visual acuity of 0.5 or lower the risk for institutional placement is over three-fold compared to persons with visual acuity of 1.0 or more (Klein et al. 2003).

Older people with eye-related diseases have in many cases additional chronic conditions. AMD correlates for example with hypertension, heart disease, thyroid disorder and cancer (Brody et al. 2001). Cataract may be associated with cardiovascular diseases, diabetes and hypertension (Borger et al. 2003). Eye-related diseases, such as AMD, glaucoma and cataract correlate with depressive symptoms. It has been reported that up to one third of persons aged 60 and over with AMD have depressive symptoms (Brody et al. 2001). Also many serious systemic diseases, such as leukaemia, cardiovascular diseases, infectious diseases and genetic diseases may decrease visual acuity (Saari 2001). In addition, a previous Finnish population-based cohort study revealed that cancer incidence among persons with visual impairment is increased for most cancer types (Pukkala et al. 1999). It has been suggested that this association may simply reflect the effects of lifestyle or other factors with a potential influence on cancer risk, namely smoking, alcohol abuse, low level of physical exercise, and poor diet (Pukkala et al. 1999, Verkasalo et al. 1999). It has also been suggested that visual impairment may be associated with an increased risk of suicide through its effect on poor health (Lam et al. 2008).

Several studies have shown that mortality rates are higher among older people with lowered visual acuity (Klein et al. 1995, Reuben et al. 1999, Taylor et al. 2000, McCarty et al. 2001, Lee et al. 2002, McCarty et al. 2002, Cacciatore et al. 2004, Freeman et al. 2005, Jacobs et al. 2005, Pedula et al. 2006) as well as among people with total blindness (Taylor et al. 1991, Krumpaszky et al. 1999). Older persons with poor visual acuity and poor contrast sensitivity are at higher risk of all cause mortality and, in particular, death due to trauma. A previous study reported that among Caucasian women aged 65 and older, all-cause mortality rates (per 100 000 person-years) ranged from 1 816 for persons with the best baseline visual acuity to 4 715 for persons with the poorest visual acuity. Similar rates were seen for contrast sensitivity. Traumatic mortality rates were about three times higher for women in the poorest visual acuity (108 per 100 000) than for those in the best visual acuity (37 per 100 000) (Pedula et al. 2006). Severe bilateral visual impairment has been shown to be strongly associated with increased injury mortality in adults aged 18 and over, increasing the risk over ten-fold compared to persons with no visual deficits (Lee et al. 2003b). In the Beaver Dam Eye Study, conducted in USA in 1988-1990, visual impairment was related to decreased survival after controlling for age and sex. However, after controlling for other survival-related factors, such as BMI, cardiovascular diseases, diabetes, cancer and inactive lifestyle this relationship was no longer significant (Klein et al. 1995, Borger et al. 2003). Other reports have shown that depression and reported number of falls also markedly attenuate the association between visual acuity and mortality among people aged 75 and over (Thiagarajan et al. 2005).

Eye-related diseases, such as age-related maculopathy, cataract, diabetic retinopathy and glaucoma correlate with shorter survival (Minassian et al. 1992, Henricsson et al. 1997, Klein et al. 1999, Taylor et al. 2000, Wang et al. 2001, Borger et al. 2003, Lee et al. 2003a, Clemons et al. 2004, Buch et al. 2005). Data from case-control studies have shown that older patients undergoing cataract extraction have significantly higher mortality than patients undergoing other, non-ocular elective surgical procedures (Hirsch & Schwartz 1983, Benson et al. 1988) or same aged persons in the US population (Street & Javitt 1992). Cataract has also shown to be associated with increased cancer and cardiovascular mortality risk (Thiagarajan et al. 2005). Further, the presence of severe diabetic retinopathy in diabetic patients increases the risk of ischemic heart disease death (Klein et al. 1999). The Rotterdam Eye Study, conducted in Netherland in 1990-2000, revealed a strong relationship between AMD and higher all-cause mortality, but after correction for additional confounders, such as smoking, BMI, cholesterol level, hypertension, cardiovascular diseases and diabetes, the association was markedly attenuated. Similar results were obtained when examining the associations between cataract and glaucoma and mortality (Borger et al. 2003). In addition, an increased risk of cardiovascular disease mortality as well as all-cause mortality among persons aged 18 and over with glaucoma has been established (Lee et al. 2003a). It is possible that the age-related eye diseases as well as visual impairment are predictors of shorter survival because they share common risk factors for mortality.

Based on these previous results, it is reasonable to assume that visual impairment at least partly reflects confounding by comorbidities, risk factors and other factors related to susceptibility to death. It is also known that visual impairment and blindness are the end-stage of many metabolic and systemic diseases (Tielsch et al. 1995). However, both visual impairment and eye-related diseases have been reported as significant risk indicators for poorer survival even after adjusting for other survival-related factors (Wang et al. 2001, Buch et al. 2005, Knudtson et al. 2006). Therefore it is also possible that visual impairment reflects biological aging, and thus its health effect is substantial. This indicates that the relationship between visual loss and mortality could also be direct. This is suggested by the results obtained by Freeman et al. (2005), who reported that persons aged 65 and older who gained in visual acuity (owing to cataract surgery or proper correction of refractive errors) over a 2-year follow-up period had a lower risk for death compared to those whose acuity worsened or did not change (Freeman et al. 2005). Although several factors on the pathway from poor vision to mortality have been identified, the interpretation of this association is still unclear and warrants further studies.

2.4 Vision in relation to postural balance and falls

2.4.1 Visual functions and postural balance

Balance refers to the ability to maintain postural control in an up-right position. Balance in the eyes open and eyes closed as well as balance during tandem standing show longitudinal age-related declines (Era et al. 2002). Balance disorders among older people represent a growing public health concern due to their association with falls and fall-related injuries.

Balance calls upon contributions from vision, vestibular sense, proprioception, muscle strength and reaction time. With increased age, there is a progressive loss of functioning of these systems which can contribute to balance deficits. In addition to age-related vision loss, the sensitivity of cutaneous receptors declines, resulting in a reduced ability to feel the quality of contact between the feet and the surface below (Shaffer & Harrison 2007, Sturnieks et al. 2008). Also a gradual decline in the vestibular system begins as early as age 30 (Park et al. 2001). Additionally, muscle strength and reaction time (Tucker et al. 2008) decline with age, which contributes to balance problems in old age (Frontera et al. 2000, Hughes et al. 2001, Tucker et al. 2008, Danneskiold-Samsoe et al. 2009). However, older people show considerable variation in postural balance. It has been suggested that the genetic influences on postural balance while standing or walking account for 14-35% of individual differences (Pajala et al. 2004, Pajala et al. 2007).

Vision plays an important role in both maintaining balance while standing still and remaining stable while moving within the environment. Vision provides the nervous system with continuously updated information regarding the position and movements of body segments in relation to the environment. This is an important source of information for postural control. A removal of visual cues by closing the eyes has been shown to increase body sway among people with normal vision, indicating difficulty in balance control in the absence of visual feedback (Brooke-Wavell et al. 2002). Equally, standing balance in older persons in nursing homes, as measured by the amount of sway has been shown to be worse for those who have visual impairment (Maeda et al. 1998). Older people with vision impairment have also impaired functional balance more often than those with better vision. A previous study by Lee & Scudds (2003) found that older people with good vision performed better and were more stable in difficult items of the Berg balance test, for example, reaching an arm forward while standing, placing alternate foot on step or stool while standing unsupported, standing unsupported one foot in front, and standing on one leg (Lee & Scudds 2003).

When the effect of visual input (eyes open versus eyes closed) is compared during standing on an unstable surface in a group of healthy community-dwelling older people, the participants have significantly more difficulties in balancing in the eyes-closed condition (Whipple et al. 1993). Also in a study of older adults with age-related maculopathy, visual acuity and contrast sensitivity were significantly associated with poorer postural stability on a foam surface (Wood et al. 2009). Similar results was obtained by Lord et al (1991), who found that among relatively independent older adults with a mean age of 83 years, decreased visual acuity was not associated with increased sway on the hard surface, but on the foam surface poor visual acuity correlated strongly with increased sway (Lord et al. 1991). These results indicate that visual influences on postural balance become more important during stance on a compliant surface. When standing on a foam mat, the proprioceptive input from the feet and ankles is reduced, and subjects are compelled to rely more on other sensory and motor systems to maintain stability.

Previous studies have also shown that the reliance on visual information for the maintenance of postural balance increases with advancing age, with older adults aged 85 and over swaying up to 38 per cent more with eyes closed than persons aged 50 to 60 years (Pyykkö et al. 1990). The increased reliance on vision for the maintenance of postural stability occurs in women as early as 50 years of age (Choy et al. 2003).

It is known that poor vision causes deterioration in the control of standing balance due to lack of visual feedback about body posture (Brooke-Wavell et al. 2002). It is also possible that deterioration in vision and in balance ability develop at the same time while the processes underlying them are independent, or they may share common risk factors, or both may be biological markers of aging. Common background factors, such as diseases, may explain the association between poor vision and decreased postural balance.

2.4.2 Visual acuity in relation to falls and fall-related injuries

Falls in older people

A fall is most commonly defined according to the definition given by the Kellogg International Work Group on Prevention of Falls by the Elderly (1987) as "an event in which the person unintentionally comes to rest on the ground, floor, or other lower level for other reasons than sudden onset of acute illness or overwhelming external force". Previous studies indicate that about one third of community-dwelling persons aged 65 years and older fall each year and half of this number fall repeatedly (Tinetti et al. 1988, Moylan & Binder 2007). Falls occur more frequently in nursing home settings, with up to 60 per cent of residents reporting at least one fall per year (Lord et al. 2003). It is also known that the proportion of older people who fall each year increases with their advancing age. Also the risk of serious injury increases with each fall (Moylan & Binder 2007).

Falling in older people is a multifactorial phenomenon, which is partly caused by intrinsic (person-related) factors, attributable to age- or disease-related changes occurring within the older adult. Extrinsic factors (those associated with environmental features) also elevate the risk for falls during the performance of activities of daily living. In many cases, falls are caused by the interaction of both of these factors (Tinetti et al. 1995b). A number of intrinsic risk factors for falls in older people have been identified. The most common underlying causes for falls include muscle weakness, gait and balance problems, visual impairment, cognitive impairment, depression, functional decline and medications, particularly psychotropics (Rubenstein & Josephson 2002, Rubenstein 2006, Hartikainen et al. 2007).

A few previous studies have separated the risk factors for outdoor and indoor falls and found that the risk factors for indoor and outdoor falls are different. In the study conducted by Bergland et al. (2003) indoor falls were affected by slower walking speed, poorer functional capacity, morbidity and poor cognition. Older people with faster walking speed, symptoms of depression or visual impairment were more likely to fall outdoors (Bergland et al. 2003). Indoor falls also increase the risk for new falls by more than two-fold in older people aged 65 and over (Close et al. 2003). In addition, older people with indoor falls have been found to be less confident in maintaining balance and also to have lower scores in the functional balance test (Kulmala et al. 2007). Often, older persons have multiple risk factors predisposing them to falls. The risk for falls increases consistently with the presence of one or several known predisposing factors, such as depressive symptoms, orthostasis, cognitive impairment, decreased sensory functions, poor balance, gait deficits, poor muscle strength and multiple medications (Tinetti et al. 1988, Nevitt et al. 1989). Newitt et al. (1989) showed that the percentage of community-residing older people experiencing multiple falls increased from 10% when only one risk factor was present to 69% for those with four or more risk factors (Nevitt et al. 1989). This multifactorial nature of falls cannot be overemphasized and therefore factors predisposing to falls need to be well understood.

The consequences of falls range from mild to severe. Falls are the leading cause of morbidity and nursing home admission in old age. Even a single non-injurious fall increases the risk of admission to a nursing facility almost five-fold over a three-year follow-up in people over 71 years of age (Tinetti & Williams 1997). Falls and fall-related injuries also appear to be independent determinants of functional decline and disability in community-dwelling older persons (Tinetti & Williams 1998, Laird et al. 2001). Each year, at least 10 percent of falls among older people lead to a serious injury, including fractures, head injuries and serious soft tissue injuries (Tinetti et al. 1988, Tinetti et al. 1995a). One of the most serious consequences of falling among older people is hip fracture, which is followed about 1% of falls and the incidence of which appears to be increasing (Kannus et al. 1999a, Kannus et al. 1999b). Hip fracture increases the use of health and social care, need for help in daily activities and use of assistive devices (Osnes et al. 2004). Approximately 20% of hip fractures lead to permanent hospitalization (Marottoli et al. 1994). High mortality rates have also been observed among older people with hip fracture (Wolinsky et al. 1997, Farahmand et al. 2005).

There are also important psychosocial consequences associated with falling, even in the absence of physical injury. These psychosocial consequences of falls include fear of falling and social isolation, which may further lead to limited activity, functional decline, muscle weakness and future falls (Tinetti et al. 1994, Moylan & Binder 2007). Of those older persons who have previously fallen without injury about 30% report fear of falling, while among persons with previous injurious falls the prevalence rate for fear of falling is 40% (Howland et al. 1993). Ideally, older people at risk for falls should be identified and modifiable risk factors should be addressed before any serious injury occurs.

Vision in relation to falls and fall-related injuries

The evidence from the current literature indicates that impairments of visual functions are associated with increased fall risk in older people (Lord et al. 1991, Koski et al. 1998, Abdelhafiz & Austin 2003, Coleman et al. 2004, Faulkner et al. 2009). Both self-reported problems with seeing (Sihvonen et al. 2004a) as well as clinically measured visual impairment (Lord et al. 1991, Klein et al. 1998, Kuang et al. 2008) are more common in fallers than non-fallers. Distance visual acuity is a commonly investigated visual function in relation to falls. In a recent review on the association between visual impairment and injuries, it was concluded that older persons with visual loss are 1.7 times more likely to have a fall and 1.9 times more likely to have multiple falls compared with peers with good vision. In previous studies, the risk estimates for falls among visually impaired persons range from 1.2 to 5.4 (Legood et al. 2002). It has been suggested that visual acuity below 0.65 increases the risk for falls by two-fold (Ivers et al. 1998).

Poor visual acuity has been shown to be a significant predictor, in particular, of recurrent falls and fall-related injuries in community-dwelling older people (Ivers et al. 1998, Koski et al. 1998, Lord & Dayhew 2001, Coleman et al.

2004). A recent prospective study showed that among persons whose visual acuity declined over a period of approximately 5 years prior to a 12-month follow-up for falls, had substantially higher risk for frequent falling during the follow-up compared to persons, who did not lose VA (Coleman et al. 2004). Visual impairment increases the risk for falls in community-dwelling (Nevitt et al. 1989, Lord et al. 1994, Ivers et al. 1998) and also in institutionalised older people (Tinetti et al. 1986).

Cross-sectional data from an emergency department showed that over 70% of the older people who had sustained an injurious fall had visual acuity lower than 0.5 (Jack et al. 1995). The risk of fall-related hip fracture is significantly increased among older people with visual loss (Grisso et al. 1991, Klein et al. 1998). Visual acuity of less than 0.2 in both eyes increases hip fracture risk more than two-fold. The strength of the association between visual acuity and hip fractures increases with the severity of the visual deficit and the association is even stronger for people aged 75 and older (Dargent-Molina et al. 1996, Klein et al. 1998, Ivers et al. 2000, Ivers et al. 2003).

Although some of the previous studies are limited by the use of retrospective data, the use of large samples provides convincing evidence of the association between reduced vision and falls and fall-related injuries. However, a few studies have failed to detect a significant relationship between visual acuity and falls (Tinetti et al. 1988, Arfken et al. 1994, Cesari et al. 2002) or between vision and hip fractures (Cummings et al. 1995). It has been suggested that the association between vision and falls may be attributable to the characteristics of the population studied. A prospective population-based study conducted in rural Finnish municipalities found that poor vision (VA < 0.3) was strongly associated with major injurious falls (including fractures, joint dislocations, laceration requiring sutures and intracranial injuries) among home-dwelling older people aged 70 and over who also had other functional disabilities, such as the inability to walk between rooms, inability to get in and out of bed and inability to do housework. However, among older people who were functionally independent the association between visual acuity and injurious falls was no longer significant (Koski et al. 1998). In addition, a recent study by Lamoureux et al. found a non-significant association between vision and falls, but reported that visually impaired people were three times more likely to fall if they were physically inactive (Lamoureux et al. 2010). These findings suggest that visual acuity may become more significant risk factors for falls when accompanied with other aspects of function decline.

Other aspects of visual functioning have also been found to correlate with fractures and other fall-related injuries. Whereas visual acuity is a measurement of fine detail vision, contrast sensitivity tests a person’s ability to detect edges under low-contrast conditions and may therefore be important in order to detect ground-level hazards. Therefore loss of contrast sensitivity may predispose older people to trip over obstacles and outdoor hazards. Poor contrast sensitivity (Lord et al. 1991, de Boer et al. 2004), visual field impairment (Ivers et al. 1998) and poor depth perception (Cummings et al. 1995, Lord & Dayhew 2001) have proved to be major risk factors for fall-related injuries in older people. A prospective study among community-dwelling people aged 63-90 showed that multiple fallers had decreased vision in all aspects of visual functioning, but impaired depth perception, contrast sensitivity and low-contrast visual acuity were the strongest risk factors for recurrent falls (Lord & Dayhew 2001). It has been suggested that inability to detect an association between visual acuity and falls in a number of previous studies may have occurred because these measures of vision have not been assessed (Tinetti 2001).

Poor vision can contribute to a fall directly through inaccurate perception of the environment as well as indirectly through difficulties in coordinating gait and balance. While many factors are associated with falls among older people, poor vision is most certainly essential for maintaining postural balance, effective mobility and avoiding falls. The visual system is the key to the early detection of potential balance threats during walking. Therefore additional studies, which deepen knowledge about fall aetiology in older people, are still needed.

2.5 Co-existing sensory deficits in relation to health deterioration among older people

Previous studies have shown that the number of impairments in old age is associated with an increasing rate of negative outcomes, such as disability (Rantanen et al. 1999, Rantanen et al. 2001, Cesari et al. 2006) and falls (Tinetti et al. 1995c). However, little is known about the combined effects of multiple impairments, despite the fact that with increasing age the proportion of persons having impairments in multiple systems (commonly referred as coimpairments) increases.

In old age, sensory impairments often coincide. Like vision impairment, hearing impairment has been identified as a major chronic condition in old age (Strawbridge et al. 2000). It has been estimated that more than half of persons aged 60 and over experience hearing impairment (Cruickshanks et al. 1998). Previous studies have also shown a strong relationship between vision and hearing impairment in older people; along with each 1-line reduction in presenting visual acuity, the prevalence of hearing loss increases by 13% (Chia et al. 2006). Cataract and age-related maculopathy are also associated with hearing loss (Chia et al. 2006). It has been estimated that the overall prevalence of concurrent vision and hearing impairment in an adult population is 3% and increases from 1% for persons aged 18-44 years to 7-8% for adults aged 70 and older and 17% for persons aged 80 years and older (Caban et al. 2005). An even higher prevalence, over 20%, has been observed among aged care clients (Jee et al. 2005).

In addition to vision and hearing, the control of postural balance is also dependent on several other systems, such as the central nervous, vestibular and somatosensory systems, which are vulnerable to age and disease-related changes. For example, it has been estimated that over 30% of US adults aged 40 years and older have vestibular dysfunction and that the proportion increases significantly with age (Agrawal et al. 2009). In addition, age-related changes in both the number and sensitivity of muscle and joint receptors contribute to a less accurate knowledge of limb position, especially when the body is moving (Shaffer & Harrison 2007).

It is assumed that the problems encountered by older people with co-existing sensory impairments are considerably greater than the effects of vision impairment alone, because when two or more sensory impairments are combined, the person is seriously deprived of compensatory strategies from other sensory sources. In cross-sectional studies, older persons with both vision and hearing loss demonstrate higher rates of ADL and IADL dependency than persons without sensory deficits (Keller et al. 1999, Lupsakko et al. 2002, Crews & Campbell 2004). Combined vision and hearing impairment has also been shown to be a strong predictor of functional dependency during a 10-year follow-up even after adjusting for sociodemographic characteristics and chronic conditions among people aged 55 and older (Reuben et al. 1999). Persons with combined sensory impairment also report low rates of excellent health and high rates of poor health and depression (Lupsakko et al. 2002, Crews & Campbell 2004). They also tend to have more restricted activity days, more days of bed rest and more visits to the physician than persons with only one impairment (Lee et al. 2005b). Further, Lin et al. (2000) reported that combined vision and hearing impairment was associated with decline in cognitive capacity (measured with the Mini-Mental State Examination) during a 4-year follow-up in women aged 69 and over (Lin et al. 2004). Mortality risk is also higher among people, who report concurrent vision and hearing impairment as compared with persons reporting either visual impairment or hearing impairment alone. This association increases with the severity of these impairments (Lam et al. 2006, Lee et al. 2007).

In a few previous studies, the effect of co-existing sensory deficits on fall risk among older people has been studied. Tinetti et al. (1995) found falling incidence to increase significantly along with the number of predisposing factors, such as slow timed chair stands, decreased arm strength, decreased vision and hearing and a high score for anxiety or depression (Tinetti et al. 1995c). In an earlier retrospective study among persons aged 70 or older, those with coexisting self-reported vision and hearing impairment were 3.0 times more likely to have fallen during the previous 12 months than persons without vision or hearing problems (Crews & Campbell 2004). The ability to maintain an upright position depends on the interaction of multiple physiological systems, including vision, the vestibular system and proprioception. These balance control systems send signals to the central nervous system about head and body movements. The complex structure of sensory input involved in maintaining an upright position and the interaction between vision and other sensory systems makes it possible for people with only one sensory impairment to compensate for the lack of information from that channel by using other sensory information available to them. This is supported by previous studies among people with blindness or deafness, where changes have been observed in the processing of information by the remaining sensory modalities (Proksch & Bavelier 2002, Dye et al. 2007). However, studies assessing co-existing sensory deficits in relation to health deterioration continue to be warranted in order to recognize more potential high-risk groups.

3 PURPOSE OF THE STUDY

The purpose of this study was to assess whether visual impairment is related to functional capacity, falls and mortality among older people. The aim was to provide new knowledge about the role of visual acuity in the multifactorial disablement process in older people.

The specific aims of the study were:

1. To examine the association between visual impairment and other impairments (decreased lower extremity muscle strength and power and impaired balance), functional limitations (decreased walking speed) and IADL disability and further, to examine the predictive value of decreased vision in the development of lower extremity impairment in a three-year follow-up. (Study I and previously unpublished data)

2. To examine visual impairment as a risk factor for falls and injurious accidents. Further, the impact of co-existing vision, hearing and balance impairments on falling incidence was assessed. (Studies II and III)

3. To determine whether visual loss is associated with increased all-cause mortality in a ten-year follow-up and what factors might lie on the pathway from poor vision to mortality in older community-dwelling people. (Study IV)

4 THE STUDY FRAMEWORK

The main pathway in the disablement process described by Nagi (1976) and later expanded by Verbrugge & Jette (1994) is that pathology (i.e. the presence of diseases) influences impairments (which are abnormalities at the physiological or anatomical level), which lead to functional limitations (i.e. limitations in basic physical actions) and finally to disability (i.e. difficulties in activities relevant to daily living). The pathway is modified by risk factors (predisposing characteristics), intra-individual factors (e.g. lifestyle and behavioral changes) and extra-individual factors, such as external support. This means that although functional limitation may be a direct consequence of pathology or impairment, it may also be caused by direct or indirect predisposing risk factors, such as behavioral characteristics or lifestyle. Also intra-individual factors, such as lifestyle or behavioral changes along with extra-individual factors, such as medical care may either slow down or accelerate the progression of the disablement process. This model is used as a method of conceptualizing the impact of deterioration of vision on older people and thus on disability. This model also enables elaboration of the connections between vision and functional limitation.

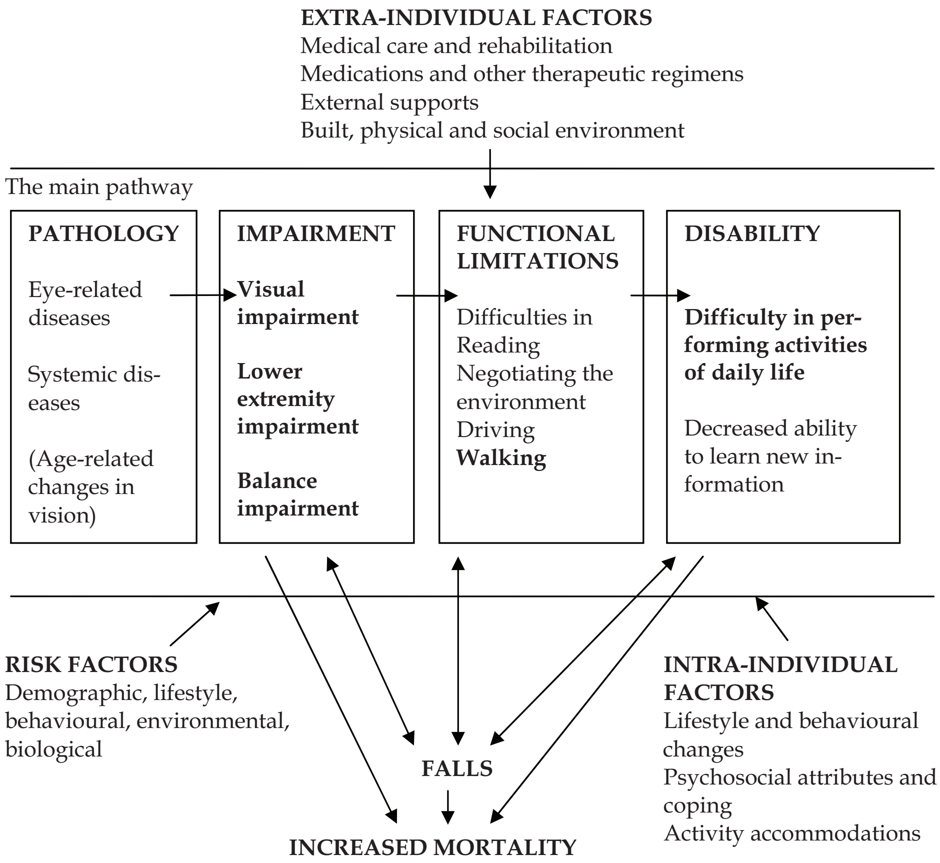


FIGURE 2 The disablement process by Verbrugge and Jette (1994) applied to visual impairment and the study outcomes.

The model has been adapted for application to those with visual impairment by Verbrugge and Jette (1994). Pathologies may be defined as conditions, such as eye-related or systemic diseases, which have negative effects on visual acuity. Impairments are abnormalities or conditions in a specific body system, such as decreased visual acuity. Functional limitations refer to restrictions in performing physical and mental actions such as physical functioning and altered communication. Disability is a negative outcome and refers, for example, to the need for assistance with daily activities (Verbrugge & Jette 1994).

Falls and injurious accidents, which are also used as outcomes in this study, are considered disability-related factors in the literature (Czerwinski et al. 2008, Lang et al. 2009, Wahl et al. 2009). They are associated with several components of the disablement pathway and they may accelerate the disablement process. Further, disability subsequently leads to significantly increased risk for falls and mortality (Fletcher et al. 2009, Klijs et al. 2010).

Examining vision in relation to impairments, functional limitation and disability-related outcomes will provide new knowledge about the factors on the pathway from visual impairment to disability and even mortality. It is important to pay more attention to early signs of disability in old age when aiming to slow down the progression of the disablement process in this life phase. Previous studies which have examined the association between poor vision and functional capacity have mainly focused on isolated components of this disablement process. This study expands the perspective by taking several factors simultaneously into account in this process.

5 PARTICIPANTS AND METHODS

5.1 Study design and participants

The analyses included in this thesis were based on prospective observational population-based studies. Three separate study samples with one- and ten-year follow-up times for falls and injurious accidents, three-year follow-up for functional capacity and ten-year follow-up for mortality were used. Two data sets came from the Evergreen project which is a multi-disciplinary, longitudinal follow-up study on the health and functional status of residents in Jyväskylä, Finland. The third data set came from the Finnish Twin Study on Aging (FITSA), which investigates the role of genetic and environmental factors in the disablement process in old age. The Evergreen project has been conducted in close co-operation with the City of Jyväskylä. The FITSA study was conducted in collaboration with the University of Helsinki. The studies used are summarized in Table 2.

5.1.1 The Evergreen Project (Studies II and IV)

The Evergreen project is a multidisciplinary, prospective study on health and functional capacity among older people. The target group for this study comprised all community-dwelling persons aged 75 years in 1989 (N=388, 261 women and 127 men) and 80 years in 1990 (N=291, 213 women and 78 men) living in Jyväskylä, Finland. Research centre examinations, which consisted clinical examinations on health and functional status, were conducted for the 75-year-old cohort in 1989 (n=295) and for the 80-year-old cohort in the year 1990 (n=206). The data also consist of face-to-face interviews on health, functioning and living habits. After the baseline measurements, follow-up data for injurious accidents was collected for 10 years after the baseline from patient records maintained by the local health care centres and central hospital. Death dates were received from the official register of the province of Central Finland.

Complete data on visual acuity was available for 416 participants, i.e. 61% of the target population. This sample is used in this thesis, in studies II and IV. Those participants who had missing data were most frequently 75-year-old women, had an average of 2 chronic diseases and only 8% of them rated their health as very good or good. No significant differences were found between participants and non-participants in gender, difficulties in reading a newspaper or functional capacity at baseline or mortality during the subsequent ten years. Comparisons between persons in the study target group with and without baseline visual acuity (VA) measurements are presented in Table 3. The study protocol in described in detail by Heikkinen (1997).

5.1.2 Finnish Twin Study on Aging (Studies I and III)

The Finnish Twin Study on Aging (FITSA) is a study of genetic and environmental effects on the disablement process in older female twins. The participants for the FITSA study were recruited from the Finnish Twin Cohort, which is a longitudinal study of the genetic and environmental factors of chronic diseases and risk factors (Kaprio & Koskenvuo 2002). The Finnish Twin Cohort comprised the same-sex twin pairs born before 1958 with both co-twins alive in 1975 (n=13 888 twin pairs). The Finnish Twin Cohort contained 1260 female twin pairs born in 1924-1937. The participants, who participated in Finnish Twin Cohort Study in 1975 and were in the age group of 63-76 years in August 2000, were selected for FITSA study. An invitation to participate in FITSA was sent to every monozygotic twin pair (n=178), every third dizygotic twin pair (n=212) and to 24 female twin pairs with uncertain zygocity. The twin study design has been described in detail by (Tiainen et al. 2004). A total of 828 women were contacted of whom 434 took part. The inclusion required that both co-twins could participate and were able to travel to the research laboratory. Altogether 428 persons took part in fall surveillance for one year after the baseline measurements. Totally 3 persons were unable to participate in fall surveillance due to poor health and 3 persons refused to participate. An invitation to take part in three-year follow-up measurements in 2004 was sent to all baseline participants. However, 8 of the participants refused to participate due to poor health, 7 had died and 106 women consented to participate solely in an interview. Thus, totally 313 women participated in follow-up measurements in laboratory. Although the sample consisted of twins, in this study we treated the sample as a set of individuals by taking into account the within-pair dependency in the statistical analyses.

TABLE 2 Summary of study designs, populations and outcomes.

Study	Data set	Population	Design	Age	Outcomes
I	FITSA	434 community-dwelling women at baseline, 313 at three-year follow-up	Observational Cross-sectional and three-year follow-up	63-76	Impairments - Maximal isometric knee extension strength - Leg extension power - Standing balance Functional limitations - Maximal walking speed
II and IV	Evergreen	416 community-dwellers Men=136 Women=280	Observational Longitudinal 10-year follow-up	75-year-olds n=223 Men n=80 Women n=143 80-year-olds n=193 Men n=56 Women n=137	Disability-related outcomes: - Injurious accidents, which required medical examination (Study II) - Mortality (Study IV)
III	FITSA	428 community-dwelling women	Observational Longitudinal 1-year follow-up	63-76	Disability-related outcome: - Falls
Previously unpublished data	FITSA	434 community-dwelling women at the baseline	Observational Cross-sectional	63-76	Disability - IADL

TABLE 3 Comparisons between persons in the Evergreen study target group with and without baseline visual acuity (VA) measurements. Frequencies, percentage and statistical significance (chi-square tests).

Characteristics	Participated in VA measurements	Did not participate in VA measurements	p-value
75-year-old persons			
Number of people	223	133	
Female gender	143 (64%)	93 (71%)	0.222
Major difficulties in reading a newspaper	15 (9%)	10 (10%)	0.443
Baseline walking speed*	1.6±0.4	1.6±0.4	0.866
Died during the 10-year follow-up	107 (48%)	65 (49%)	0.871
80-year-old persons			
Number of people	193	75	
Female gender	137 (71%)	51 (74%)	0.643
Major difficulties in reading a newspaper	24 (13%)	9 (15%)	0.649
Baseline walking speed*	1.3±0.4	1.1±0.6	0.108
Died during the 10-year follow-up	138 (72%)	56 (77%)	0.393

*mean ± SD, statistical significance tested with independent samples t-test

5.2 Measurements

The complete battery of laboratory examinations lasted approximately 5 hours per each participant and comprised measurements of physical functions, functional abilities and an examination conducted by a physician.

5.2.1 Impairments

Visual acuity (explanatory variable, Studies I-IV)
The visual acuity data were collected as part of the clinical examination at the Sports and Health Laboratory at the University of Jyväskylä. Visual acuity (VA) measurements were carried out first without and then with participants' own spectacles using the illuminated Landolt ring chart (Oculus 4512). Subjects were seated during the measurement and the chart was positioned at five meters distance. Both eyes were examined separately. Participants were requested to state in which direction the gaps in black circles on the white background point (up,

down, right, left). If the answer was correct, the subject was asked to perform the same task for the next smaller line and so on until the line with the smallest circles was reached. The Landolt ring chart consists of 13 lines, where visual acuity is scored from 0.125, if the subject can only see the first line, to 2.0, if the subject can correctly see the last line. The Landolt rings are widely accepted as the standard of reference in measuring distance VA (Sloan et al. 1952).

In the Evergreen study, by modifying the WHO and the Unites States criteria, the following three visual acuity groups were formed. VA of <0.3 in the better eye was defined as visual impairment (VI). VA of ≥ 0.3 but ≤ 0.5 in the better eye was defined as lowered vision (LV) and visual acuity of more than 0.5 was defined as normal vision (NV). Visual acuity of 0.5 and 0.3 are conventional cut points that have also been used in other studies (Tielsch et al. 1990, West et al. 1997, Reuben et al. 1999, Thiagarajan et al. 2005). In addition, visual acuity of 0.5 is a statutory driving cut point in Finland.

In the FITSA study, the participants were rather healthy and well-functioning. In this study population, the proportion of those with visual acuity of less than 0.5 was very small (47 persons, 11% of the study population). With such a small group, it was not possible to conduct meaningful analyses. For this reason, we decided to use the standard definition of good vision (VA of 1.0) as a cut point. Participants from the FITSA data are therefore divided into those with visual acuity of less than 1.0 (n=191) and to those with visual acuity of 1.0 or over (n=237). Table 4 summarizes the definitions of normal vision and visual impairment used in this study.

TABLE 4 Definitions of normal visual acuity and visual impairment in this study.

	FITSA		EVERGREEN	
Definition	Visual acuity	n	Visual acuity	n
Normal vision	≥ 1.0	237	> 0.5	228
Lowered vision			≥ 0.3 but ≤ 0.5	123
Visual impairment	< 1.0	191	< 0.3	65

Hearing (explanatory variable Study III)

Audiometric measures were performed by an experienced audiology assistant in a soundproof booth, using a clinical Madsen OB 822 audiometer equipped with THD 39 headphones (Madsen Electronics, Denmark). The better ear hearing threshold level was defined as a pure-tone average of thresholds at 0.5, 1, 2 and 4 kHz. In accordance with the European Union Working Group recommendations, a person was defined as having hearing impairment if the hearing threshold level of the better ear was ≥ 21dB (Stephens 2001).

Balance (outcome measure Study I, explanatory variable Study III)

Balance was measured using the Good Balance force platform measurement system (Metitur Ltd, Jyväskylä, Finland) (Pajala et al. 2008). The tests were carried out by two trained physiotherapists. The medio-lateral and antero-posterior movements of the center of pressure (COP) were measured during semitandem stance (heel of one foot positioned alongside the big toe of the other foot) with eyes open and gaze fixed at a point marked at eye level at a distance of two meters. During the balance testing, the participants were instructed to stand as still as possible in a well-balanced position, with their arms held down by their sides. COP movement was recorded for 20 seconds. When all the measurement points were read, the medio-lateral (*x*) and anteroposterior (*y*) coordinates of the center of pressure were calculated on the basis of these vertical force signals using the Good Balance software. To compensate for the possible influence of the center of mass being located at the higher point among the taller subjects, the absolute COP measures were standardized for height [(COP variable/subject height) x 180]. The mean moment of velocity (VEL; mm^2/s) was calculated as the mean of the areas covered by the movement of COP during each second of the test. Lower scores represent better balance. Adequate reliability of this force platform method has been demonstrated by Sihvonen & Era (1999).

Muscle strength and power (outcome measure Study I)

Maximal voluntary isometric knee extension strength (Study I) was measured from the side of the dominant hand in a sitting position using an adjustable dynamometer chair (Good Strength, Metitur Ltd., Jyväskylä, Finland). The measurement was done at a knee angle of 60° from full extension. The ankle was fastened by a belt to a strain-gauge system. After familiarization with the measurement, three to five maximal efforts, each separated by a 1-min rest interval period, were conducted. The data were digitized into Newtons (N), recorded and stored on a computer using the Good Strength software package (Metitur Ltd.). For each subject the best performance with the highest value was accepted as the result. In our laboratory, the coefficient of variation for knee extension strength between two consecutive measurements performed 2 weeks apart has earlier been 6.3% (Rantanen et al. 1997).

Leg extensor power (Study I) was measured using the Nottingham Leg Extensor Power Rig (Bassey & Short 1990) in an upright sitting position with arms folded across the chest, the active leg towards the push-pedal and the free leg resting on the floor. The push-pedal was located in front of the seat, which makes the direction of movement almost horizontal. First, the leg on the dominant hand side was measured, followed by the other leg. The subject was instructed to push the pedal as hard and as rapidly as possible. Two to three practice trials were allowed for the participants to familiarize themselves with the method. The measurement was repeated until no further improvement occurred, but at least five times. The intertrial rest period was 30 s. For each subject, the highest value was used in the analysis. The results were recorded, computed, and expressed in watts (W) using the Leg Rig software package (PC214E; University of Nottingham, Medical Faculty Workshops, Queen's Medical Centre, Nottingham, UK). Muscle power measurement with the Nottingham power rig has been validated and found to be safe and acceptable among older people (Bassey & Short 1990). The test-retest coefficient of variation for this population in our laboratory was 8% between two measurements one week apart (Tiainen et al. 2005). In this study, impairments in strength and power are considered as lower extremity impairments.

5.2.2 Functional limitations

Walking speed (outcome measure Study I, mediating factor Studies II and IV)
In both study populations maximal walking speed over 10 meters was measured in the laboratory corridor using photocells for timing. Three meters were allowed for acceleration. Participants were instructed to "walk as fast as possible, without compromising safety". Participants wore walking shoes or sneakers and use of a walking aid was allowed if needed. The test was done twice and the faster performance was documented as the result. For the analyses, maximal walking speed (m/s) was calculated. The test-retest coefficient of variation in our laboratory after an interval of 1–2 weeks in 63-76-year-old women was 5 % (Pajala et al. 2005).

5.2.3 Disability and disability-related outcomes

IADL disability (outcome in previously unpublished data)
Information on instrumental activities of daily living (IADL) disability was collected with regard to eight IADL tasks: preparing meals, washing clothes, shopping, coping with heavy housework, administering and taking medications, using the telephone, using public transport and handling finances (Lawton & Brody 1969). The participants were asked whether they 1) had no difficulty in performing the task, 2) had some difficulty, 3) had a lot of difficulties, and 4) were not able to do the task or needed help in performing the task. For each individual IADL task, participants were categorized into those who were able to do the task without any difficulty and to those who has at least some difficulty. A summary score for these eight tasks, ranging from 0 to 8 was calculated.

Disability-related outcomes: falls, injurious accidents and mortality (outcome measure Studies II-IV, mediating factor Study IV)
In the Finnish Twin Study on Aging (FITSA), the follow-up data for falls during 12 months were gathered from 428 participants (Study III). A fall was defined as unintentionally coming to rest on the ground, floor or other lower level for reasons other than unexpected overwhelming force (Kellogg International Work Group on Prevention of Falls by the Elderly 1987). The participants were requested to report their falls each day by marking in their calendars whether a fall had happened or not. At the end of each month, the participants mailed the relevant calendar page to the research centre. If a fall had occurred, the research assistant called the participant and asked about the immediate environment, circumstances, causes and consequences of the fall.

In the Evergreen project information about injurious accidents, i.e. accidents which required medical examination, was collected for 10 years after the baseline from patient records maintained by the local health care centres and central hospital (Studies II and IV). Information was collected on the dates, course of events (falling, traffic accident or other), diagnosis and medical treatment. The data on participants without an accident were censored at the time of death or at the end of the follow-up. Death dates during the ten-year follow-up were received from the official register of the province of Central Finland.

5.2.4 Health status and background information

Mediating, confounding and descriptive variables (Studies I-IV)
The presence of chronic diseases was assessed by a physician on the basis of the subjects' self-report, current medication and clinical examination. In particular, cardiovascular, musculoskeletal and neurological status was evaluated in order to avoid risks in the functional performance measurements. Self-rated health was elicited at the baseline using a noncomparative question: "How would you describe your health at the moment: very good, good, average, poor, or very poor?”. Participants' weight was measured with a beam scale, and height with a stadiometer. Body mass index (BMI) was calculated by dividing weight (kg) by height (m) squared.

The Mini-Mental State Examination (MMSE) was used to test cognitive capacity (Folstein et al. 1975). Depressive symptoms were measured using the Center for Epidemiologic Studies Depression Scale (CES-D) (Radloff 1977). The CES-D scale consists of 20 items with a total score ranging from 0 (no symptoms) to 60 (maximal number of depressive symptoms). In our analyses, persons who scored 16 points or over were classified as having depressed mood (McDowell & Newell 1996). The socioeconomic status of the participants was measured as the length of full-time education in years.

Self-reported physical activity level was assessed on the six point scale developed by Grimby (1986): 1) most activities done sitting down, 2) light physical activity, 3) moderate physical activity about 3h per week, 4) moderate physical activity at least 4h per week or heavy physical activity ≤ 4h a week, 5) intensive physical exercise at least 3h per week and 6) competitive sports several times a week. For the statistical analysis, the answers were re-classified into 3 categories; 1) low physical activity only (answers 1 and 2), 2) moderate physical activity (answers 3 and 4) and 3) high physical activity (answers 5 and 6).

5.3 Ethics

Permission to the Evergreen project has been granted by the Ethical Committee of the Central Finland Health Care District and the FITSA by the Ethical Committee of the Jyväskylä Central Hospital Board. Participants in both studies have been informed about the purpose of the research and gave their written informed consent to participate. Studies were carried out according to the guidelines for good clinical and scientific practice laid down in the Declaration of Helsinki.

5.4 Statistical analyses

5.4.1 Descriptive statistics

Descriptive statistics were obtained using SPSS (SPSS Inc., version 14.0 and 15.0) and STATA statistical softwares (Stata Corp., College Station, TX, 2001) before the constructing the multivariate models. The level of statistical significance was set at $p < 0.05$. Although in the FITSA study the sample consisted of twins, the sample was treated as a set of individuals (Studies I and III). The STATA software was used when analyzing the FITSA data, because this software can accommodate the statistical interdependency of twins. The mean differences in continuous variables and the distribution of discrete characteristics were tested with the Wald test adjusted for within-pair dependency.

In the Evergreen study, the statistical analyses were first performed separately for the 75- and 80-year-old populations (Studies II and IV). If the results were parallel, the data were pooled to obtain a larger sample size. Baseline characteristics were compared by a t-test for independent samples for continuous variables, and by cross-tabulation analysis with chi-square tests for categorical variables. Mean differences in possible mediators were tested with one-way ANOVA with the Tukey test and cross-tabulation with the chi-square test. The incidence of injurious accidents was calculated for each group and expressed as the number of cases per 1000 persons each year. Person time was calculated from the date of the baseline measurements to the date of the first injurious accident, death or the end of the study follow-up, which ever happened first. Mortality rates were expressed as number of deaths per 1000 person-years and person time was calculated from the date of the baseline measurements to the date of death or to the end of the follow-up. Using the Kaplan-Meier procedure with log-rank tests, mortality functions for the three different visual acuity levels were estimated.

5.4.2 Multivariate models

In order to improve comparability between the balance and lower extremity function measures, the distribution of the values obtained for isometric knee extension strength, leg extension power, velocity moment and maximal walking speed were classified into quintiles. Odds Ratios (OR) per quintiles of distributions of the results of the balance and lower extremity function tests were calculated using logistic regression. Visual acuity (good vs. impaired) was used as the explanatory variable. Similarly, when studying vision in relation to IADL disability, a logistic regression model was used. The regression modelling was performed using STATA statistical software. Using SPSS, analysis of variance for repeated measures (ANOVA) having the vision (good vs. impaired vision) as a grouping factor was used to assess changes in balance and lower extremity function during the three-year follow-up. With this analysis, it is possible to detect the main effects for both VI group and time. We included only those persons who had both baseline and follow-up measurements. The drop-out analyses were performed using the adjusted Wald tests to compare vision, lower extremity impairment and self-rated health at baseline between the subjects who were tested three years later and those who dropped out of the study.

The negative binomial regression model (Afifi et al. 2007) was used to study the association between visual impairment and coexisting sensory deficits and falls. The negative binomial regression model takes into account that falls are non-independent observations, tend to be recurrent events and that one fall makes future falls more likely. The following five exclusive groups were formed on the basis of visual acuity, balance and hearing: 1) Participants with visual acuity of 1.0 or over (the reference group), 2) Impaired vision, but no other impairments, 3) Coexisting vision and balance impairment, 4) Coexisting vision and hearing impairment, 5) All three impairments (vision, hearing, balance). The strength of the association between sensory impairments and fall incidence was calculated with Incidence Rate Ratios (IRR). IRRs are interpreted as relative risk estimates. In addition, 95% confidence intervals were estimated. The modelling was performed using STATA statistical software.

Multivariate analyses with the Cox proportional hazards model (Cox 1984) were used to examine vision as a predictor of injurious accidents and mortality. When examining vision in relation to injurious accidents, the number of days from the baseline measurements to the first injurious accident was used as an outcome. In the study of visual acuity and mortality, the outcome was the number of days from the baseline measurements to the date of death. In order to assess differing mortality risk in the age and vision groups, we tested the significance of an interaction term involving vision and age in the Cox model. Scaled Schoenfeld residuals were used to test the proportionality of hazards using the method developed by Grambsch and Therneau (1994). Plots of these residuals against the untransformed time variable and using rank of time were used to gain insight into potential outlying observations. Because the interaction term of visual impairment with age was statistically significant (p=0.030), the 75- and 80-year-old persons were analyzed separately. The mortality analyses were continued in order to find factors on the pathway from poor vision to mortality. Diabetes, cardiovascular diseases, body mass index (BMI), physical activity, walking speed, depressed mood and injurious accidents were added to the base model one at a time. As the event dates for injurious accidents were known, they were added into the Cox regression model as a time-dependent covariate. In constructing the time-dependent variable, we assumed that the effect of an injurious accident would last for six months. The participant was counted in the category of having an injurious accident from the date of the accident until 180 days later. After six months, unless another accident had occurred, the participant was recategorized as having no injurious accident until another accident occurred or until the end of the follow-up. The relationship between VA and each potential factor on the pathway was tested with one-way analysis of variance for continuous variables. For categorical variables cross-tabulation with chi-square tests was used. The association of each potential factor on the pathway with mortality was studied with independent samples t-test for continuous variables and cross-tabulation analysis with chi-square tests for categorical variables. When the variable was significantly related to both VA and mortality and attenuated their association, it was considered to be a factor on the pathway from poor vision to mortality. The relative contribution of a potential factor on the pathway was estimated by first computing the hazard ratio (HR) for the vision terms in the model unadjusted for the factor on the pathway ($Risk_{baseline}=HR_{baseline}-1$), and then by calculating the hazard ratio for the vision terms in the model adjusted for a factor on the pathway ($Risk_{adjusted}=HR_{adjusted}-1$). The relative contribution of the factor was then calculated using the expression: $[(Risk_{baseline}-Risk_{adjusted})/ Risk_{baseline}] \times 100\%$. These analyses were carried out using SPSS and STATA statistical software.

6 RESULTS

6.1 Characteristics of the participants

Table 5 summarizes the baseline characteristics of the participants in the Evergreen and FITSA studies.

TABLE 5 Baseline characteristics of participants in the Evergreen and FITSA data sets.

	Evergreen 75-year-old cohort, n=223	**Evergreen** 80-year-old cohort, n=193	**FITSA** n=343
Characteristics	Mean±SD	Mean±SD	Mean±SD
Age (years)	75	80	68.6±3.4
Chronic diseases (number)	2.1±1.5	2.9±1.6	2.0±1.5
Medication (number)	3.6±2.7	4.0±2.7	2.0±2.2
Education (years)	6.0±3.0	5.8±3.5	8.6±3.1
	%	%	%
Women	64	71	100
Cataract	24	36	19
Glaucoma	9	9	6
AMD*	4	11	4
VA** < 1.0	88	71	45
VA < 0.5	40	23	11
VA < 0.3	21	9	6

*Age-related macula degeneration
** Visual acuity

The FITSA participants (Studies I and III) were younger than the Evergreen participants (Studies II and IV), had fewer chronic diseases and prescribed medications. They were also more educated than the Evergreen participants. In addition, visual acuity among the FITSA participants was better than among the

Evergreen participants. The FITSA participants consisted only of women, whereas the Evergreen study included both men and women.

6.2 Visual acuity of the participants

Mean visual acuity in the FITSA study group was 0.9±0.3. A total of 191 persons (44%) had a VA below 1.0. The proportion of those with visual acuity of less than 0.5 was 11% (47 persons). Vision impaired subjects (VA< 1.0) were somewhat older than persons with good vision (69.1 vs. 68.1, p=0.001), and had a lower MMSE score (mean 26.7 vs. 27.2, p=0.003) than people with good vision. In addition, the prevalence of impaired balance was higher among vision impaired persons compared to those with good vision, although the difference was of borderline statistical significance (p=0.053). There were no significant differences in the prevalence of chronic diseases, prescribed medications, body mass index or prevalence of hearing impairment between the VA groups.

In the Evergreen study (75- and 80-year-olds combined), the mean value of VA was 0.6±0.3. Men had a visual acuity of 0.7 (SD±0.3) and women a visual acuity of 0.6 (SD±0.3). Out of 416 persons, 65 subjects (16%) had visual impairment (VA lower than 0.3), 123 subjects (30%) lowered vision (VA ≥0.3 but ≤0.5) and 228 subjects (55%) normal visual acuity (>0.5). Table 6 shows the baseline comparisons between the visual acuity groups in the 75- and 80-year-old Evergreen study populations.

TABLE 6 Baseline characteristics in relation to vision in the Evergreen study. Percentages and statistical significance between the vision groups (chi-square test).

Characteristics	NV	Vision LV	VI	p-value
75-year-old persons	n=101	n=75	n=47	
		%		
Female (n=143)	59	68	68	0.409
Diabetes (n=15)	5	9	6	0.515
Cardiovascular disease (n=132)	49	69	66	0.012
Physical activity				
Low*	14	25	38	
Moderate†	76	71	60	
High‡	10	4	2	0.011
Depression§ (n=68)	22	45	29	0.006
		Mean±SD		
Walking speed (m/s)	1.7±0.4	1.6±0.4	1.4±0.5	<0.001#
BMI (kg/m²)	26.8±4.1	27.4±5.3	27.4±4.2	0.618#
80-year-old persons	n=127	n=48	n=18	
		%		
Female (n=137)	66	77	89	0.078
Diabetes (n=26)	9	21	22	0.075
Cardiovascular disease (n=128)	63	75	67	0.325
Physical activity				
Low*	29	50	22	
Moderate†	67	50	78	
High‡	4	0	0	0.052
Depression§	44	43	29	0.540
		Mean±SD		
Walking speed (m/s)	1.4±0.4	1.2±0.4	1.3±0.2	0.010#
BMI (kg/m²)	26.4±4.2	26.3±3.6	27.0±3.5	0.790#

* Moderate physical activity less than 4 hours per week
† Moderate physical activity ≥ 4 hours per week
‡ Intensive physical exercise more than 3 hours per week or competitive sports
§ Depressive symptoms were measured using the Center for Epidemiologic Studies Depression Scale (CES-D); a total score of 16 or over was defined as depression.
# statistical significance calculated with one-way ANOVA
Note: NV = normal vision; LV = lowered vision; VI = visual impairment

6.3 Vision, lower extremity function and balance (Study I)

Among relatively healthy women aged 63-76 years, balance and lower extremity impairment were associated with visual impairment. Maximal isometric knee extension strength was significantly lower among participants with visual impairment (273.2±SE 6.4N) compared to those with good vision (306.5±5.9N, adjusted Wald test, $p<0.001$) as well as leg extension power (95.2±2.7W vs. 104.2±2.6W, $p=0.009$) and maximal walking speed over 10 meters (1.6±0.02m/s vs. 1.8±0.03m/s, $p<0.001$). In addition, higher velocity moment in the balance test among persons with VI (53.5±2.7mm^2/s vs. 42.7±1.4mm^2/s, $p<0.001$) indicated that persons with visual impairment had poorer standing balance compared to persons with good vision.

In the logistic regression analyses, when only age and the interdependency between the twin sisters were taken into account, decreased isometric knee extension strength was associated with VI (OR per quintiles of distributions 1.28, 95% CI 1.10-1.47) as well as lower maximal walking speed (OR 1.37, 95% CI 1.17-1.61). Additionally, poorer standing balance (OR 1.18, 95% CI 1.02-1.37) and poorer leg extension power (OR 1.15, 95% CI 1.00-1.33) were related to VI. Adjustment for the confounders (socioeconomic status, diabetes, cardiovascular diseases, cognitive capacity) produced only little change to the estimates. Table 7 shows the adjusted associations between vision and balance impairment and lower extremity impairment.

TABLE 7 Association between balance and lower extremity impairment and vision. Odds Ratios per quintiles of distributions of the results of the balance and lower extremity impairment tests for visual impairment (Visual acuity < 1.0).

Variable	n	OR	95% CI	p-value
Isometric knee extension strength	404	1.26	1.09–1.45	0.002
Leg extension power	407	1.14	0.99–1.31	0.075
Maximal walking speed	404	1.34	1.13–1.59	0.001
Standing balance (velocity moment)	412	1.16	1.00–1.35	0.049

Analyses are adjusted for age, cognitive capacity, socioeconomic status, cardiovascular diseases, diabetes and interdependency between the twins.

A total of 138 (71%) of those who were visually impaired at the baseline participated in the three-year follow-up measurements. The corresponding number of persons with good vision at baseline was 175 (73%), indicating that the drop-out was not significantly different between the vision groups (p=0.688). However, when comparing those with follow-up measurements, participants without the follow-up measurements had somewhat poorer leg extension power (94.9±4.0W vs. 102.3±2.3W, p=0.100), maximal isometric knee extension strength (274.6±9.7 vs. 297.7±5.6, p=0.039) and higher velocity moment in the balance test at baseline (51.1±3.7 vs. 46.1±1.6, p=0.211), although only the differences in maximal isometric knee extension strength were statistically significant. Maximal walking speed at baseline did not differ between those with and without follow-up measurements (1.7±0.03 vs. 1.7±0.02, p=0.149). However, only 69% of persons who rated their health as very poor, poor or average at the baseline participated in the follow-up measurements compared to 80% of those who rated their health as good or excellent (p=0.031).

In the longitudinal analyses, only minor changes were found between the vision groups in balance and lower extremity function over the three-year follow-up period. The subjects with visual impairment showed a greater decline in leg extension power than those with good vision, but a statistically significant group-by-time interaction was not found (p=0.121). However, isometric knee extension strength declined somewhat more among persons with good vision at baseline compared to those with visual impairment (p=0.030). Persons with good vision showed a slight improvement in maximal walking speed over the three years, whereas among those with visual impairment no change was observed (p=0.963). Change in standing balance over time did not differ between the vision groups (p=0.991). The results of the longitudinal analyses are shown in Figure 3.

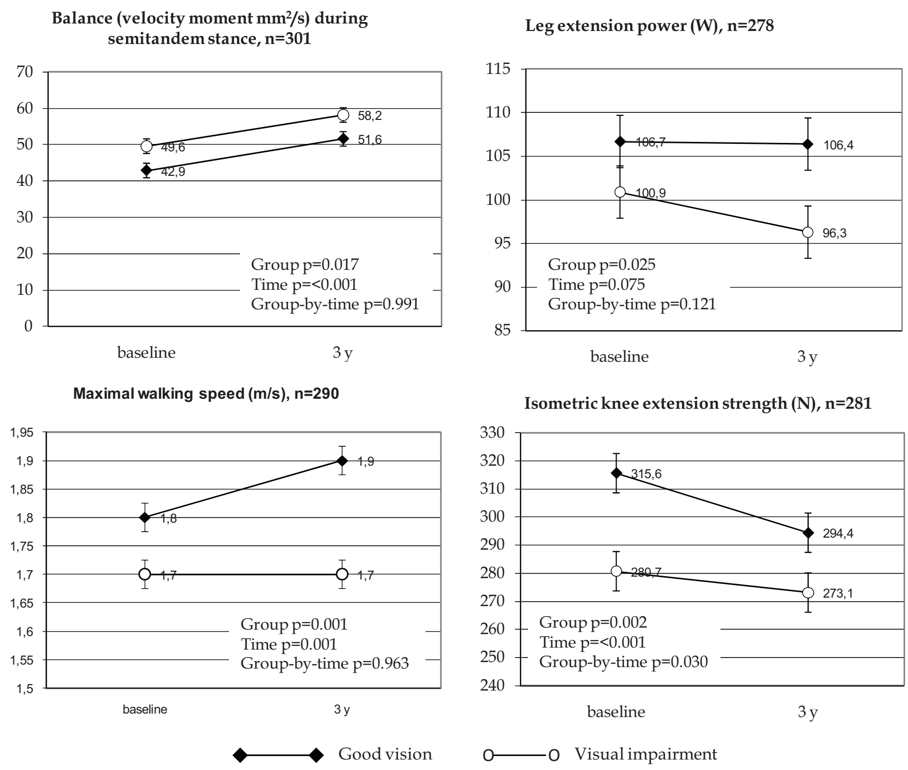


FIGURE 3 Mean values and standard errors of balance and lower extremity functions among persons with and without visual impairment at baseline and three-year follow-up in FITSA study. The p-values are for group, time and group-by-time interaction (tested with ANOVA for repeated measures).

6.4 Vision and disability

Previously unpublished data

Among the 63-76-year-old women in the FITSA study (n=434), 56% (108 persons) in the visually impaired group had IADL disability (difficulties in at least one task). The corresponding number among the participants with normal vision was 43% (102 persons). The difference was statistically significant (Adjusted Wald test p=0.005). Figure 4 shows the percentage differences in IADL disability in each task between persons with and those without visual impairment.

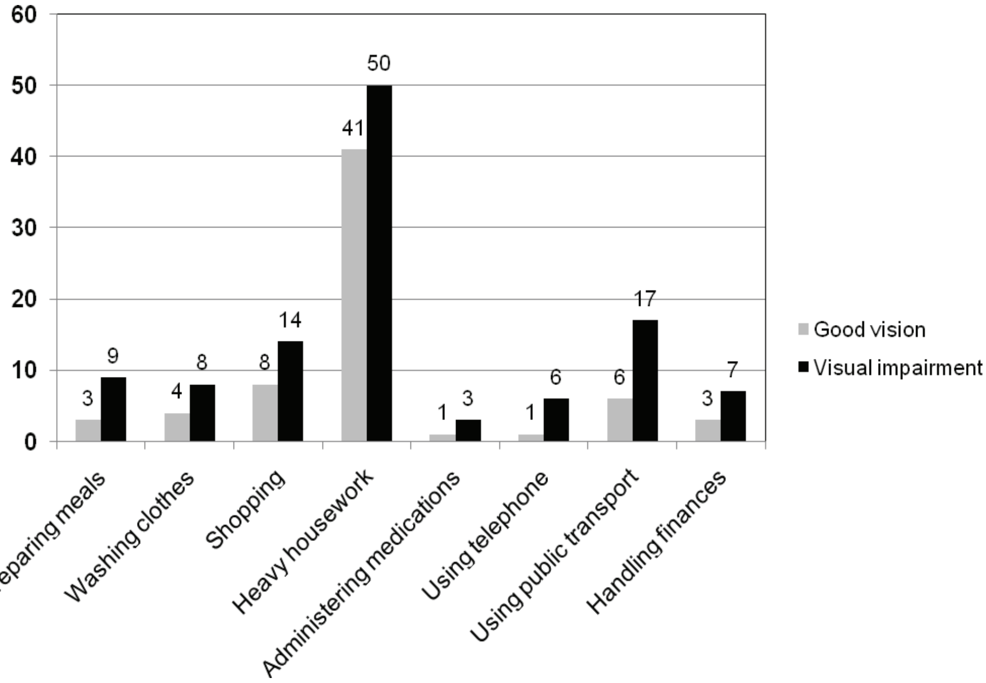


FIGURE 4 Percentages of persons with disability in IADL tasks among 63-76-year-old women with or without visual impairment.

The mean score in IADL disability was 0.95 (SD 1.23) among the visually impaired participants compared to 0.60 (SD 0.86) among persons with good vision (p=0.001). When tested with logistic regression, taking into account the interdependency between the twins and adjusted for age, chronic diseases and prescribed medications, the IADL disability score was significantly associated with visual impairment (OR 1.33, 95% CI 1.10-1.62).

6.5 Visual acuity and co-impairments in relation to falls and injurious accidents (Studies II and III)

Visual impairment as a predictor of injurious accidents (Study II)
During the 10-year follow-up, 239 (58%) persons aged 75 and 80 years at baseline sustained at least one injurious accident. Of these, 203 were falls, 13 were traffic accidents, 19 were other injurious accidents and in 4 cases the type of accident was unknown. The mean time to the first injurious accident was 1961 days (~5 years). The accident rate per 1000 person-years of follow-up was 79 among participants with normal vision, 115 among participants with lowered vision and 90 among participants with visual impairment. Table 8 presents the frequencies and incidence rates of injurious accidents according to visual acuity.

TABLE 8 Frequencies (f) and Incidence Rates, IR, (cases/1000 person years) of injurious accidents according to visual acuity and statistical significance between groups (chi-square test).

	Normal vision > 0.5 n=228		Lowered vision ≤ 0.5 but ≥ 0.3 n=123		Impairment < 0.3 n=65		
Injurious accidents	f	IR	f	IR	f	IR	p-value*
Falls	102	67	69	102	32	80	0.559
Traffic accidents	8	5	3	4	2	5	0.720
Other injurious accidents	11	7	6	9	2	5	0.760
All together	121	79	78	115	36	90	0.116

*chi-square test

Note: Evergreen project data; total of 416 persons aged 75 and 80 years at baseline.

The risk for injurious accidents in the multivariate model among participants with lowered vision was 1.45 (95% CI 1.08-1.94) compared to those with normal VA. Impaired vision did not predict injurious accidents. Of the confounding factors, only female gender was related to increased risk for injurious accidents, HR 2.14 (95% CI 1.56-2.93). Maximum walking speed over ten metres did not differ between those who subsequently sustained an injurious accident (0.75±0.31m/s) compared to those with no accidents (0.77±0.35m/s, p=0.561). Furthermore, physical activity level did not differ between persons with and without accidents. In the multivariate logistic regression model, neither of these variables had a material effect on the relationship between lowered vision and injurious accidents (Table 9).

We also examined separately the association between visual loss and falls and visual loss and traffic accidents. The associations were not statistically significant, but the relative risk for falls for those with lowered vision (HR 1.29, 95% CI 0.95-1.76) was quite similar to the risk for all accidents, indicating that the results of our analysis concerning all injurious accidents are mostly based on fall risks. Because of the small number of accidents other than falls, meaningful analyses were not possible for each category separately.

TABLE 9 Association between different levels of visual acuity and injurious accidents among persons aged 75 and 80 years at baseline. Cox regression models for risk for injurious accidents among those with lowered and impaired vision compared to those with normal vision (n=416).

Sequental adjustment	HR (95% CI) Lowered vision ≤ 0.5 but ≥ 0.3	p-value	HR (95% CI) Visual impairment < 0.3	p-value
Unadjusted	1.53 (1.15-2.03)	0.004	1.21 (0.84-1.74)	0.303
Adjusted for confounders*	1.45 (1.08-1.94)	0.013	1.20 (0.82-1.75)	0.342
+walking speed*	1.48 (1.10-1.99)	0.010	1.15 (0.78-1.70)	0.471
+physical activity*	1.49 (1.11-2.01)	0.008	1.19 (0.81-1.75)	0.374
for all†	1.47 (1.09-1.99)	0.011	1.14 (0.77-1.68)	0.519

* Adjusted for age, gender, diabetes, eye-related diseases and cardiovascular diseases.
† Adjusted for age, gender, diabetes, eye-related diseases, cardiovascular diseases, walking speed and physical activity
Note: HR = hazard ratio; CI = Confidence interval

The effect of co-impairments on fall-risk (Study III)

Altogether, 227 women aged 63-76-years at baseline reported no falls during the 1-year follow-up, while 201 participants (46% of the study population) reported a total of 440 falls within a mean follow-up time of 345±39 days. The mean incidence of falls was 8.9 falls per 100 person-months. There were no significant differences between fallers and non-fallers in age, MMSE score, prescription medications, chronic diseases, hearing impairment or balance impairment. BMI was somewhat higher among participants who experienced at least one fall compared to those who did not fall (28.6 kg/m^2 vs. 27.5 kg/m^2, p=0.022).

According to the standard definition of normal VA, the participants were categorized into those with visual impairment (VA < 1.0) and those with good vision (VA ≥ 1.0). In accordance with the European Union recommendations (Stephens 2001), a person was defined as having hearing impairment if the hearing threshold level of the better ear was ≥ 21 dB. According to the distribution of values in the balance test, participants were categorized into three equal groups. The cut-off values for the tertiles were 32.9 mm^2/s and 50.2 mm^2/s (range 10.0 mm^2/s - 263.5 mm^2/s). Nine persons were incapable of performing the test and were included in the poorest tertile. Participants in the poorest tertile were classified as having balance impairment. Altogether, 75 (18%) participants had only vision impairment, 40 (9%) had co-existing vision and hearing impairment, 42 (10%) had co-existing vision and balance impairment and 34 (8%) participants had all three impairments. Figure 5 shows that the proportion of fallers in general, and in particular recurrent fallers, was higher among participants with coexisting vision, hearing and balance impairments than in the other groups.

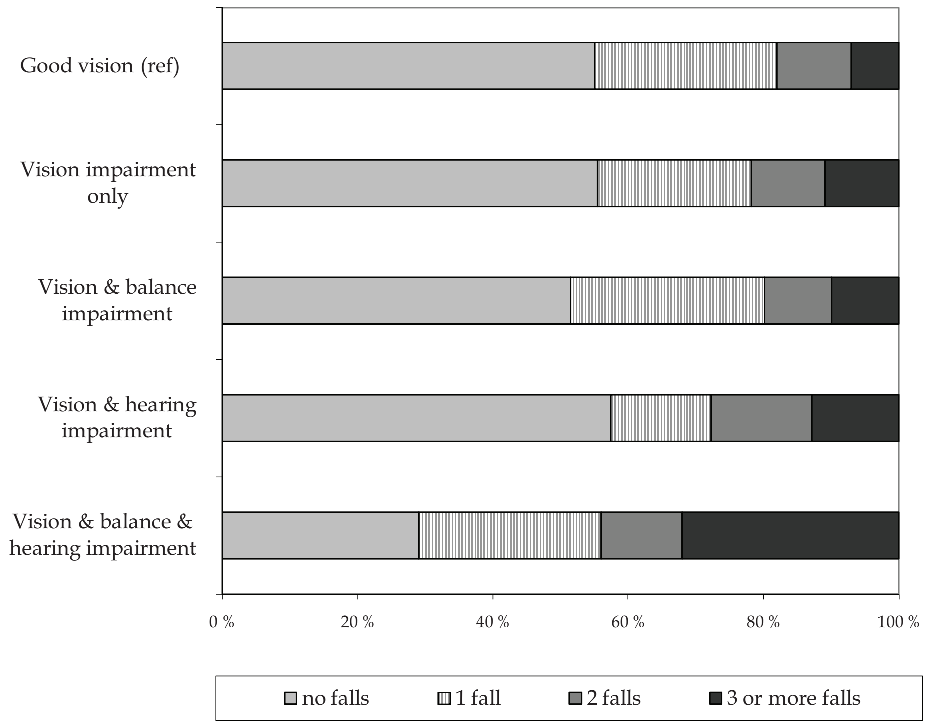


FIGURE 5 Percentages of persons with 0, 1, 2 and recurrent falls in groups formed on the basis of VA, balance and hearing ability in FITSA study.

Table 10 shows the results of the negative binomial regression modelling. The model, adjusted for age and interdependency between the twin sisters, showed that participants with vision impairment, but no other sensory impairments had a slight, but not significantly, increased risk for falls compared to persons with good visual acuity. However, participants who had vision impairment and the poorest standing balance had 2.7 times higher risk for falls during the one-year follow-up, although the increased risk was of only borderline statistical significance. Subjects with coexisting vision and hearing impairment had 4.2 times the risk for a fall, and those with co-existing vision, hearing and balance impairment had a further increased risk for falls of 29.4 (95% CI 5.8-148.3).

TABLE 10 Risk for falls in one year follow-up among persons with vision loss and coexisting sensory impairments compared to persons with good vision.

Variable	Participants at baseline	Falls during the follow-up	IRR*	95% CI	p-value
Normal vision	237	201	1		
Visual impairment (VI)	75	63	1.5	0.6-4.2	0.39
VI + balance impairment	42	34	2.7	0.9-8.0	0.073
VI + hearing impairment	40	65	4.2	1.5-11.3	0.006
VI + balance + hearing impairment	34	77	29.4	5.8-148.3	< 0.001

All analyses are adjusted for age and interdependency between the twins.
* Incidence rate ratio

6.6 Visual acuity and mortality and factors on the pathway (Study IV)

The analyses are based on the 10-year mortality follow-up of 223 participants aged 75 and 193 aged 80 in the Evergreen study. Over the 10-year follow-up 107 (48%) persons aged 75 years and 138 (72%) aged 80 years at the baseline died. The mean length of the follow-up until death or the end of the surveillance was 3172 (SD 1127) days among the 75-year-olds and 2654 (SD 1248) days among the 80-year-olds. The mortality rate per 1000 person-years was 70 among the 75-year-old men and 47 among the 75-year-old women. The mortality rates for the 80-year-old men and women were 101 and 81, respectively. Among the 75-year-olds, the follow-up mortality rate per 1000 person-years was 34 among participants with NV, 70 among participants with LV and 75 among participants with visual impairment. The corresponding numbers among the 80-year-olds were 83, 101 and 75.

The log-rank tests showed that among the 75-year-olds mortality differed significantly according to level of visual acuity (p=0.002). Participants with normal vision had lower mortality throughout the ten-year follow-up than those with LV or VI. Among persons aged 80 mortality did not differ according to visual acuity (p=0.433). Figure 6 shows the cumulative mortality in the different visual acuity groups in both age groups.

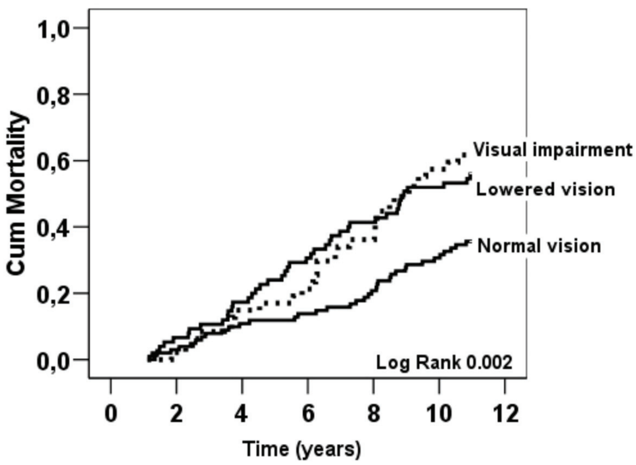
In the Cox regression model visual acuity did not predict mortality among the 80-year-olds. However, among the 75-year-old persons according to the base model (adjusted for gender and socioeconomic status), both LV and VI increased the risk for mortality almost two-fold in comparison with subjects having NV. We further investigated the possible effects of body mass index, diabetes, cardiovascular diseases, physical inactivity, walking speed, depressed mood and injurious accidents, because of their postulated association with mortality and visual loss among older people.

The analyses showed that in the 75-year-old people the presence of cardiovascular diseases, physical inactivity and lower walking speed correlated with both poorer vision and increased mortality. In addition, we found that the prevalence of depressed mood was higher among persons with LV and VI compared to those with NV. Among the 80-year-old persons higher prevalence of cardiovascular diseases, lower physical activity and lower walking speed were associated with mortality. Lower walking speed also correlated with poor vision.

Table 11 shows the association between vision and mortality after adjusting for gender and socioeconomic status. Each factor potentially on the pathway from poor vision to mortality was added to the base model one at the time. We found that among the 75-year-old persons a higher prevalence of cardiovascular diseases explained 28% of the association between LV and mortality and 19% of the association between VI and mortality. Lower physical activity explained 24% of the association between VI and mortality, but it did not attenuate the association between LV and mortality. Lower walking speed explained 22% of the association between higher mortality and VI, but it did not attenuate the association between LV and mortality. Depressed mood explained 17% of the association between VI and 13% of association between LV and higher mortality. Injurious accidents explained 9% and diabetes 8% of the association between VI and mortality, but they did not explain the association between LV and mortality. Body mass index did not attenuate the association between vision and poorer survival.

When the variable was significantly related to VA and mortality and attenuated their association in the multivariate model, it was considered to be a factor on the pathway from poor vision to mortality. Therefore based on these results, lower walking speed, physical inactivity and higher prevalence of cardiovascular diseases may be considered as factors on the pathway from poor vision to mortality among the 75-year-old persons. We also found that injurious accidents, diabetes and depressed mood each attenuated the increased risk markedly in the Cox regression models. However, in the final model, lowered vision remained a significant predictor of mortality among the 75-year-old participants, even after including all variables in the model.

A.



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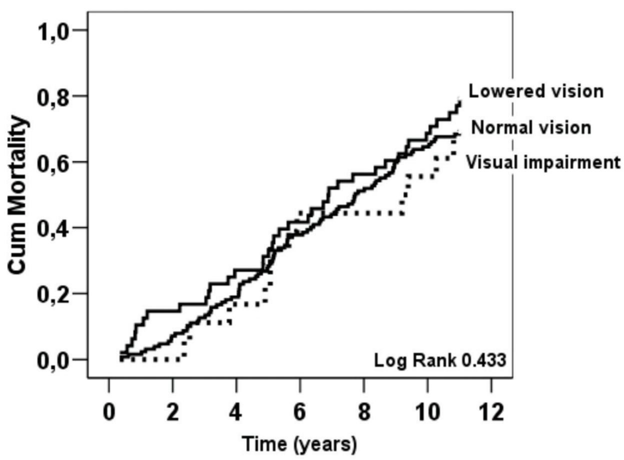

FIGURE 6 Cumulative mortality during the 10-year follow-up according to visual acuity among persons aged 75 (A) and 80 (B).

TABLE 11 Association between different levels of visual acuity and mortality among 75-year-old (n=223) and 80-year-old persons (n=193). Cox regression models for risk for death among those with lowered vision (LV) or visual impairment (VI) compared to participants with normal vision.

	75-year-old persons		80-year-old persons	
	LV	VI	LV	VI
	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)
Base model*	1.98 (1.25–3.13)	1.90 (1.12-3.20)	1.13 (0.74-1.72)	0.92 (0.47-1.78)
Base model adjusted for†				
Body mass index	2.06 (1.28–3.32)	2.00 (1.16–3.45)	1.15 (0.75–1.76)	0.96 (0.50–1.87)
Diabetes	2.02 (1.28–3.20)	1.83 (1.08–3.09)	1.11 (0.73–1.70)	0.87 (0.45–1.69)
Cardiovascular dis.	1.71 (1.07–2.72)	1.73 (1.07–2.72)	1.13 (0.74–1.72)	0.94 (0.48–1.83)
Walking speed	2.04 (1.28–3.24)	1.70 (1.00–2.92)	0.93 (0.60–1.46)	0.89 (0.46–1.72)
Physical activity	2.02 (1.27–3.22)	1.68 (0.97–2.91)	0.98 (0.64–1.51)	1.10 (0.56–2.16)
Depression‡	1.85 (1.15–2.98)	1.75 (1.02–3.00)	0.71 (0.70–1.70)	0.74 (0.34–1.62)
Injurious accidents§	1.99 (1.25–3.14)	1.82 (1.08–3.08)	1.05 (0.69–1.61)	0.93 (0.48–1.80)
All of above	2.11 (1.27–3.48)	1.34 (0.75–2.39)	0.77 (0.48–1.26)	0.75 (0.33–1.67)

* Adjusted for gender and socio-economic status.
† The base model was adjusted for possible factors on the pathway one at a time.
‡Depressive symptoms were measured using the Center for Epidemiologic Studies Depression Scale (CES-D)
§ Injurious accidents were added into the model as the time-dependent variable assuming that the effect of an injurious accident would last for six months.
Note: HR = Hazard Ratio; CI = Confidence Interval

7 DISCUSSION

The aim of this study was to investigate whether reduced visual acuity in old age is associated with balance and lower extremity impairments, functional limitations, disability and disability-related outcomes i.e. falls and mortality. Additionally, the effect of co-existing sensory deficits in relation to falling incidence was studied. Three population-based datasets were used in this study. The present findings suggest that visual impairment has a profound effect on multiple health outcomes, functional limitations and disability. Further, the results showed that the burden of co-existing sensory impairments seems to be greater than the sum of the single impairments involved.

7.1 Prevalence of visual impairment in study populations

Among the 63 to 76-year-old women the prevalence of visual impairment (VA < 0.3) was marginal, only 6%. However, even lower rates (0.6-3%) of VI have been reported in a comparable community-dwelling populations (Klaver et al. 1998, Munoz et al. 2000, van der Pols et al. 2000, Congdon et al. 2004). Typically, studies suggest that VI affects about 10% of people aged 65-75, and 20% of those aged 75 or older (Evans & Rowlands 2004). In this study, conducted among women aged 63-76, the proportion of persons with good visual acuity (VA ≥ 1.0) was 66%. This finding seems to be consistent with Iwano et al. (2004), who found that the prevalence of VA of 1.0 or better is about 70% in community-dwelling women aged 60-69 (Iwano et al. 2004). A previous study by Buch et al. (2001) found that the prevalence of best corrected visual acuity of 1.0 in persons aged 60-65 is almost 90%, but it declines significantly with age, falling to 40% in persons aged 75-80 (Buch et al. 2001). However, previous studies using this standard definition of good vision in relation to adverse health outcomes, especially among older people, are scarce. Therefore our results contribute knowledge on the role of slightly decreased visual acuity, which in many cases remains undetected, in relation to the progression of disablement process among older people.

Among the 75- and 80-year-old men and women, the prevalence of persons with VA of ≤ 0.5 was 46%. Although population-based studies on the prevalence of visual impairment are potentially limited in their generalizability, the prevalence rates found in this study seem to be consistent with those reported previously, where the prevalence of presenting visual acuity of less than 0.5 ranged from 4 to 35% in a 65- to 84-year-old community-dwelling older people (Munoz et al. 2000, Congdon et al. 2004). The prevalence of visual impairment (VA < 0.3) of 16 % in the present 75- and 80-year-old population was similar to that obtained in previous studies, where the prevalence has ranged between 4 and 26 % (Alemayehu et al. 1995, Munoz et al. 2000, Hyman et al. 2001, Lord & Dayhew 2001).

7.2 Consequences of decreased visual acuity for functional capacity

In this study, the effect of decreased visual acuity on functional capacity was studied in relatively healthy, 63-76-year-old community-dwelling women. The study revealed that decreased VA was associated with muscle impairments, poor balance and lower walking speed. Cross-sectionally each quintile reduction in maximal walking speed, lower extremity muscle strength and standing balance were associated with increased odds (1.14-1.34) of having VI. Cross-sectionally visual impairment was also associated with IADL disability among women aged 63-76. Visually impaired women reported more difficulties in every IADL task compared to older women with good visual acuity. However, in our study population, the subsequent changes in balance or lower extremity function over the three-year follow-up did not differ according to the presence of VI at baseline.

Adequate visual function has been recognized as an important factor for functional independence in adults aged 55 and older. Previous studies of older people have reported a strong association between VI and in self-reported functional status, especially in ADLs and IADLs (West et al. 1997, Keller et al. 1999, Reuben et al. 1999, Haymes et al. 2002, Laitinen et al. 2007) and self-reported mobility (Bibby et al. 2007, Laitinen et al. 2007). According to previous studies binocular visual acuity worse than 0.5 appears to have an impact on all the self-reported measures of functional status (West et al. 1997). Also self-report of visual impairment is associated with difficulties in ADLs and IADLs (Reuben et al. 1999), although it should be conceded that self-report is considered a less reliable indicator of visual impairment. Our findings are in line with previous studies, as the 63- to 76-year-old women with visual impairment in our sample reported more difficulties in every IADL task compared to those with good visual acuity. It should be noted that in the present study, visual acuity of < 1.0 was defined as visual impairment. Therefore our results show that a lower level of visual loss than reported previously is associated with functional limitations and disability in older people.

A few studies have investigated the cross-sectional association between vision and performance-based physical functions, such as balance, walking ability, the chair stand test and stair climbing among people aged 55 and above (Salive et al. 1994, West et al. 2002, Laitinen et al. 2007). These studies have shown a somewhat stronger association between poor vision and functional limitations than observed in the present study. However, our findings about vision and lower extremity impairment are not directly comparable with those of earlier studies because of the use of different indicators of functional capacity and a well-functioning study population.

The association between visual loss and lower extremity and balance impairments may have several explanations. It is possible that persons with poorer vision become physically inactive, which has been shown to result in loss of muscle strength (Rantanen et al. 1997, Rantanen et al. 1999). It is also known that poor vision causes deterioration in the control of standing balance due to lack of visual feedback about body posture (Brooke-Wavell et al. 2002). Similarly, slower walking speed among persons with difficulties in seeing is most likely a consequence of uncertainty about the environment. It is also possible that vision and lower extremity impairments develop at the same time while the processes underlying them are independent, or they may share common risk factors or both may be biologic aging markers. Common background factors, such as diseases, may explain the association between poor vision and lower extremity impairment. For example, it is known that diabetes is associated with gait abnormalities, such as lower walking speed (Allet et al. 2008) as well as visual deficits. However, in the present study we do not know the time of onset of visual loss or of the decrease in balance or lower extremity function and therefore causal interpretations cannot be made; even if known, the possibility of common underlying factors cannot be ruled out.

In older adults, deterioration of normal vision is caused by normal age-related physiological as well as pathological changes (Elliott et al. 1995, McKendrick et al. 2007). It is possible that poor vision is one marker of frailty in old age. Frailty refers to decline in multiple physiological systems causing increased risk of falls, morbidity and hospitalization (Fried et al. 2001, Lang et al. 2009). The standardized definition of frailty in community-dwelling older adults, introduced by Fried et al. (2001), includes the presence of three or more of the following: unintentional weight loss (4-5 kg in past year), self-reported exhaustion, weakness (muscle strength), slow walking speed and low physical activity level (Fried et al. 2001). The present results showed that visual impairment correlated with poorer muscle strength and slower walking speed. Poor vision was also associated with increased risk of injurious accidents and falls as well as higher mortality, which are considered as consequences of frailty (Lang et al. 2009). Therefore visual impairment should be included in frailty assessment. This is suggested also by Klein et al. (2003), who found that decreased vision correlates strongly with standard measures of frailty, such as slower walking speed and the lowest quartile of handgrip strength among persons aged 43-86 (Klein et al. 2003).

In the three-year follow-up, changes in balance or lower extremity function did not differ between the groups formed according to baseline visual impairment. Vision has previously been reported to be a predictor of, in particular, self-reported functional decline among older persons (Rudberg et al. 1993, Reuben et al. 1999, Lin et al. 2004). On the basis of our prospective analyses we would not rule out that visual impairment plays an important role in the development of lower extremity impairment, as our follow-up period was relatively short and only a few persons in our study population had severe visual impairment. Our cross-sectional results and previous studies on the association between vision and incidence of falls (Lord & Dayhew 2001) and perceived difficulties in functional capacity (Rudberg et al. 1993, Reuben et al. 1999, Lin et al. 2004) indicate that visual acuity as a predictor of adverse health outcomes and functional decline cannot be ignored.

7.3 Vision and co-existing sensory impairments in relation to falls and injurious accidents

In the high-functioning 63- to 76-year-old women, a little less than half of the subjects reported at least one fall during the one-year follow-up. Falling incidence in this study is in line with earlier findings among community-dwelling older women (Tinetti et al. 1988, Talbot et al. 2005). On average 6% of the population aged 75- and 80-years at baseline had an injurious accident that needed medical attention, per year. It has been reported earlier that about 5-11% of falls in old age lead to an injury, which requires medical care (Lilley et al. 1995, Kannus et al. 1999b). The results of this study agree with those estimates.

In this study lowered vision, i.e. visual acuity of ≥ 0.3 but ≤ 0.5, was predictive of injurious accidents during the 10-year follow-up among the 75- and 80-year-old persons. Visual acuity below 0.3 did not predict accidents in this study population. The results of these analyses suggest that moderate loss of visual acuity is one of the risk factors predicting injurious accidents among community-dwelling older people. Also among the healthy women aged 63-76-years at baseline, visual acuity below 1.0 slightly increased the risk of falls during the one-year follow-up (IRR 1.5, 95% CI 0.6-4.2), although in this study population the risk was not statistically significant.

Several previous studies have reported that visual impairment is associated with falls and fractures (Ivers et al. 1998, Lord & Dayhew 2001, Ivers et al. 2003), but the definition of visual impairment has varied. The study by Ivers et al. (1998) suggested that visual acuity below 0.65 increases the risk for falls by two-fold (Ivers et al. 1998). Some other studies, in which visual impairment has usually been defined as 0.4 or lower, have reported that visual impairment is not associated with falls (Arfken et al. 1994, Cesari et al. 2002). These findings strengthen our results, which suggest that older people with minor visual loss are more likely to sustain an injurious accident than those with severe visual impairment or normal visual acuity. There might be several explanations for this finding, for example decreased mobility, fear of falling or other strategies adapted to compensate for visual loss among those with visual impairment. In an attempt to discover the mechanism underlying the association between lowered vision and injurious accidents, we examined the role of walking speed and physical activity because of their known linkage to vision and falls (Tromp et al. 2001, Bootsma-van der Wiel et al. 2003). However, in this study neither walking speed nor physical activity level had a mediating role in the association between visual loss and injurious accidents among the 75- and 80-year-old persons.

Previous studies have reported that severe visual loss is related to fear of falling (Arfken et al. 1994, Murphy et al. 2003). Fear of falling may increase fall risk (Hill et al. 1999, Friedman et al. 2002, Lajoie & Gallagher 2004), but on the other hand it may also lead to avoidance of certain activities and reduced social participation and therefore protect from injuries. The increased use of assistive devices in performing activities of daily living (Dahlin-Ivanoff & Sonn 2004) may also protect against injuries among those with severe visual impairment. However, among the 75- and 80-year-old persons in this study, 20% of those with normal VA, 28% with lowered vision and 25% with visual impairment used a walking aid (e.g. cane or walker) and the differences were not statistically significant.

Among women aged 63-76, poor vision increased the risk for falls particularly when it was accompanied with loss of hearing or balance and, even further, when accompanied with loss of both hearing and balance. We are not aware of other prospective studies on the effects of objectively measured coexisting sensory impairments on fall risk, although the predictive value of single sensory impairments as a risk factor for falls has been shown. Previously, Tinetti et al. (1995) found falling incidence to increase significantly along with the number of predisposing factors, such as slow timed chair stands, decreased arm strength, decreased vision and hearing and a high score for anxiety or depression (Tinetti et al. 1995c). In an earlier retrospective study among persons aged 70 or older, those with coexisting self-reported vision and hearing impairment were 3.0 times more likely to have fallen during the previous 12 months than persons without vision or hearing problems (Crews & Campbell 2004).

It is known that vision plays an important role in balance control. Previous studies have shown that when people with normal vision stand with their eyes closed, postural sway increases markedly, indicating difficulty in balance control in the absence of visual feedback (Brooke-Wavell et al. 2002). In addition, people with vision impairment have impaired functional balance more often than those with better vision (Lee & Scudds 2003). However, in addition to vision, the ability to maintain an upright position depends on the interaction of multiple physiological systems, including the vestibular system and proprioception. These balance control systems send signals to the central nervous system about head and body movements. The complex structure of sensory input involved in maintaining an upright position and the interaction between vision and other sensory systems makes it possible for people with only one sensory impairment to compensate for the lack of information from that channel by using other sensory information available. This is supported by previous studies among people with blindness or deafness, where changes have been observed in the processing of information by the remaining sensory modalities (Proksch & Bavelier 2002, Dye et al. 2007). Therefore in the presence of co-existing sensory loss, the lack of compensatory information about body posture and the environment from other sensory sources may predispose older people to functional limitations and falls.

In the present study, the processes that lead to loss of function in multiple sensory modalities remain unresolved. First of all, poor vision may cause deterioration in the control of standing balance due to lack of visual feedback about body posture (Brooke-Wavell et al. 2002). Hearing impairment may also be causally linked to poor postural control through lack of acoustic information about the environment or through its correlation with vestibular function (Gerson et al. 1989). It is also possible that vision and hearing impairments may develop at the same time, but the mechanisms underlying them are independent, or they may share common risk factors. The latter is suggested by an earlier study where older persons with vision impairment were likely to have hearing impairment as well (Chia et al. 2006).

Falling in older people is a multifactorial phenomenon which is caused by intrinsic (person-related) or extrinsic (environmental) factors or the interaction of both (Tinetti et al. 1995b). Often, older persons have multiple risk factors predisposing them to falls. Observational fall-risk studies have underlined the importance of regular ophthalmic examination and timely treatment for eye diseases, as visual loss in older people is frequently correctable. In addition, audiometric screening followed by appropriate treatment and rehabilitation could help prevent falls. Earlier, interventions aiming at improve balance have been found effective in preventing falls in older persons (Sihvonen et al. 2004b, Madureira et al. 2007). While these studies have not specifically comprised individuals with vision and hearing impairment, it is conceivable that training focused on improving awareness of postural control could be useful for them as well in terms of fall prevention. Also functional limitations have been reported as mediators between vision and falls in older people (de Boer et al. 2004). Therefore interventions targeted at improving functional capacity may have the potential to prevent falls and other injuries, also in the case of older adults with visual loss. In addition, the study by Campbell et al. (2005) reported that a home safety program, which identified hazards which could lead to falls, reduced falls in older people with visual impairment (Campbell et al. 2005). The results of an earlier study on the present data underline the value of such interventions as it was shown that the majority of injurious falls among the 75- and 80-year-old people took place indoors (Saari et al. 2007). Therefore it is important to pay attention to ensuring a safe home environment. Furthermore, attention should also be paid to the prevention and treatment of diseases, such as diabetes and cardiovascular diseases, which affect sensory systems negatively (Hausdorff et al. 2003, Menz et al. 2004). In the light of the fact that the injurious accidents which were included in our analyses needed medical examination (Study II), our results provide evidence that minor visual loss is associated with most severe falls and other serious injuries in older people. Therefore early intervention strategies may have potential in preventing these serious injuries in older people.

7.4 Visual acuity and mortality

The results of our analyses showed that visual loss predicted mortality among 75-year-old people. In addition, we found several factors which lie on the pathway connecting poorer vision with mortality. An association between visual loss and higher mortality has been found in previous studies (Klein et al. 1995, Reuben et al. 1999, Lee et al. 2002, Cacciatore et al. 2004, Freeman et al. 2005, Jacobs et al. 2005, Pedula et al. 2006), but the factors on the pathway identified in our study are new. Further, the interaction term involving vision and age in the Cox model showed that vision-related mortality risk differed according to age at the study baseline. Among persons aged 80 years at baseline, poor vision did not correlate with mortality.

The findings of the present study suggest that different processes may underlie the role of vision and deterioration in health at different ages. Some existing studies have produced findings in line with our observations. For example, in the study by Thiagarajan et al. (2005) visually impaired participants with a mean age of 81 years did not have increased risk for mortality after adjusting the model for a wide range of markers of frailty (Thiagarajan et al. 2005). Knudsen et al. (2006) found that visual acuity of 0.5 or lower decreased survival more in younger age group (persons aged 43-65) than among persons aged 65-84 (Knudtson et al. 2006). It has been suggested that the predictors of mortality may change over time (Ben-Ezra & Shmotkin 2006). In our study, visual acuity was measured either at the age of 75 or 80 years. Despite the overlap in mortality surveillance at ages 80-85, the situation is not necessarily comparable as the age of the baseline assessment differed. Previous studies have found that low vision becomes increasingly common after 80 years of age (Hirvelä & Laatikainen 1995, Buch et al. 2001). Therefore it is possible that among those who already have lowered vision or visual impairment at age 75, underlying serious systemic factors, such as disease processes, are causing the higher mortality. In this study, among the 75-year-old participants cardiovascular diseases were more prevalent among those with lowered vision or visual impairment. In comparison, among the participants aged 80 at baseline, the prevalence of diseases did not correlate with VA. In our analyses cardiovascular diseases explained almost the third of the increased mortality risk among the participants aged 75. Further, we found that among the 80-year-olds in our study, including those with normal vision, the mortality rate was very high. As low vision becomes more common with increasing age, with the decline accelerating around age 80, it is possible that vision correlates with health differently at different ages.

Although an association between visual loss and mortality has also been found in previous studies, only a few studies have differentiated between levels of visual loss and their association with mortality. In most analyses, severe visual impairment (VA 0.3 or lower) has been studied (Krumpaszky et al. 1999, Taylor et al. 2000, Lee et al. 2002, Thiagarajan et al. 2005). The results obtained by McCarty et al. (2001) are consistent with our results. They found that mortality risk was highest among those with visual acuity between 0.5 and 0.3; however, the participants ranged widely in age (McCarty et al. 2001).

To discover the factors behind the association between lower vision and mortality, we examined the role of BMI, diabetes, cardiovascular diseases, walking speed, physical inactivity, depressed mood and injurious accidents because of their known correlation with poor vision and survival. We found that lower walking speed, physical inactivity, and higher prevalence of cardiovascular diseases explained part of this association among those with either LV or VI. We also found that injurious accidents, diabetes and depressed mood each markedly attenuated the increased risk. In previous studies the factors explaining the association between vision and higher mortality have not been widely studied. Freeman et al. (2005) investigated the mediating effect of depression behind the association between visual impairment and mortality, but in their study depression did not explain the increased risk for death among participants with visual loss (Freeman et al. 2005). Thiagarajan et al. (2005) reported that after adjusting for depression, body mass index, number of falls and physical activity, the association between vision and higher mortality was markedly attenuated. They did not, however, investigate the extent to which each variable separately attenuated this association (Thiagarajan et al. 2005).

In all likelihood there are also other intervening factors behind the association between loss of vision and poorer survival than those studied here. Because we measured visual acuity with the participants wearing their own spectacles, best corrected VA could in some cases have been better than the values obtained in this study. The use of health care services may therefore also be one factor on the pathway from poor vision to mortality in our study population. It is possible that persons with inappropriate correction of refractive errors do not seek the care they may need for other health issues either and therefore their risk for mortality is increased. Lowered vision, due to inappropriate correction of refractive errors, may lead to several other difficulties in daily activities, which increase the risk for death. A previous study by Lupsakko et al. (2003) reported that deterioration in cognitive function was strongly associated with the lack of eye examination for visual impairment among persons aged 75 and over (Lupsakko et al. 2003). Therefore cognitive capacity or dementia could also explain some of the association between visual loss and mortality.

Changes in vision could for example be a marker of physiological or biological age. A biomarker of aging, which is a biological parameter of an organism, will predict functional capacity in old age better than chronological age (Baker & Sprott 1988). In older adults, deterioration of normal vision is caused by normal age-related physiologic as well as pathologic changes (Elliott et al. 1995, McKendrick et al. 2007). It has also been suggested that age-related cataract, which in some cases may have caused vision loss, may be one of the diseases that is due to common biological processes such as oxidative stress and therefore correlates with high mortality (Thiagarajan et al. 2005). As discussed earlier, it is possible that poor vision is one marker of frailty in old age. In our analyses, lower walking speed, one marker of frailty, explained part of the association between poor vision and mortality. In this study, the major part of the association between poor vision and higher mortality in 75-year-old community-dwelling persons remained unclear. This indicates that the relationship between visual loss and mortality could be direct. This is also suggested by Freeman et al. (2005), who reported that persons aged 65 and older who gained in visual acuity (owing to cataract surgery or proper correction of refractive errors) over a 2-year follow-up period had a lower risk for death compared to those whose acuity worsened or did not change (Freeman et al. 2005).

Visual acuity is most likely associated with higher mortality via numerous pathways. Visual loss may be a marker of other underlying serious systemic factors or the aging process. Factors on the pathway from poor vision to higher mortality may also be behavioural or economic, for example inadequate use of health care services. It is important to be aware of even slight vision problems and pay more attention to early signs progressive onset of disability in old age. If being one marker of frailty, decline in visual acuity may also be one indicator of general functional decline in older adults. Therefore screening for vision problems should be taken into consideration in order to prevent functional decline in multiple domains in old age.

7.5 Methodological considerations

This study is based on two prospective observational studies with follow-up periods of up to 10 years. The major concern in population studies is nonparticipation, which may cause nonresponse bias. Participants in the Evergreen project, all the people born in 1910 and 1914, were recruited using the population register database. This kind of selection method reduces selection bias due to socioeconomic background or health. However, it should be noted that complete data on visual acuity were available for only 61% of the Evergreen study target population. Although statistically significant differences were not found between persons with and without visual acuity measurement (as shown in the Methods section), it is still possible that people with poorer health dropped out of the study. This may have resulted in underestimation of the effect of visual impairment at the population level.

The FITSA data is equally population-based and thus representative of older women aged 63-76-years of age. However, the FITSA data consisted of older women only and the age range was quite narrow. Some previous studies have reported higher prevalence of visual impairment among women (Congdon et al. 2004), while other studies, including our results from the Evergreen study, have found no differences between the sexes (Munoz et al. 2000). It is also known that women are more prone to falls. In the FITSA study, the requirement that both individuals of the twin pair had to participate may also have resulted in the exclusion of persons with poorer vision or functional capacity. It is also likely that 63- to 76-year-old women, whose lower extremity function or balance ability declined during the three-year follow-up, dropped out of the study. Therefore, selective drop-out may have resulted in the unexpected lack of differences between the vision groups in the longitudinal analyses. In addition, a three-year follow-up is considered a relatively short time for changes related to aging to take place. Therefore additional prospective studies with more heterogeneous study populations and longer follow-up periods for functional capacity are warranted in order to fully explore the relationship between visual impairment and functional performance in old age.

The measurement used in the present study to evaluate visual acuity (Landolt rings) is widely accepted as the standard of reference in measuring distance visual acuity (Sloan et al. 1952). The International Council of Ophthalmology considers the Landolt ring the purest research standard and requires all other research approaches to be calibrated against the Landolt ring (International Council of Ophthalmology 1984). However, it should be noted that in the FITSA data, all participants with a VA of < 1.0, in accordance with standard definition of normal VA, were classified as having visual impairment. In this study the participants were relatively healthy, and the proportion of persons with severe vision impairment was very small. Therefore the present study may not capture the impact of more severe vision loss on falls or functional status. The results of the visual acuity measurements may also have been affected by purely coincidental factors (mood, tiredness). Moreover, visual acuity is not a static state. No data in either study were available about possible cataract surgery or other eye-related events, which could have improved vision and consequently for example the level of physical activity and lower extremity function among women with visual impairment at baseline. Change in visual acuity during the follow-up may have also affected susceptibility to falls or mortality.

Valid and reliable measures of health and functional capacity were used in this study. All the measurements were conducted under standardized circumstances in the laboratory. Performance-based measures provide data that differ from data assessed by self-report. Self-reported data on functional capacity is affected, for example, by the person's expectations of his or her ability to perform the task and also of the person's understanding of the task difficulty. Performance-based measurements require the test to be conducted in a proper and acceptable way. In addition, persons with cognitive impairment may be able to perform a given task, yet when asked, report difficulties in performing the same task. Performance-based tests, which provide a continuous measure of function may also be more sensitive compared with categorical self-reported data (West et al. 2002). However, the performance-based tests of balance and lower extremity function used in this study only capture people able to do them, with the result that persons with severe functional limitation drop out of the study.

The three data sets used in this study include detailed 1-year follow-up data on falls and 10-year register-based follow-up data on injurious accidents. Compared to self-reported data on falls and accidents, which may be affected by memory bias, the results from the present study can be considered a rather realistic estimate of the effect of sensory deficits on falls in well-functioning older women in and injurious accidents in older population. Further, the binomial regression model, which was used in the fall-risk study (III), takes into consideration that fall events are nonindependent observations, in other words falls tend to be recurring events and the occurrence of a fall makes a subsequent fall more likely. With this approach, it is possible to enter the Poisson-distributed count variable for number of falls in the models. This method also allows for the analysis of incomplete data, that is inclusion of the relatively few women who withdrew before the end of the surveillance period. However, we did not separate indoor and outdoor falls or accidents, which may be caused by different risk factors. Also, the time of day when the fall or the accident occurred was not evaluated. Night-time falls may happen when distance glasses are removed, which means that a person may have been visually impaired at the time of the fall or accident, instead of having normal vision as classified in the analyses.

This study showed that poor visual acuity predicted mortality in the 75-year-old population. We also discovered several factors which explained the increase in mortality. Although our potential factors on the pathway attenuated the risk for mortality, it is unclear whether loss of vision precedes or follows the factors included in the model. The available data are not sufficient to identify the causal relationships, with the exception of injurious accidents. For example diabetes and cardiovascular diseases may have occurred earlier and therefore they may be factors leading to visual loss. On the other hand, visual loss may have preceded physical inactivity and depressed mood and therefore these factors could be mediators between visual loss and higher mortality. Ideally, the potential factors on the pathway from poor vision to mortality should be measured as events occurring after incident visual loss.

The disablement model by Nagi (1976) and Verbrugge and Jette (1994) is well suited to investigate the role of visual acuity on different aspects of functioning, disability and mortality. The model outlines the relationships between visual impairment and proximal (i.e. other impairments) as well as distal (disability) factors on this pathway. In the present study, we showed that visual impairment, which is often caused by pathology on an organ level, was connected with other impairments, such as balance and lower extremity deficits. Visual impairment also correlated with functional limitations (measured here as slower walking speed). Furthermore, poor vision was shown to be associated with IADL disability. In addition, visual impairment was a strong predictor of disability-related outcomes, such as falls and other injuries, which most likely accelerate the progression of the disablement process. Finally, visual impairment was associated with higher mortality independently and via numerous pathways. The disablement model framework enables the identification of older persons without disability, but who have functional limitations, and also persons without functional limitations, but who have, for example, visual impairment. This allows for appropriate interventions to be targeted to different points in this pathway (Guralnik & Ferrucci 2009).

The present study was observational and therefore it provides preliminary evidence about the role of visual impairment in relation to falls and the progression of the disablement process. These results can be used as hypotheses, which should be tested in experimental studies.

7.6 Future directions

Vision impairment is highly prevalent, but often remains undetected in the older population. Without screening and early detection, age-related vision loss can lead to multiple adverse health outcomes and functional disability. When aiming to prevent vision-related adverse health events, the first step is to identify older persons whose visual acuity has decreased. Health care practitioners must be aware of the importance of adequate vision and they should be able to identify persons with visual deficits. Older population should be screened to detect gradual and slow deterioration of vision. Simple screening, for example with eye charts, ought to be included as a part of older persons' routine physical examinations at their own homes as well as in primary care in health care centres. Similarly, in institutionalised care, health care practitioners should be aware of patients' sensory functions. In addition to visual acuity, attention should also be paid to other aspects of visual functioning, such as contrast sensitivity, visual field and poor depth perception, which correlate, in particular, with falls. Attention should be also paid to co-existing sensory impairments, since they further increase the risk for functional dependency.

When visual impairment is detected, primary care providers should refer older person for further ophthalmic evaluation. Visual deficits are often correctable and therefore proper correction of refractive errors and timely treatment for eye diseases is essential. In addition to proper correction of visual impairment, optometrists and ophthalmologists should pay attention to accurate guidance of eye care and the use of new spectacles. Attention should also be paid to prevention and good treatment of the underlying diseases, such as diabetes and cardiovascular diseases, which negatively affect the visual system. Additionally older persons' socioeconomic status should be evaluated, since it may act as a barrier to the purchase of new spectacles or seeking appropriate eye care.

Well-designed randomized controlled trials are needed to examine to what extent, for example, educating older persons and their families about vision problems and providing information about eye care and/or proper correction of refractive errors improve vision in old age. The effects of these interventions on adverse health events should then be investigated using functional capacity, falls or injuries and even death as an outcome. Although in previous literature recommendations for annual eye examinations have been given, empirical proof that eye examinations actually improve functional capacity or decrease fall-rates among older people is lacking. For example, Cumming et al. (2007) found that in frail older people, comprehensive vision and eye assessment, with appropriate treatment, resulted in a significant increase in both the rate and risk of falling (Cumming et al. 2007). However, contrary results have been reported by Sloan et al. (2005), who found that regular eye examinations reduced decline in vision and improved functional status, especially IADSs (Sloan et al. 2005b). Since the results from the previous studies are inconsistent, additional evidence is needed. Data that support the effectiveness of specific programs is essential to increase the targeting of resources to these services.

It is also possible that visual acuity cannot be corrected to the normal level, for example, due to diseases that have permanently affected vision negatively. However, there are very few randomised controlled studies on interventions aimed at preventing disability or falls among older persons whose visual acuity cannot be corrected. In a previous study, a home safety intervention appeared to be effective in reducing risk of falling among older people with visual impairment (Campbell et al. 2005). However, the effectiveness of other interventions aiming at disability prevention among older people with visual loss is uncertain. Interventions such as balance and strength training as well as optimising medication have been found effective in preventing falls in older persons (Madureira 2007, Gillespie et al. 2009). Studies of this kind should also be targeted to older persons with sensory loss, as interventions focused on improving awareness of postural control as well as improving mobility could be useful contribute to fall and disability prevention. Further work is required to establish this.

More research needs to be undertaken before the association between vision and the progression of the disablement process in old age is more clearly understood. In order to prevent disability in older people, effective treatment for chronic diseases and visual impairment should be delivered to those with these conditions. Better yet, effective strategies that prevent diseases and visual loss should be sought and implemented to delay or prevent the onset of visual impairment in older people. The most important target for preventing the onset of disability are older people with minor impairments and functional limitations, the main goal being to promote the functional independence of older persons. Because older people with visual impairment frequently experience numerous additional disabilities, which impede their independent functioning, a multi-disciplinary approach is needed in order to improve the quality of life and well-being of older people with sensory deficits.

8 MAIN FINDINGS AND CONCLUSIONS

The main findings and conclusions can be summarized as follows:

1. Visual impairment is associated with lower extremity impairment and poor balance among relatively healthy older women. It is possible that decreased visual acuity is a marker of underlying systemic factors or of the aging process, which lead to poorer functional capacity, or there may be shared background factors, which lead to decreased vision and lower extremity impairment.

2. Lowered visual acuity, in particular, is an independent risk factor for injurious accidents in older persons. Severe visual impairment, however, did not increase the risk. This may be due to decreased mobility, fear of falling or other strategies adopted to compensate for visual loss among those with visual impairment.

3. The impact of vision impairment on fall risk is higher when accompanied with other sensory and balance impairments. It is likely that the presence of other impairments prevents the reception of compensatory information about body posture and environment being received from other sensory sources.

4. A significant and independent relation exists between both lowered vision and visual impairment and mortality in 75-year-old persons. Further, higher prevalence of cardiovascular diseases, lower maximum walking speed, self-reported physical inactivity, depressed mood, diabetes and injurious accidents attenuated the risk estimates. However, visual acuity is most likely associated with higher mortality via numerous pathways. Visual loss may be a marker of other underlying serious systemic factors or of the aging process. Factors on the pathway from poor vision to higher mortality may also be behavioural or economic, for example inadequate use of health care services.

YHTEENVETO (FINNISH SUMMARY)

Heikentyneen näöntarkkuuden vaikutus toimintakykyyn, kaatumisiin ja kuolleisuuteen iäkkäillä henkilöillä

Normaalit näköjärjestelmän ikääntymismuutokset sekä monet silmä- ja yleissairaudet vaikuttavat ikääntyneen ihmisen näkökykyyn heikentävästi. Aikaisemmissa tutkimuksissa on todettu, että heikentynyt näkö vaikuttaa oleellisesti ikääntyneen henkilön itsenäiseen selviytymiseen. Heikentynyt näkö on usein yhteydessä myös yleiseen toimintakyvyn heikentymiseen sekä kaatumisiin, jotka edelleen lisäävät vaikeiden toiminnanvajavuuksien riskiä. Vaikka heikentyneen näön vaikutuksia esimerkiksi kaatumisiin jo tunnetaan, ovat tulokset aikaisemmista tutkimuksista ristiriitaisia. Lisäksi aikaisemmassa kirjallisuudessa on vain vähän tietoa siitä, miten heikentynyt näkö yhdessä heikentyneen kuulon tai tasapainon kanssa vaikuttaa ikääntyneiden ihmisten kaatumistapaturmiin. Myös tietoa heikentyneen näön merkityksestä ikääntyneiden toiminnanvajauksien syntyprosessissa tarvitaan lisää. Vaikka aiemmissa tutkimuksissa on todettu heikentyneen näön olevan yhteydessä jopa suurentuneeseen kuolleisuuteen iäkkäässä väestössä, ilmiötä selittäviä mekanismeja ei juurikaan ole tutkittu. Tämän tutkimuksen tarkoituksena oli selvittää heikentyneen näöntarkkuuden vaikutusta ikääntyneiden henkilöiden fyysiseen toimintakykyyn, kaatumisiin ja muihin vammoja aiheuttaneisiin tapaturmiin sekä kuolleisuuteen. Lisäksi tutkittiin, miten samanaikaiset useiden aistitoimintojen vajavuudet ennustavat kaatumisriskiä.

Tutkimuksen aineistona käytettiin kahta Jyväskylän yliopistossa aikaisemmin kerättyä Ikivihreät- ja FITSA – pitkittäisaineistoa. Näöntarkkuus mitattiin käyttämällä valaistua Landoltin C – taulua. FITSA aineisto sisälsi 428 toimintakyvyltään hyväkuntoisen 63–76-vuotiaan naisen laboratoriossa mitattuja fyysisen toimintakyvyn muuttujia, yhden vuoden kaatumisseurannan sekä kolmen vuoden seurantamittausaineiston fyysisen toimintakyvyn muuttujista. Kaksosaineistosta huolimatta FITSA tutkimuksen henkilöitä käsiteltiin tämän tutkimuksen analyyseissä yksilöinä. Ikivihreät -aineisto koostui alkumittauksissa 75- ja 80-vuotiaiden henkilöiden laboratoriomittauksista sekä 10 vuoden tapaturma- ja kuolleisuusseurannasta.

Tutkimuksen tulokset osoittavat, että ikääntyneiden heikentynyt näkö on yhteydessä moniin terveyden ja toimintakyvyn indikaattoreihin. Poikkileikkausasetelmassa 63-76-vuotiailla naisilla heikentynyt näkö oli yhteydessä heikentyneeseen alaraajojen voimaan sekä hidastuneeseen kävelynopeuteen. Heikkonäköisillä myös vartalon huojunta voimalevyllä suoritetussa tasapainotestissä oli normaalinäköisiä suurempaa, mikä kertoo heikkonäköisten normaalinäköisiä suuremmista vaikeuksista tasapainonhallinnassa. Poikkileikkausasetelman lisäksi tutkimuksessa pyrittiin selvittämään heikentyneen näön vaikutusta toimintakyvyn laskuun kolmen vuoden seurannassa. Kuitenkaan suhteellisen terveillä, fyysisesti hyväkuntoisilla naisilla heikentynyt näkö ei ennustanut

toimintakyvyn laskua. Tässä tutkimuksessa yhteyden puuttumista saattaa selittää se, että henkilöt, joilla toimintakyky laski merkittävästi seurannan aikana, jäivät pois seurantamittauksista. On myös mahdollista, että tällä aineistolla kolmen vuoden seuranta-aika on liian lyhyt tutkittaessa ikääntymisen vuoksi tapahtuvaa toimintakyvyn laskua.

Tutkimus osoitti myös sen, että heikentynyt näkö yhdessä heikentyneen kuulon ja tasapainon kanssa lisäsi merkittävästi kaatumisriskiä vuoden seurannassa toimintakyvyltään hyväkuntoisilla 63–76-vuotiailla naisilla. Myös niillä naisilla, joilla vain näkö oli heikentynyt, oli kaatumisriski normaalinäköisiä suurempi, tosin riski ei ollut tilastollisesti merkitsevä. Tutkimuksen perusteella näyttääkin siltä, että heikentyneen näön aiheuttamaa haittaa voidaan ainakin joiltakin osin kompensoida muiden jäljellä olevien aistien avulla. Mikäli taas aistitoiminnoissa on tapahtunut samanaikaista heikentymistä, nämä kompensointimenetelmät menetetään ja kaatumisriski lisääntyy voimakkaasti.

75- ja 80-vuotiailla henkilöillä heikentynyt näkö lisäsi hoitoa vaatineiden tapaturmien riskiä kymmenen vuoden seurannassa. Näyttääkin siltä, että näön merkitys erityisesti vakavien tapaturmien ehkäisyssä on tärkeä. Lisäksi 75-vuotiailla heikkonäköisillä kuolleisuus kymmenen vuoden seurannassa oli normaalinäköisiä merkittävästi suurempi. Suurentunutta kuolleisuusriskiä selittivät osittain heikentynyt kävelynopeus, fyysinen inaktiivisuus, sydän- ja verisuonisairaudet, diabetes, masennusoireet ja tapaturmat. Näillä tekijöillä ei kuitenkaan pystytty kokonaan selittämään heikentyneen näön ja suurentuneen kuolleisuusriskin välistä yhteyttä. Onkin mahdollista, että heikentynyt näkö iäkkäillä henkilöillä on merkki niin sanotusta hauraus-raihnaisuus –oireyhtymästä (engl. frailty), jolla tarkoitetaan useiden samanaikaisten elinjärjestelmien heikentymistä ilman, että taustalla olisi selvää diagnosoitua sairautta. Tätä olettamusta vahvistaa se, että tässä tutkimuksessa heikentyneen näön havaittiin olevan yhteydessä myös heikentyneeseen lihasvoimaan ja kävelynopeuteen, jotka on aikaisemmassa kirjallisuudessa havaittu hauraus-raihnaisuus –oireyhtymän tyypillisiksi piirteiksi. Lisäksi hauraus-raihnaisuus –oireyhtymään liittyy lisääntynyt kaatumis- ja kuolleisuusriski. Aistitoimintojen heikentyminen ei perinteisesti ole kuulunut osaksi hauraus-raihnaisuus –oireyhtymän määritelmää, mutta tämän tutkimuksen tulokset antavat aiheen tutkia asiaa tarkemmin. Toisaalta on myös hyvin todennäköistä, että heikentyneen näön ja kuolleisuuden välistä yhteyttä selittää ainakin osittain jokin muu kuin tässä tutkimuksessa huomioitu asia, esimerkiksi terveyspalveluiden käyttö.

Henkilöillä, jotka olivat alkumittauksissa 80-vuotiaita, heikentynyt näkö ei ollut yhteydessä suurentuneeseen kuolleisuusriskiin kymmenen vuoden seurannassa. Tätä saattaa selittää se, että heikkonäköisyys yleistyy huomattavasti yli 80-vuotiailla henkilöillä. Mikäli jo 75-vuoden iässä näkö on heikentynyt, taustalla saattaa olla sairauksia, jotka ovat ennenaikaisesti heikentäneet näköä ja jotka ovat myös yhteydessä suurentuneeseen kuolleisuusriskiin. Esimerkiksi sydän- ja verisuonisairauksia todettiin 75-vuotiailla heikkonäköisillä enemmän kuin niillä, joilla näkö oli säilynyt hyvänä. 80-vuotiaiden ikäryhmässä tällaista eroa ei löydetty. On lisäksi huomattava, että myös niillä 80-vuotiaille, joilla näkökyky oli säilynyt hyvänä, kuolleisuus kymmenen vuoden seurannassa oli hyvin suuri. Tämä viittaa siihen, että näin korkeassa iässä muut terveyden heikkenemisen osa-alueet tulevat näkökykyä merkittävimmiksi kuolleisuuden ennustajiksi.

Tämän tutkimuksen avulla saatiin uutta tietoa näkökyvyn vaikutuksesta toiminnanvajauksien syntymiseen iäkkäillä henkilöillä. Näkökyvyn heikkeneminen aiheuttaa monia terveydelle ja toimintakyvylle haitallisia seurauksia. Ikääntyneiden heikkonäköisyyteen tuleekin kiinnittää huomiota, jotta toiminnanvajauksien syntyprosessia voitaisiin hidastaa. Lisäksi näön sekä usean samanaikaisen aistitoiminnan heikentymiseen tulisi kiinnittää huomiota, kun pyritään vähentämään ikääntyneiden henkilöiden kaatumistapaturmia. Heikentynyt näkö on usein korjattavissa optimaalisilla silmälaseilla tai hoitotoimenpiteillä, joten säännölliset silmälääkäri- ja optikkokäynnit ovat ensisijaisen tärkeitä. Lisäksi kuulon ja tasapainon parantamiseen tähtäävät toimenpiteet voivat ennaltaehkäistä kaatumisia myös heikkonäköisillä ikääntyneillä.

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