Prismatic displacement effect of progressive multifocal glasses on fall risk in elderly people

Ashton Ellison

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Abstract

World Health Organization statistics show that falls are the second leading cause of unintentional injury-related deaths worldwide. Multifocal glasses (bifocals, trifocals, and progressive addition lenses (PALs)) increase the risk of a fall in elderly people but how they do so is unclear. To explain why glasses with a PAL increase the risk of a fall and whether this can be attributed to false projection, this study aimed to 1) map the prismatic displacement of a PAL, 2) test whether this displacement impaired the response to loss of balance, and 3) test whether PALs alter stability.

The reaction time and accuracy of healthy ≥75 year olds (n = 31 participants) were measured when grasping for a bar and touching a black line. These were positioned according to the maximum and minimum prismatic displacement effect through the PALs, mapped using a focimeter. Anterior posterior (AP) deviation was measured while standing on a balance platform. Participants performed each test twice, alternatively wearing their PALs and newly matched single vision (distance) glasses in random order.

Results showed that PALs have large areas of prismatic displacement, especially in the central visual axis. Reaction time was faster for PALs compared to single vision (distance) glasses (mean difference ± SEM, horizontal grab bar in centre -0.101 ± 0.050 s, P = 0.011, repeated measures analysis adjusted for order of glasses, days since participants updated their PALs and amount of prismatic displacement; horizontal black line 300 mm down from centre -0.080 ± 0.016 s, P = 0.007). There were no differences in the balance measures.

PALs have large areas of prismatic displacement, but did not alter stability. Older people appeared to adapt to the false projection of PALs in the central visual axis. This adaptation meant that swapping to new single vision glasses may have affected the visual-spatial stored information. This may lead to a fall, especially in unfamiliar surroundings.

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List of abbreviations

AAP	-	Adelaide activities profile
ADL	-	activities of daily living
AP	-	anterior posterior
ARMD	-	age related macular degeneration
CI	-	confidence interval
EQ	-	equilibrium score
FES-I	-	falls efficacy scale – international
IRR	-	incidence rate ratio
LED	-	light emitting diode
MMSE	-	mini mental state examination
O&M	-	orientation and mobility
OR	-	odds ratio
P	-	probability
PAL	-	progressive addition lens
QALY	-	quality adjusted life years
SD	-	standard deviation
SEM	-	standard error of the mean
UK	-	United Kingdom
VA	-	visual acuity
VSI	-	visual-spatial information

Chapter 1 – Preamble

Based on World Health Organization statistics falls are the second leading cause of accidental or unintentional injury-related deaths worldwide. 424,000 people die every year from falls which is second to road traffic accidents. A fall in an elderly person is sudden and the sequelae are lasting, potentially taking away independence and confidence. Many older people do have a fear of falling and there is good reason. A fall is an independent risk factor for long term care with 27% of fall related hospital admissions leading to this in the united kingdom (UK) [1]. Furthermore, falls in the elderly population are unfortunately common, for instance 57% of all injury-related hospitalisation in the UK were related to falls [1].

Multifocal glasses are a known contributor to falls in the elderly population [2]. Why and how multifocal glasses increase falls is not completely known. Given that 52% of elderly people wear multifocal glasses means that a large proportion of falls may be preventable [3]. Of particular interest to this project is the prismatic displacement effect multifocal glasses have on balance and correcting stability. Although, the prismatic displacement effect of multifocal glasses is alluded to as a potential cause for falls no one, as of yet, has tested this effect.

Multifocal glasses in the form of bifocals have been available since 1784 when Benjamin Franklin converted his distance and reading pair of glasses into one pair. He described the nuisance of changing glasses for long distance sight and then again for reading. He mentioned that these new pair of glasses allowed him to visualise what the French politicians were saying at the same time eat his meal [4].

Multifocal glasses are convenient for activities such as cooking, shopping and driving. However, when multifocal glasses are worn while negotiating steps, outdoor environments and around the home they increase the chance of having a fall. The VISIBLE trial showed that wearing single vision (distance) glasses outside compared to multifocal glasses was non-significant for number of falls (IRR, 0.92; 95% CI, 0.73 – 1.16) [5]. However, in more active

people the intervention reduced falls by 40% (IRR, 0.60; 95% CI, 0.42 – 0.87). Conversely, pre-planned sub-analysis for less active people the number of falls overall are insignificant but the intervention increased outdoor falls by 56% (IRR, 1.56; 95% CI, 1.11 – 2.19). Another problem is those who wear single vision glasses have more non-fall related injuries compared to multifocal glasses, 26% to 17% respectively (P=0.01) for lacerations, lifting or twisting injury, burn/scald, eye injury, collision, pedestrian injuries [5].

Given the current level of knowledge regarding multifocal glasses and falls, further investigation is needed in this field. Therefore, the specific null hypotheses to be tested in this study were that:

1. Map the subjective and objective prismatic displacement effect of a progressive addition lens (PAL).
2. Measure accuracy and reaction time when grabbing a bar and pushing a black line comparing PALs to single vision (distance) glasses.
3. Assess visual stability comparing PALs to single vision (distance) glasses.

Thirty one participants over the age of 75 and 10 volunteers helped answer the second/third and first aims, respectively. This involved using a modified Hess test and focimeter to answer the first aim, and the second and third aims were answered by a walking frame brake and foam pad switch set-up and BalanceMaster/In VISION system, respectively. The second aim's end point was reaction time and accuracy, which was inferred to affect the protective response for grabbing a handrail if a trip, slip, or loss of balance occurs. And the third aim's endpoint was AP angle sway. This will be explained in more detail in the methods section.

In chapter 2, the review of the current literature will cover an in-depth overview of falls – the visual aspect of falls – multifocal glasses and falls – as well as the current thinking about why multifocal glasses cause falls.

Chapter 2 – Introduction and literature review

2.1 Introduction to falls

About 4 million years ago in the plains of East Africa, humans became a bipedal species relying on a complex set of mechanisms to stay upright, and to adapt to external changes in the environment [6]. To balance on two lower limbs there needs to be a constant sensory feedback mechanism. Stimuli which are crucial for the upright posture include proprioception, the vestibular system, pressure sensors and vision. All of these senses are orchestrated at the cerebral hemispheres and cerebellum, and if there is a problem with this finely tuned system then a fall could occur.

A fall is defined by the World Health Organization as 'an event which results in a person coming to rest inadvertently on the ground, floor or other lower level'. The elderly population is the most at risk of having a fall resulting in a poor outcome, ranging from benign bruises and grazes, to more serious outcomes such as a fractured neck of femur or brain haemorrhages. Hip fractures from a fall are also associated with a poor outcome. Hip fractures are associated with a mortality rate of 7% to 10% at 30-days, 18% at 120 days and at 1 year a mortality rate of 26% to 32% [7-9]. Furthermore, in an elderly person who has significant cognitive dysfunction the mortality rate at 1 year can reach up to 56% for hip fractures [10]. Hip fractures are expensive to treat and manage, and create a huge economic and medical burden on New Zealand's health system. Even if a fall does not result in an injury, the resulting fear and anxiety of another one occurring can be debilitating. Furthermore, those that are anxious about falling are more likely to fall again [11].

The direct and indirect cost of falls is immense. In the UK, £647 million was spent on falls in 1999 [1], and the mean cost for each fall in the United States was $6,606 [12]. Compounding this problem is the increasing elderly population. The 'baby boom' was a spike in the birth rate at the end of WWII lasting from 1946 -1960. A major effect of this in New Zealand, is an increasingly aging population in the coming years, which can be seen in Figure 2.1 [13]. With an increase in elderly people and the rate of fall related health problems, this will stretch an already understaffed and under-resourced primary and secondary care health system [14, 15]. Prevention is imperative to reduce the total cost of falls on New Zealand's health system and increase the independence of our aging population.

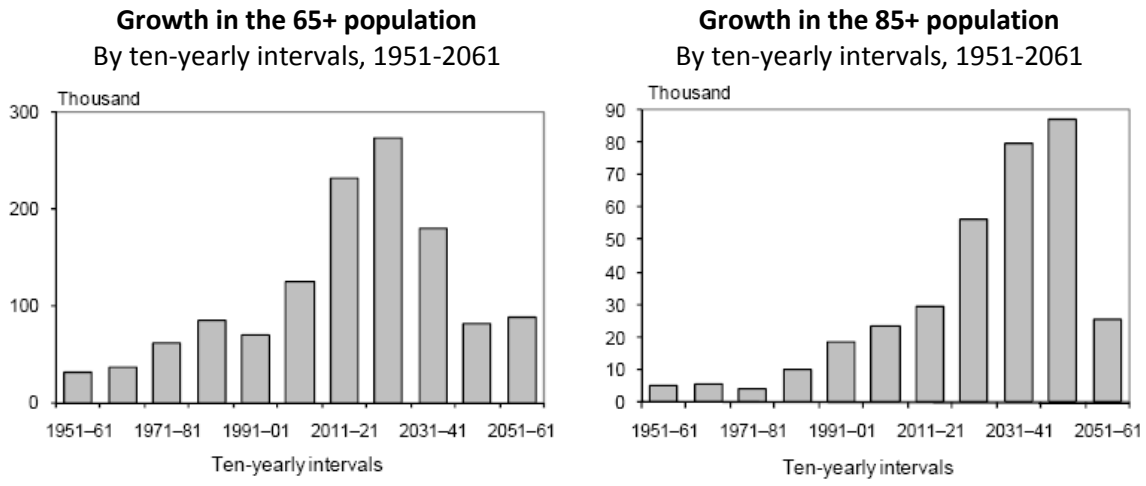


Figure 2.1. Forecasts of the population distribution for 65+ and 85+ year olds, in ten-yearly intervals [13].

2.2 Risk factors for falls

The aetiology of a fall is multifactorial and a holistic approach is needed to prevent falls. Prevention programmes are based on a number of studies assessing the risk factors for having a fall; these studies have indicated that any medication use [16-18]–especially psychotropic drugs [19], impaired cognition [20], reduced level of activity and/or taking more risks that is beyond their physical capacity [19], and finally impaired vision [56] increases the risk of older people having a fall.

Medications are a known risk factor for increasing the fall risk in the elderly population. Specific drug classes such as benzodiazepines, antidepressants and antipsychotics, if avoided, could prevent falls [21]. Polypharmacy and diuretics are known risk factors for postprandial hypotension. Benzodiazepine, antidepressants, alcohol, vasodilators, diuretics and phenothiazines are prominent risk factors for orthostatic hypotension. Both postprandial and orthostatic hypotension have the potential to cause a fall [22]. Polypharmacy is a contributor to falls; if ≥4 medications are taken by an older person this is associated with 1 or more falls compared with elderly controls taking <4 medications (odds ratio (OR), 1.3; 95% CI, 1.0 to 1.7) [23]. With polypharmacy, one specific medication mechanism cannot be shown to cause orthostasis alone, and so all should be considered as possible contributors and have a synergistic effect on falls. This association seems to be independent from the co-morbidities that the medications are treating [24], however more research may be needed on this topic.

2.3 Prevention of falls

In 2009, 111 falls prevention randomised controlled trials were included in a Cochrane systematic review, which collated the results of the programmes tested and revealed statistically significant outcomes [25]. In this review they found that multiple-component group exercise reduced rate of falls and risk of falling (rate ratio (RaR) 0.78, 95% CI 0.71 to 0.86; risk ratio (RR) 0.83, 95% CI 0.72 to 0.97), also Tai Chi (RaR 0.63, 95% CI 0.52 to 0.78; RR 0.65, 95% CI 0.51 to 0.82), and individually prescribed multiple-component exercises at home (RaR 0.66, 95% CI 0.53 to 0.82; RR 0.77, 95% CI 0.61 to 0.97) [25]. Prevention programmes that increase elderly people's level of activity by a combination of balance and gait activities alone are effective in decreasing the rate but not the risk of a fall. In other words, this intervention reduces re-occurrence of falls. Furthermore, strength and resistance exercise programmes alone have positive fall-related outcomes [26]. Exercise programmes are effective if there is an adequate amount of time to exercise, high compliance to the intervention, or an effective strategy implementing the exercise programme [26]. For example, walking programmes alone do not contribute to a reduction in falls, but balance training and programmes with a large amount of exercise time are effective exercise programmes. However, any form of exercise is beneficial for fitness, weight loss and lowering blood pressure [27].

When exercise programmes are incorporated into multifactorial interventions comprising assessment of home hazards, medication adjustments and other similar methods, whilst using a multidisciplinary team of health workers, the outcomes are also clinically significant for preventing falls in elderly people. However, assessment and multifactorial intervention reduced rate (RaR 0.75, 95% CI 0.65 to 0.86), but not risk of falling [25]. Gillespie et al. mentions that multifactorial programmes are complex interventions, and the context in which they are effective is for further research.

Single focus interventions such as vitamin D and calcium supplementation in individuals who are hospitalised or in nursing care, and targeting inappropriate medications, may have potential to reduce falls [28]. Another study looking at single focus interventions tested a home safety programme and an exercise programme delivered by a physiotherapist plus vitamin D. Campbell *et al.* recruited 391 ≥75 year olds with severe vision impairment, and found that these participants benefited from a home safety intervention delivered by an occupational therapist (incidence rate ratio (IRR), 0.39; 95% CI, 0.24 to 0.62), while the Otago Exercise Programme prescribed by a physiotherapist did not show a significant

decrease in falls (IRR, 0.79; 95% CI, 0.48 to 1.28). The falls prevention programme delivered by an occupational therapist to elderly people with visually impairment, resulted in 41% fewer falls (95% CI, 0.58 to 0.17) and the incremental cost per fall prevented was $NZ650 (2004 prices) [29]. Single focus programmes target specific populations and avoid redundant interventions, so may be more cost effective and correct risk factors for falls in those who need it. This means that a single focus programmes may be superior and easier to implement compared with multidisciplinary teams delivering multifactorial interventions [30].

2.4 Staying upright with vision

Balance requires an interaction between vision, vestibular function, and proprioception with experience of how the body reacts and foreknowledge of this [31]. When we are young we rely heavily on proprioception and vestibular function, but with the aging process, the nerve endings of the peripheral nerves in the lower extremities lose some of their function. Consequently, elderly people rely proportionately more on vision to stay upright. The Romberg quotient, which is a measure of sway with eyes open and eyes closed, is used to describe the effect of vision on someone's posture. The Romberg quotient showed that over the age of 85 50% of control is due to vision, compared with 20% in 50-60 year olds ($p<0.01$) [32]. Vision is important in balance but also in negotiating hazards outside, around the home, going up and down stairs, and supporting oneself if a fall does occur. Poor vision is common in the elderly and cataracts, glaucoma, and macular degeneration are strongly related to increasing age [33]. Visual impairment is a risk factor for falls and specific aspects of vision which cause a fall include that which has been mentioned plus age related macular degeneration, impaired visual acuity (VA), depth perception, visual field loss, and edge contrast sensitivity [34].

However, caution must be taken when correcting for visual problems. One randomised controlled trial recruited 616 men and women from an outpatient aged care service, who were over the age of 70. They were then randomised into two groups and the intervention group received treatment to correct their vision, with a new pair of glasses and referral to an ophthalmologist for glaucoma, age-related maculopathy treatment and cataract surgery, if needed. Controls did not receive a review by an ophthalmologist or optometrist. This study showed a significant increase in falls in the intervention group (RR, 1.57; 95% CI, 1.20 to 2.05) [35] but as 92% of the intervention group acquired a new pair of glasses, the results may be due to adjusting to this new pair. The risk of falling is greatest in the first month of follow-up after the eye check-up [35], which supports the idea that older people may find it difficult

to initially adjust to a new pair of glasses. The author's explanation for the results are that the control subjects at baseline were frailer than the intervention group, there was a high level of contamination between the two arms, reporting bias of falls was a factor and improving vision could encourage more risky behaviour [35]. These results do suggest anomalies when correcting vision in older adults and vigilance is required.

2.5 First and second eye cataract surgery on falls

Symptomatic cataracts are contributors to falls and injuries in older adults [36]. Cataracts are opacification of the crystalline lens in the eye, formed by the accumulation of water and/or denaturation of lens proteins [37]. Cataracts obscure vision, as light cannot pass through the lens due to reduced transparency, and in nuclear sclerosis type cataracts the lens itself becomes more round and induces myopia [37]. Three hundred and six ≥70 year olds were randomly assigned to either expedited cataract surgery of 4 weeks or the usual wait list of 12 months. Harwood *et al.* found that expedited cataract surgery reduced falls by 33% (RR, 0.66; 95% CI, 0.45-0.96) [38]. This reduction in falls from cataract surgery is not only seen in those people who have severe cataracts but also seen in those who have 'mild' cataracts, with VA better than the limit to drive (binocular VA 6/12). The cohort for first eye cataract surgery consists of frail elderly people who are the target population for falls prevention. Frailty is defined by whether the older person has a history of falls in the preceding year, are using appliances for mobilising, and taking more than four drugs. The greater the frailty the more they will benefit from cataract surgery with regards to falls prevention [39]. When second eye cataract surgery was performed within half of the same cohort who underwent expedited first cataract surgery, there was no significant reduction in falls (RR 0.68, 95% CI 0.39 – 1.19; P = 0.18). A systematic review and meta-analysis collating the randomised control trials on expedited cataract surgery found an improvement in VA but not a reduction in falls [40]. However, even though second eye cataract surgery did not improve falls risk it did improve VA, contrast-sensitivity, stereoscopic, confidence, visual disability and level of handicap [40, 41]. The absolute improvements with second eye cataract surgery were much less than the absolute improvements from first eye cataract surgery, possibly due to a ceiling effect.

The cost analysis of first cataract surgery was favourable over the person's life-time [42]. The UK National Health Service threshold for willingness to pay is £30,000 per quality adjusted life years (QALY) and first cataract surgery for a 78 year old woman costs £13,172 per QALY gained over 10 years [42]. Furthermore, cataract intervention seems favourable compared with other health care interventions. Three quarters of the population studied for

first expedited cataract surgery had a ‘mild’ cataract, which suggests a low threshold to perform cataract surgery to prevent falls.

2.6 Glaucoma and falls

Glaucoma is optic disc atrophy, which leads to visual field loss (arc scotoma) and, if untreated, can result in total blindness. It is an important condition because it is common, with a prevalence of 1% in people ≥40 years of age [37]. Because older people rely so much on their peripheral vision to carry out activities of daily living, the risk of falling is a significant factor in glaucomatous patients. Older people with glaucoma are more likely to have fallen in the previous year than age-adjusted controls (OR (adjusted), 3.7; 95% CI, 1.14 – 12.05) [43], and visual field impairment of 40% or greater was associated with falling (OR of falling, 3.0; 95% CI, 0.94 to 9.8) [44]. Glaucoma in 104 community dwelling older people >65 years was an independent risk factor for recurrent falls versus single falls, P = <0.001 [45]. Additionally, glaucomatous changes are associated with reduced postural stability - explaining almost 20% of the variance in balance in a cohort of 54 community dwelling >65 year olds [46]. By slowing the progression of glaucoma the rate of falls decreases [47]. Furthermore, glaucoma medications such as long term beta-blocker, prostaglandin and their combination were used in 148 subjects and their falls risk after adjusting for confounders, showed no significant difference in falls rate between the glaucoma medications [47]. In summary, vision loss in glaucoma is costly and costs increase with severity of visual loss, but treatment of glaucoma can result in a reduction of falls [48].

2.7 Age related macular degeneration and falls

Age related macular degeneration (ARMD) affects the macular and fovea, distorting the central image which is tested by the amsler grid. ARMD is either dry (drusen deposits) or wet (haemorrhage from angiogenesis) type and each type has a different outcome and clinical course. In the advanced stages of the disease, the central part of the vision is lost completely (central scotoma) but the visual fields stay intact and older people can still perform activities of daily living (ADL). However, this loss and distortion of central vision is why falls occur in this cohort of older people [49], increasing their falls risk by two-fold [50, 51]. Furthermore, the bending of an image, metamorphopsia, can be similar to the effect seen with PALs – a prismatic displacement effect, which is described in Chapter 3 of this thesis.

2.8 Visual acuity

Poor binocular VA is associated with falls in the elderly population [52], and the reason appears to be twofold: 1) poor VA increases sway [53], and 2) problems with foot clearance [54]. In 95 older adults, when standing on a compliant surface, sway was significantly associated with poor visual acuity and contrast sensitivity (partial correlation analysis controlling for age revealed 0.28 and 0.26, respectively) [53]. In addition, when VA was artificially blurred in 36 healthy older females, the foot clearance of a step increased in height. This result was possibly due to the apprehension around ascending a step and allowed the foot more space to clear the edge of the step, which would appear blurred [54]. Furthermore, binocular VA worse than 20/60 (6/18) was associated with hip fractures (OR, 1.5, 95% CI, 1.1 to 2.0) when adjusted for confounders [33].

The Beaver Dam eye study followed 3722 participants between the ages of 43 to 86 years old over a 5 year period and had a dropout rate of 25%. This study found that the odds ratios for nursing home placement was statistically significant for those with the poorest category of visual sensitivity when controlling for confounders in multivariable models [55]. Poor VA, binocular acuity, near acuity, contrast sensitivity and visual sensitivity all correlate to a history of falls within the past year [52].

It is not VA alone which can cause falls but the difference in VA between each eye [56]. A study that assessed VA in each eye found that a large VA difference increased the rate of falls [56]. This is in direct contradiction to cataract surgery findings, in which correction of the VA of one eye significantly decreased the rate of falls but correction of both eyes did not.

For elderly people with visual impairment, adaptation strategies are postulated to prevent falls from occurring [29, 57]. A Cochrane review assessed the effectiveness of orientation and mobility (O&M) training to help those visually impaired [57]. The training technique teaches the participant to rely on other forms of sensation inputs and given tools to negotiate the environment safely and independently. They found no differences between O&M when compared with physical activity, for the potential to trip and hurt themselves [57].

2.9 Presbyopia

Presbyopia is a normal aging process, which begins around the age of 40 and is due to the lens hardening and reducing its ability to accommodate. Accommodation is the ability of the lens to focus the retinal image when an object is placed close to the eye; the ciliary muscle

contracts which causes this muscle to fatten, which in turn relaxes the tension on the suspensory zonules and causes the lens to become more convex. The ability of the lens to become spherical decreases with age and this process first becomes noticeable around the age of 45, when near vision glasses are often required for reading. If the person has distance glasses already, then bifocals can be prescribed. By the age of 65 all accommodation is lost and must be replaced by near vision spectacles [37].

2.10 Multifocal glasses

Multifocal glasses are practical, especially for those who require a distance prescription, are active and have presbyopia. The term multifocal glasses include bifocals, trifocals and progressive lenses. Bifocals comprise two lenses, a lens for distance vision (at the top) and a plus lens (addition) for near vision (at the bottom). Trifocals have three lenses: the top one third corrects for distance, the middle corrects for intermediate distance and the bottom third corrects for near vision. While the progressive lens has a power spectrum down the lens. The progressive lens thus allows for near and distance vision without a stepwise jump. However, the progressive lens has large areas of aberration in the peripheral section, which is illustrated in Figure 2.2. Anecdotal evidence suggests that walking while wearing a pair of progressive multifocal glasses, ‘makes the world appear to oscillate at the sides’ [58].

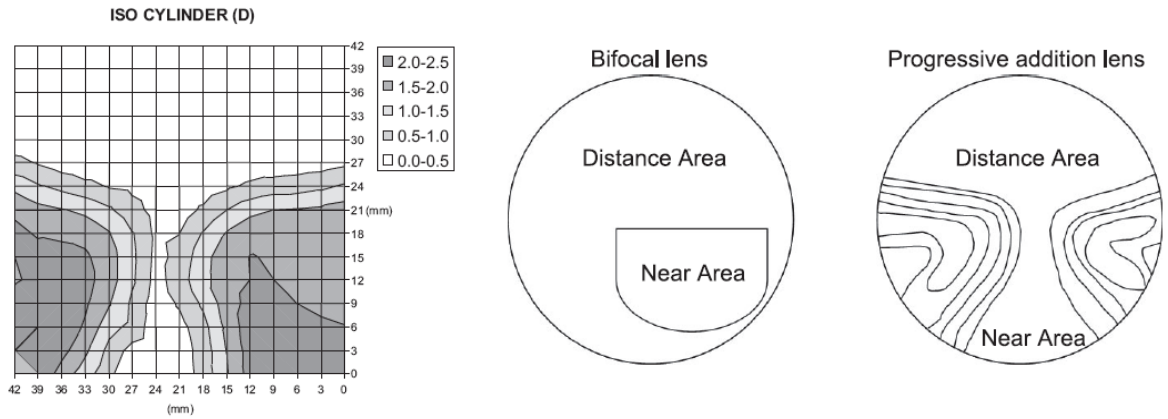


Figure 2.2. An isocylinder plot of a plano +2.00D addition. This shows the VA contours on a progressive lens depicted on the left and right. Bifocal lens is depicted in the centre [59, 60].

Wearing multifocal glasses are known to increase falls in older people compared with wearing non-multifocal glasses [2] but exactly how they contribute to falls is not known. Poor VA, stereopsis, contrast sensitivity and visual field defects are associated with an increased risk of low fragility hip fractures [33, 61]. Multifocal glasses are shown to affect edge contrast sensitivity and depth perception when looking through the reading section of the lens at far away objects, and limit the visual fields because of the small section for distance vision [2].

Moreover, multifocal glasses cause objects to be falsely projected due to the prismatic displacement effect where the different powers of the glasses meet. The extent of these effects and its contribution to falls will be discussed in this chapter and presented in more detail in Chapters 3, 5 and 6 of this thesis.

2.11 Depth perception

Depth perception is relied on heavily when negotiating hazards. Binocular vision requires reasonably clear images from both eyes, cerebral fusion mechanisms, and precise co-ordination of the movements of the two eyes for all directions and distances of gaze [37]. Lack of depth perception is associated with an increased risk of falls (OR, 6.0; 95% CI, 3.2 to 11.1), as is decreasing stereopsis (trend $P = 0.0001$) [33].

Older people rely on depth perception to balance. Lord *et al.* looked at whether specific visual abilities accounted for the variation in sway among 156 older people, mean age 76.5 (SD, 5.1), when standing on a foam rubber pad. Results showed that contrast sensitivity, stereopsis and quadriceps strength were the most significant independent predictors, accounting for 21% of the variance in sway [62]. Vale *et al.* looked at foot clearance when stepping onto a step with a monocular blur of +2D, in young healthy subjects. The monocular blur affects stereoacuity and the participants' vertical foot clearance was higher, which probably signifies a compensation to avoid having a trip [63]. Furthermore, Oner *et al.* looked at the visual function of people with hip fractures with age-matched controls, mean age of 76.3 ± 7.6 years, and showed that VA and stereopsis was significantly decreased in those who had a hip fracture [64].

Moreover, when looking through the reading section of multifocal glasses, depth perception was found to be impaired by 2.0 ± 2.3 cm ($P < .001$), compared with the distance portion [2]. Whether or not impaired depth perception with multifocal glasses is contributing to falls, is uncertain.

2.12 Visual field loss

Peripheral vision helps to predict where hazards are in the environment and negotiate round them. It was noted that lower visual field obstruction results in increased risk of obstacle contact and increased gait variability in healthy middle-aged participants [65]. This result was thought to be due to decreased accuracy of the sensory-to-motor transformation of the lower limbs when only the top edge of the obstacle was visible.

A reduced visual field results in an older person being more cautious when negotiating hazards. In a sample of 2375, 65 to 84 year olds, visual field loss was associated with an increased risk of falling (OR 1.08 for a 10 point loss of points, 95% 1.03 to 1.13). However, when central and peripheral field loss was in the same model, only the peripheral visual field loss was associated with falls (OR 1.06, 95% CI 1.01 to 1.10) [66]. Binocular visual field loss due to bilateral lens opacities and glaucomatous nerve changes may explain why 33.3% of women who fell frequently had a fall [67]. Again, another study found that binocular visual field loss in older women is attributed to 33.3% of frequent falls. The adjusted odds ratio for the risk of at least two falls over mild, moderate, and severe binocular visual field loss was 1.17, 95% CI 0.95 to 1.43; 1.37, 1.01 to 1.84; and 1.50, 1.11 to 2.02; respectively [68].

Both elderly and young people perform the same when localising peripheral visual stimuli. However, elderly people with low level executive function were slower to process and had less down-saccades when presented with obstacles in their peripheral vision [69]. Consequently, elderly people with reduced executive abilities and localising obstacles in their peripheral vision may be at increased risk of a fall.

2.13 Contrast sensitivity

Contrast sensitivity is a measure of one's ability to notice small spatial differences at less than 100% luminance [68]. The ability to detect corners of objects and to distinguish one thing from another in a murky fog – or through an oedematous cornea or cataract - is very important to perform one's ADL [37]. Poor contrast sensitivity produces this effect and is a risk factor for falls, as previously mentioned. Abrupt changes of luminance affect contrast as opposed to a gradual change which cannot be detected. Moreover, VA can be corrected through prescription of glasses, while contrast sensitivity could be improved through better lighting, from mesopic to photopic (high luminance) light conditions [70].

Visual contribution to postural stabilization is significantly associated with those who have had a fall compared with non-fallers, and is significantly associated with contrast sensitivity [53, 71, 72]. Contrast sensitivity is reduced when forced to look through the lower part of the multifocal glass [2]. This is illustrated in Figure 2.3, and suggests reasons why contrast sensitivity can cause a fall.

Figure 2.3. Simulated view of a street scene with a step in the path as viewed through single vision (distance) glasses (panel A) and bifocal glasses (panel B) [3]. Panel C is a flight of stairs viewed down through a progressive addition lens.

2.14 Negotiating a step

Falls on stairs are a leading cause of accidental death, multiple injuries and hospitalization in older people [60]. Older people rely heavily on vision to mobilise and negotiating stairs can stretch this ability. It has been noted that the anticipatory phase for stair negotiation is increased in elderly participants with blurred vision [74, 75], and that it takes more time to process exoreceptive information in the central nervous system to plan the required stepping movement.

Heasley *et al.* [74-76] investigated how vision affects several aspects involved in negotiating steps, namely: toe clearance, postural sway in the AP and medio-lateral direction, forces applied to the ground, and the length of time for stepping up and down from varying step heights. In short, when a person with blurred vision steps up onto a raised surface two things may be affected: the medio-lateral displacement and the foot height (Figure 2.4). The medio-lateral displacement is reduced to diminish the potential for a sideways fall, which could cause a hip fracture. Conversely, foot height is raised so a trip does not occur and result in a fall forward. Medio-lateral displacement is reduced more in the older population compared with younger people when vision is blurred [75]. This may be because younger people are more dexterous and have greater confidence if a sideways fall occurs. In elderly people, increasing step height and stepping down from a height is accompanied by reduced medio-lateral displacement. This illustrates a biological gradient and validity of the medio-lateral reduction [74].

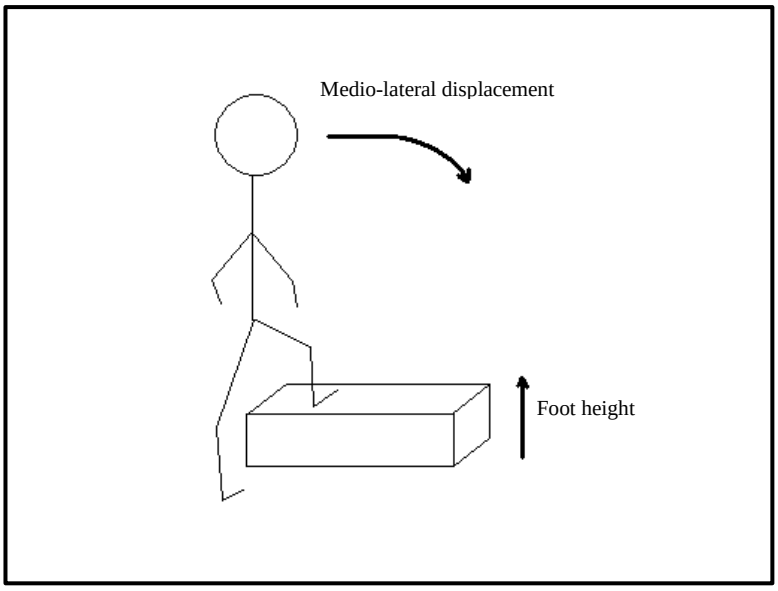


Figure 2.4. Illustration of a person negotiating a step onto a ledge. In order for the lead limb to clear the step sufficient foot height and/or medio-lateral displacement is required.

When vision in the elderly population is blurred, foot clearance was shown to increase when stepping up onto a block [76]. There was no reduction in foot clearance seen between young and old when vision is blurred but there was a difference in medio-lateral divergence between the two age groups. The explanation for this is that elderly participants trade increasing their step clearance with medio-lateral instability because sideways, as opposed to a front-on fall, is more of a threat [75].

The same effect is seen when wearing multifocal glasses versus single vision (distance) glasses. When 19 healthy elderly subjects (mean age, 71.4 years) wore multifocal glasses there was 20% greater within participant variability for vertical foot clearance compared with single vision glasses (P = 0.0004; P = 0.013 for PALs and bifocals, respectively). Furthermore, those who wore multifocal glasses were the only ones that had a trip during the trial [59].

When older individuals wear multifocal glasses their ability to step down from a height is impaired [60]. It has been demonstrated through kinematic measurements of stair descent that wearing multifocal glasses is more likely to cause a drop onto the lower level, compared with the well-controlled manner with single vision (distance) glasses. Multifocal glasses tend to increase peak ankle and knee angular velocity compared with single vision glasses, but increase the vertical centre of mass velocity. Even though participants wearing either of the glasses have similar peak forces during landing, those wearing multifocal glasses have increased time to peak force. As such there is an increase in momentum, attenuated with a longer period of descent compared with those participants wearing single vision glasses [60]. If lateral centre of mass velocity is increased the possibility of a sideways fall that could cause a hip fracture is also increased. However, the lateral centre of mass velocity is reduced while wearing multifocal glasses. When an individual is uncertain about the precision of landing they are more likely to reduce the lateral centre of mass velocity. In brief, multifocal glasses cause individuals to drop to the next step in a less precise manner [60].

To summarise, multifocal glasses may increase the probability of a fall on a flight of stairs in at least two ways: by increasing the likelihood of a trip when stepping up onto a height, and landing on both feet with less precision when stepping down from a height.

2.15 Sway with multifocal glasses

Two of the many factors that contribute to a fall are posture and balance. An upright posture is maintained by continuously relaying spatial information through the eyes, especially in elderly people [32]. Without this stimulation, sway in older people is increased by 20-70% [56]. It has been shown that elderly people cannot adapt when visual input is removed, when measuring balance [32]. Since vision has a large effect on balance, this suggests an irreversible and deterioration of the other sensors required to stay upright. As we age the central nervous system and stimuli providing the exoreceptive feedback diminishes. It is known that the co-efficient for the Romberg test increases with age [32]. Factors which

affect an older adult's visual input will have a significant influence on their stability and risk of a fall.

Johnson *et al.* looked at the effect multifocal glasses have on sway in elderly people. Eighteen healthy older habitual multifocal spectacle-wearers (mean age 72.1 ± 4.0 years) were recruited for a randomised, cross-over study comparing their original glasses with single vision (distance) glasses. Stability was measured by the root mean square of the centre of pressure in the sagittal plane, whilst the participant stood on a foam pad. The participants were asked to look at different markers, one at eye-level and one on the ground. The trial also included different head positions so that they were forced to look through the near and distance part of the multifocal glasses. Perhaps due to the small sample size (n = 18) no statistically significant difference on stability measures were demonstrated when wearing single vision or multifocal glasses ($P = 0.74$) [77].

Other sensory inputs such as proprioception and vestibular function are also involved in assisting balance. So, the actual influence that multifocal glasses have on visual input and thus balance would be small and possibly this is why Johnson *et al.* did not find a significant difference. Therefore, if the other stimuli contributing to an upright posture are removed and visual input is focused on, then a difference may be found. Furthermore, any slight disturbance affecting balance could lead to a fall. Therefore, the effect of multifocal glasses on balance will be reviewed further in the study reported in Chapter 6.

2.16 Head position and posture

Position of the head in relation to the body influences sway and the possibility of having a fall. Johnson *et al.* study demonstrated that static head positions affect stability [77], and that if participants have their head in full extension this decreases postural stability ($P < 0.001$). This may arise due to tilting of the utricular otoliths out of their optimal working range. Over 30 degree of extension would decrease utricle sensitivity by about 40% [78].

In the Johnson *et al.* trial, head position was shown to affect stability. The least amount of sway was demonstrated with the head tilted down and the eyes focused straight ahead. Conversely, a significant amount of imbalance was demonstrated with the head held in the neutral position and the participant focusing on the ground, whilst wearing multifocal glasses [77]. As such when people are first prescribed multifocal glasses they are advised to tuck their

chin in and to flex their head forwards particularly when negotiating steps and stairs. This forces them to look through the distance part of the glasses [77].

Habitually when one ascends a step they tend to, on average, flex their head by 24 degrees - regardless of whether spectacles are worn ($P > 0.1$) [59]. There is no change in head flexion with step height ($P > 0.1$) [59]. However, for step descent, block height does affect head flexion and this is greater with increasing step height [60]. This angle of head flexion means that older people may look through the reading vision section of their multifocal glasses when descending a step. Because of the limited head flexion and the problems associated with the bottom portion of the multifocal glasses, as previously mentioned, this supports the results found by Timmis *et al.* looking at step descent from varying heights. This suggests that while wearing multifocal glasses, older participants are less precise and uncertain when stepping down from a height [60].

By dynamically moving the head it is possible to stress the vestibular system and decrease stability. One study looked at increasing frequencies of dynamic head movements in the pitch and roll planes by measuring sway by AP and medio-lateral displacement. The outcome measure for AP and medio-lateral displacement was an angle used in the equation 'equilibrium score (EQ) = 100 x (1 – (θ/12.5))'. Twelve point five degrees represents the angle over which a fall will occur. The EQ score could be used to compare frequency of head movements and pitch versus roll planes. Medio-lateral displacement showed little deviation in the roll and pitch of dynamic head movements. However, the AP sway increased for both dynamic and increasing frequency of head movements. For varying frequencies of 0.14Hz, 0.33Hz and 0.60Hz EQ scores for roll are 32.4, 47.1 and 59.2, respectively and for pitch 39.9, 54.4 and 65.5, respectively [78].

2.17 Effect of replacing multifocal with single vision (distance) glasses

It is clear from the discussion previously that wearing multifocal glasses increases the risk of having a fall compared with non-multifocal glasses wearers. One large trial, the VISIBLE trial, looked at providing older multifocal wearers with single vision (distance) glasses and educated the participants on their use. Optometrists advised the intervention group to wear their single vision glasses for most walking and standing activities but the use of multifocal glasses was not discouraged for seated tasks that needed frequent changes in focal length [5]. The results showed no overall statistically significant improvement of falls with this intervention (incidence rate ratio (IRR) 0.92, 95% CI 0.73 to 1.16) [5]. However, those people

who were frequently active outside the home benefited from the intervention (IRR 0.60, 95% CI 0.42 to 0.87) [5]. In contrast, those people who were less active had a significant increase in outside falls (IRR 1.56, 95% CI 1.11 to 2.19) [5]. When replacing multifocal glasses with single vision (distance) glasses the number needed to prevent one person from falling overall was 13 and the number needed to cause one person to fall overall was 24, for active and less active participants respectively.

However, the intervention group were advised to acquire transition lenses that become darker in sunlight, or had a tint of less than 30%, or a graduated tint for their new pair of single vision glasses [5]. This tint could reduce outdoor glare and decrease the effect of cataracts on vision. So, the single vision glasses alone may not solely be contributing to the decrease in falls in highly active older adults. Furthermore, the decrease in VA with tinted glasses and the delay in change for photochromic lenses could have contributed to the risk of falling in some participants [79].

Lastly, 26% of the intervention group had a non-fall related injury (e.g. laceration, lifting or twisting injury, burn/scald, eye injury, collision and pedestrian injuries) compared with 17% of controls (P = 0.01) [5]. This effect could be due to the convenience of multifocal glasses when carrying out everyday tasks such as cooking, shopping or other such tasks. There is a need to understand why multifocal glasses cause falls and how to avoid this problem, compared with replacing them for single vision glasses.

2.18 Prismatic displacement

Prismatic displacement is the effect a prism causes, which displaces an image and creates a false projection. Light waves move through the prism and bend due to the light slowing in the denser medium. The effect causes a shift of the image relative to the object (Figure 2.5). An illustration of this occurs when throwing a stone at a fish in water, the fish will appear in a different place than it actually is because water is denser than air and light will change direction when it travels through the two media. This causes a false projection of a fish. Furthermore, the amount a ray will deviate when it passes through a prism depends on the apical angle, the index of refraction of the material (and the material surrounding it), the wavelength of the ray, and the angle from which the ray approaches the prism [80]. Similarly, this effect could cause a false projection of a support rail when an elderly person wearing multifocal glasses attempts to grab the rail if they have a slip, trip or loss of balance.

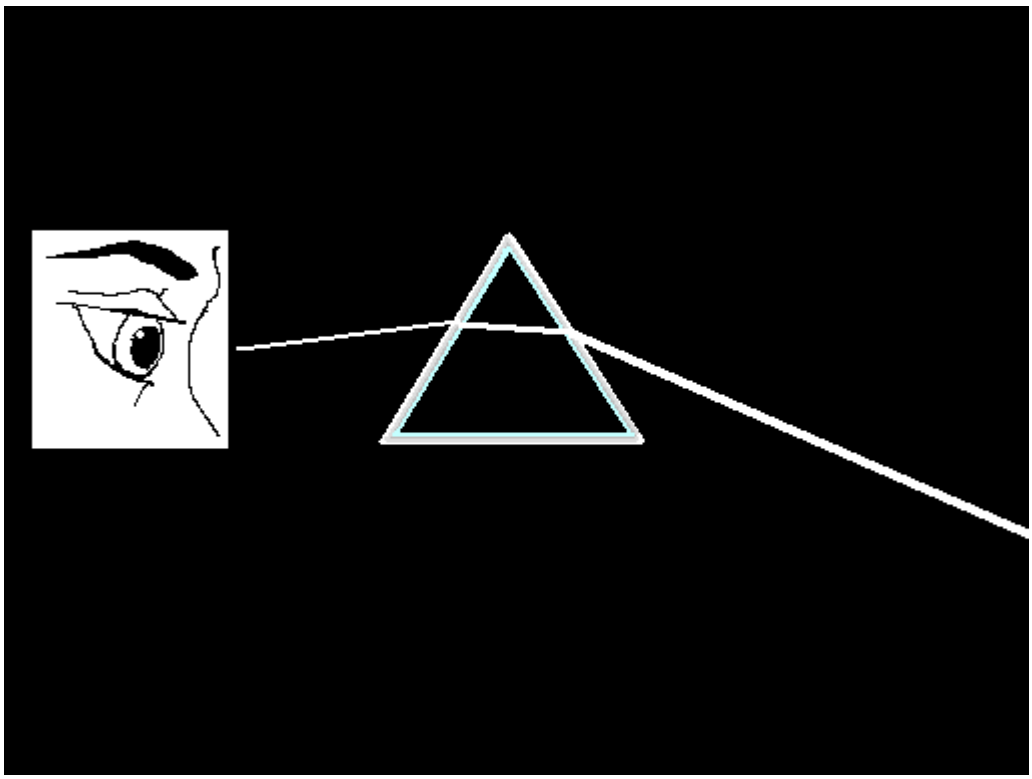


Figure 2.5. Illustrates the prismatic displacement effect. A depiction of a prism and the bending of light it creates.

The perception of our environment is an integration of not only visual information but how we process that information in our cortex. Studies have illustrated that animals have less ability to adapt to a change in perception of their world. Hess and Shipman (1965) demonstrated that when chickens wear prisms on their eyes they lose weight because the chicken pecks to the left of the grain by seven degrees due to the prismatic displacement effect and subsequent false projection of the grain [81]. Sperry (1943) established that when a salamander's retina is rotated 180 degrees and presented with a stimulus moving upwards, the salamander's head will move down [73]. Both animals showed no signs of adaption over time, however, humans do have this ability to adapt to a change in visual perception. When wearing prisms that distort the environment humans are possibly able to adapt to this change within minutes. Also, after removal of the eye wear there is possibly an apparent 'after-effect', which may illustrate that there is an adaptation to the change in perception [82].

Prisms are different to the prismatic effect of PALs. This is because PALs have a graded prismatic effect as opposed to a single complete image shift, seen with a prism. This difference means that the body will adapt differently to the change in location. When someone is wearing a single prism their proprioception and thus arm position will possibly be corrected to the perceived visual change [82, 83]. Conversely, adaptation to PALs prismatic displacement effect is possibly by a change or recalibration of the eye movements [83].

A new prescription of glasses takes time for the wearer to adjust to. Cummings [35] showed that receiving a comprehensive vision and eye examination increased falls by 57% (RR 1.57, 95% CI 1.20 -2.05, P = 0.001) compared with controls who did not get their eyes examined. In this study, new eyeglasses accounted for 92 of the 146 participants who required some form of improvement to their vision in the intervention group, and most of the new pair of glasses had a large change in prescription [35]. During this 12-month study, the largest number of falls per month took place in the first 2 to 3 months after the initial intervention period compared with controls. This suggests a period of adaptation to the new prescription of glasses and an associated vulnerable period for having a fall.

It was also discussed in the Johnson *et al.* trial on sway that the significant result with the 'head-neutral gaze-down stance' was possibly due to a prismatic effect of the lens. However, they also mentioned that the glasses frame could possibly have an effect on central vision and thus sway [77]. Further research is required to understand this link between prismatic displacement effects on sway in older people, and this study is reported in Chapter 6.

2.19 Hypotheses and aims of this thesis

There is some suggestion that the prismatic displacement effect of multifocal glasses could affect falls in older adults [2, 5, 60, 77, 79]. It is possible that this prismatic displacement effect could inhibit the protective response such as grabbing a rail when a fall occurs, or influence stability. No one, as yet, has measured the subjective prismatic displacement effect of a PAL and found if and how this contributes to an elderly person having a fall. Given the current level of knowledge regarding multifocal glasses and falls, further investigation is needed in this field. Therefore, the specific null hypotheses to be tested in this study were that:

1. Map the subjective and objective prismatic displacement effect of a PAL.

2. Measure accuracy and reaction time when grabbing a bar and pushing a black line, compared with wearing PALs and single vision (distance) glasses.

3. Compare visual stability while wearing PALs and single vision glasses.

Chapter 3 – Prismatic displacement of a progressive addition lens

3.1 Overview

In this chapter, I discuss the prismatic displacement effect of a PAL. The prismatic displacement effect is illustrated by viewing a fish in water (Figure 3.1). As light passes through the boundary between two media, with different densities, it bends and so creates a false projection of the fish; or a false projection of a support rail to grab if an older person has a slip, trip or loss of footing. This preliminary study was aimed to elucidate the prismatic displacement effect of a plano +4D PAL. Measurements were made of the degree and direction of displacement of a PAL, by two methods:

1. Subjectively, using a modified Hess test (Figures 3.2 and 3.5);
2. Objectively, using a focimeter (Figure 3.3).

The following results will show where, on a PAL, the largest prismatic displacement effect occurs. These data were subsequently used in the design of the stability and reaction time studies reported in Chapters 5 and 6.

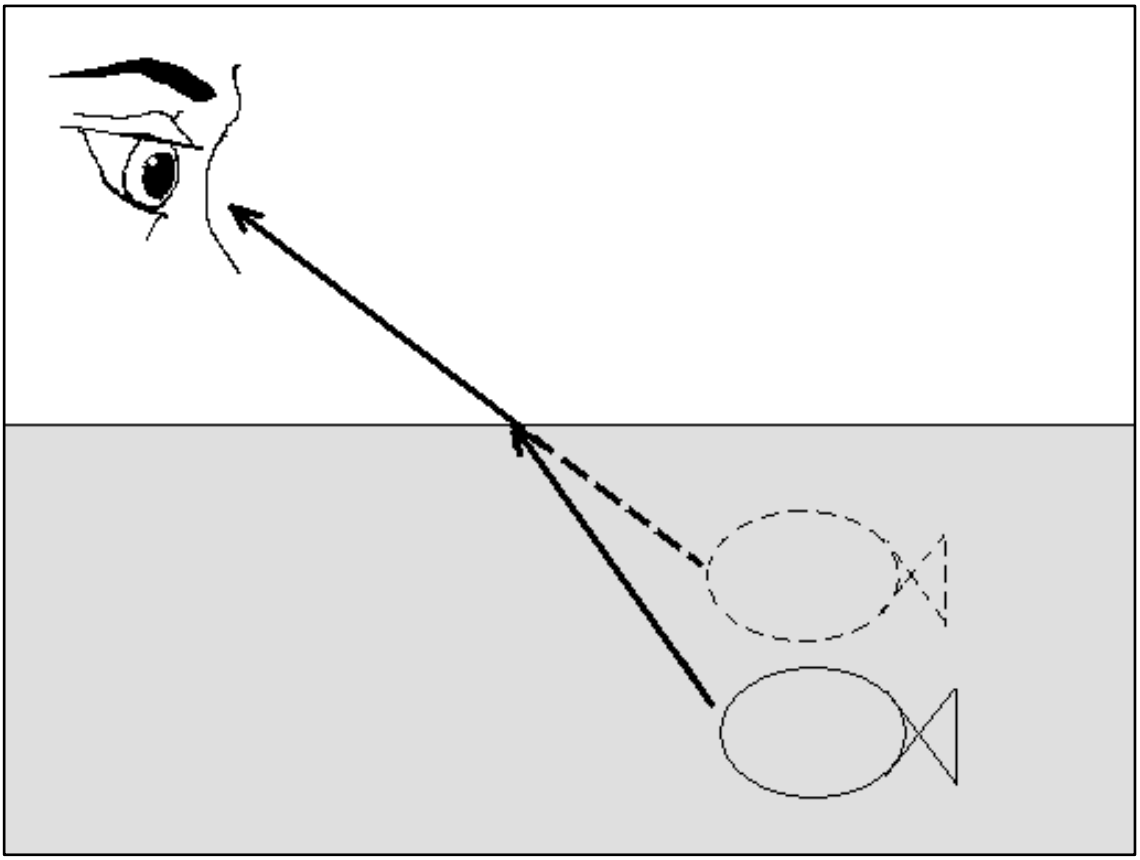


Figure 3.1. Illustration of the prismatic displacement effect of a fish in water. The bold lines represent the true path of light, while the dotted line and fish represents the false projection.

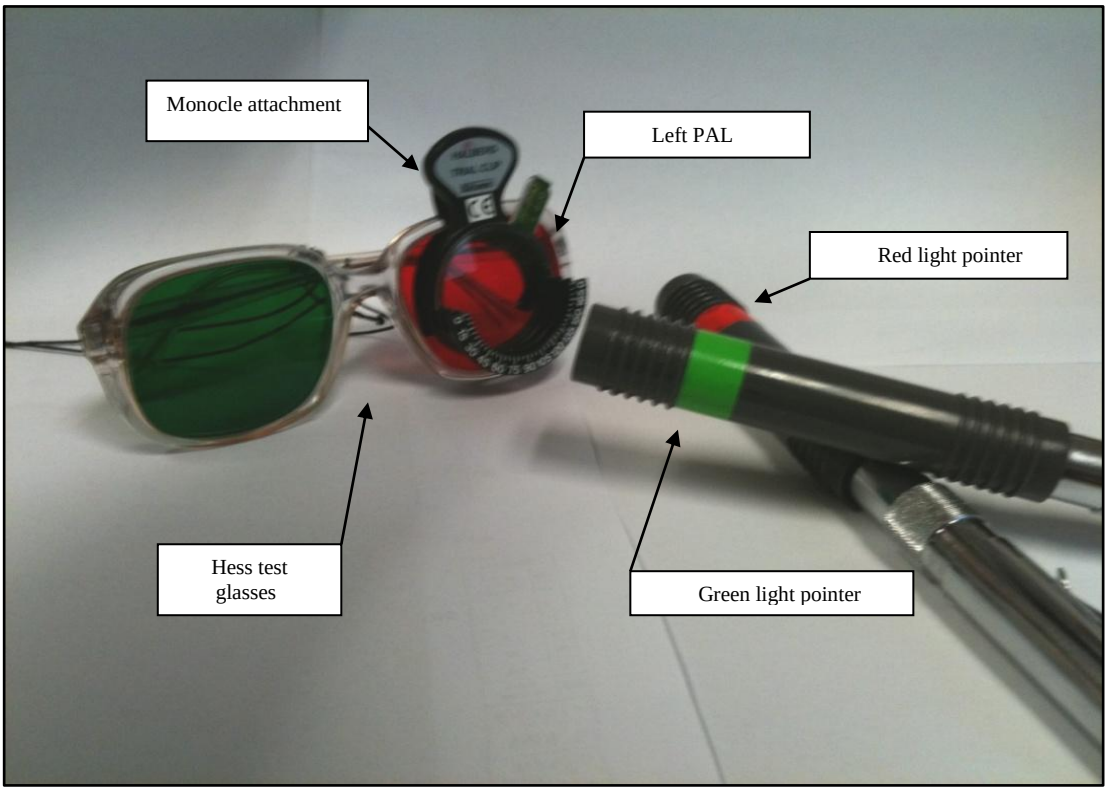


Figure 3.2. The Hess test is modified with the monocle attachment and left PAL, and allows the prismatic displacement effect to be mapped. Hess test glasses (left), red and green light pointers (right), monocle attachment

Figure 3.3. Nikon projection focimeter.

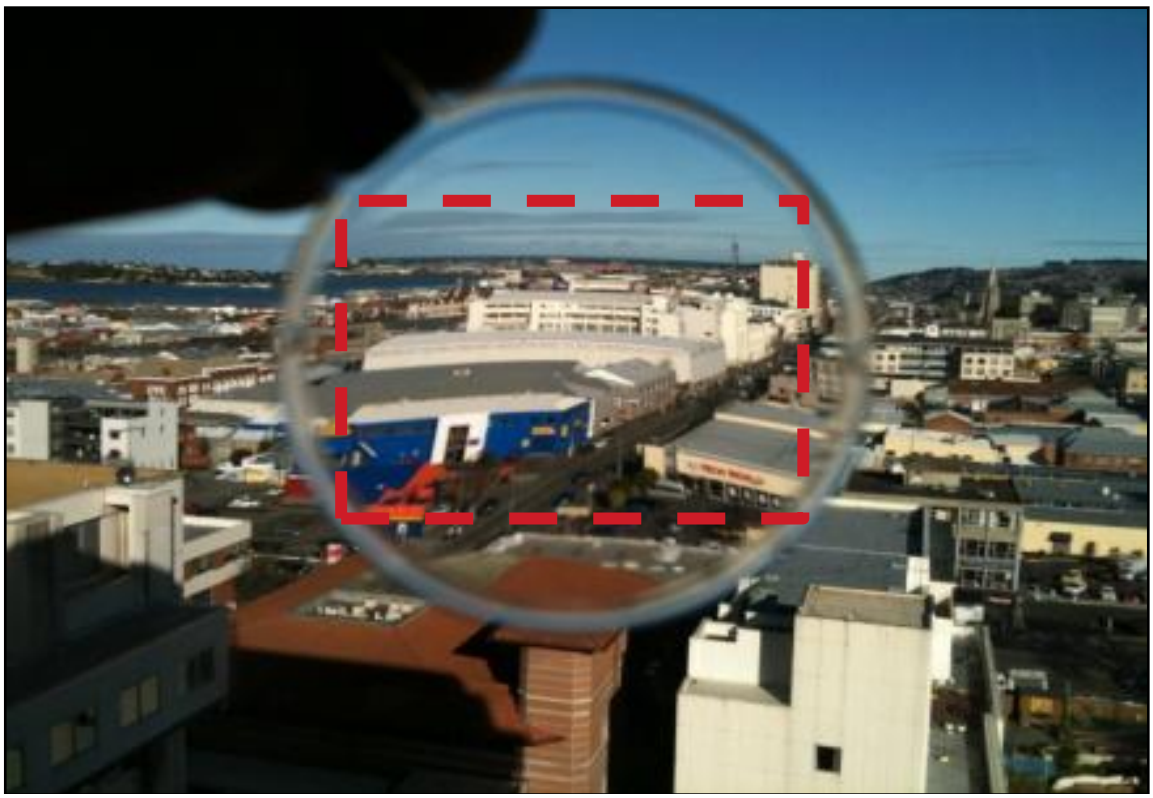


Figure 3.4. Left, plano +4D power PAL. Dotted lines represent the section of lens that was mapped.

3.2 Methods and materials – the Hess test (subjective)

3.2.1 Volunteers

I recruited 10 healthy volunteers from the Dunedin area, mean age of 22.6 (SD 2.8) years. They had 6/6 vision or better, and had not seen an optometrist or ophthalmologist within 24 months. They were not myopic, hypermetropic, or astigmatic, and they had normal retinal correspondence and central fixation. Volunteers were excluded if they had any mechanical or neurological ocular problems.

3.2.2 Equipment

The Hess test is used clinically to detect extra-ocular muscle deficiencies, and essentially dissociates the eyes so that each eye's movements can be recorded [84]. The Hess test consists of a pair of glasses with the right-sided lens filtered green and the left-sided lens filtered red, and two coloured light pointers corresponding to the two lens colours for the Hess test glasses (Figure 3.2). The light pointers project a V shaped coloured light onto a surface. The surface used was 1100mm by 800m plain white paper, and consisted of a grid of points separated by 100mm, vertically and horizontally (7 by 11 points, respectively). A Keeler Halberg monocle attachment, which could fit a PAL, was placed on the Hess test glasses. The lens used was a left and right PAL, plano +4D powered, the typical type of multifocal glasses prescribed for older people and which would enhance the largest prismatic displacement effect.

3.2.3 Trial

The volunteers stood with their eyes two thirds of a meter away from, and in the middle of, the grid of points. The head was positioned in the centre of the grid of points by first measuring the height of the participant. This measurement was taken from the ground to half way up the participant's glasses. The centre of the grid of points was then placed at this height. Participants were repeatedly asked to keep their head as still as possible throughout testing. The glasses were placed 15mm away from the eyes, initially without the monocle attachment or lens. The volunteer was given the green V light pointer and instructed to match the tip of the V with the tip of the examiner's red V light pointer, which was shone on the grid of points. Because the red filtered lens is on the participant's left eye, only the volunteer's left eye can see the examiner's red V light pointer (Figure 3.5). The normal Hess test was performed for the right eye and recorded with a blue dot on the grid of points. This was done to indicate the presence of and to control for possible heterophoria.

The monocle attachment and the right PAL was placed on the right lens of the Hess test glasses (Figure 3.2), and the PAL was 20mm away from the eye. The Hess test was repeated and recorded with a red dot on the grid of points. The normal and modified Hess test was then repeated but instead the right eye was fixating, the examiner held the green V light pointer, the participant held the red V light pointer, and the lens plus monocle attachment was on the left lens of the Hess test glasses with the left PAL.

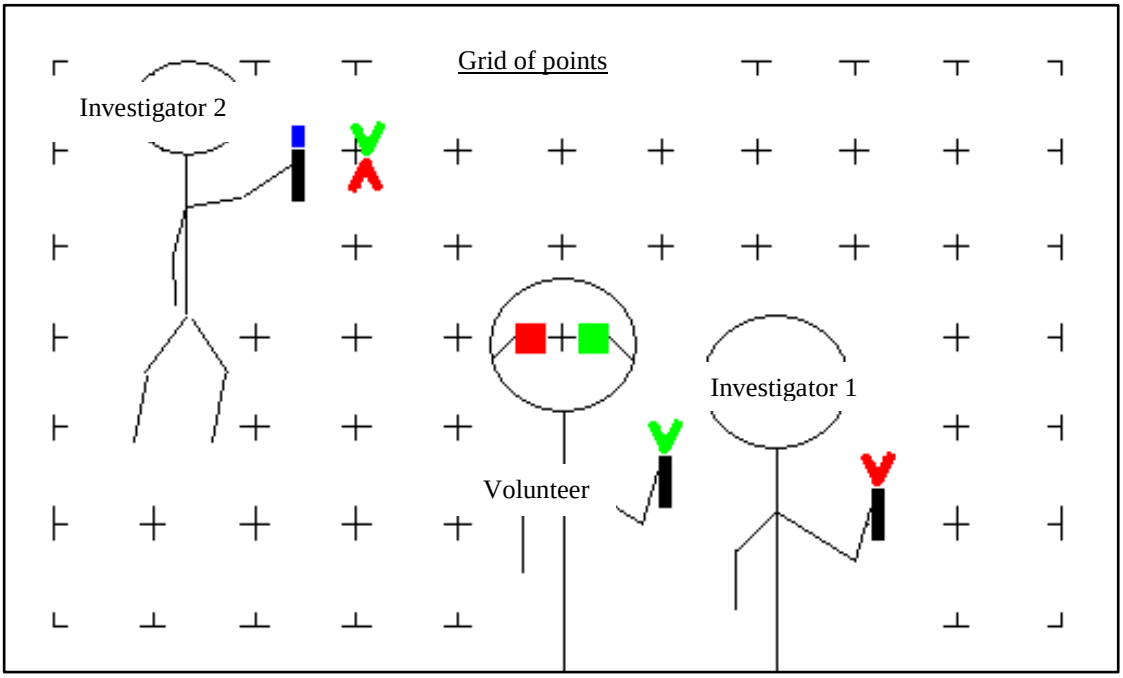


Figure 3.5. Illustrates the Hess test with two investigators, red and green light pointer, blue marker and the volunteer wearing the Hess test glasses (red and green filtered lens).

3.2.4 Measurement

A ruler measured the distance (mm [±1mm]) of the blue dot in relation to the red dot, vertically and horizontally, which represents the base-line normal Hess test and the modified Hess test measuring the PALs prismatic displacement, respectively. The measurements were given a positive or negative value depending which direction the displacement was, and the results for each point was averaged and plotted on a three dimensional graph.

3.3 Methods and materials – the focimeter (objective)

3.3.1 Equipment

The Nikon projection focimeter is essentially a light box that can measure prismatic displacement of a lens placed in the aperture of the line of light (Figure 3.3). The focimeter was used to map a right and left, SMT-Pro plano +4D powered PAL. A plastic ‘mask’ (Figure

3.6), 40mm in diameter, with a grid of holes (each hole 1mm in diameter and 2mm deep) 3mm apart, vertically and horizontally (7 by 11 holes, respectively) was used. By using trigonometry, the 'mask' and its holes, correspond exactly to the grid of points used for the Hess test and section of the PAL mapped, red dotted line in Figure 3.4. Using trigonometry to calculate the distance between each hole on the 'mask' - by taking the distance from the volunteer's eye to the lens to be 20mm, the distance from the volunteer to the grid of points to be 666.6mm, and the distance between each grid of points to be 100mm; a calculation of:

$$angle\ x = \tan^{-1}\ \ 100mm\ \ 2\ \ \div 666.6mm\ ,$$

$$length\ O = \ \ 666.6mm - 20mm\ \ \tan\ angle\ x\ ,$$

$$100mm - \ \ length\ O \times 2\ \ = length\ x,$$ (Figure 3.7).

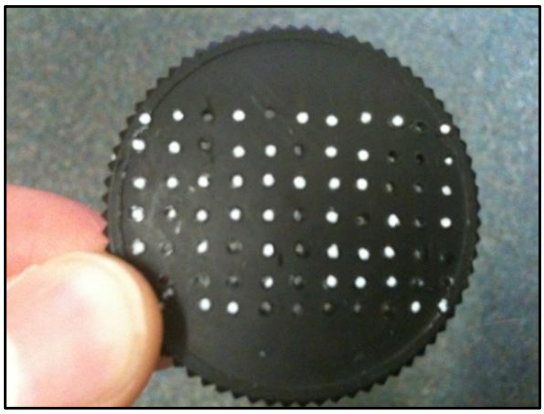


Figure 3.6. Illustrates the 'mask' used to map the prismatic displacement of a PAL, with the focimeter.

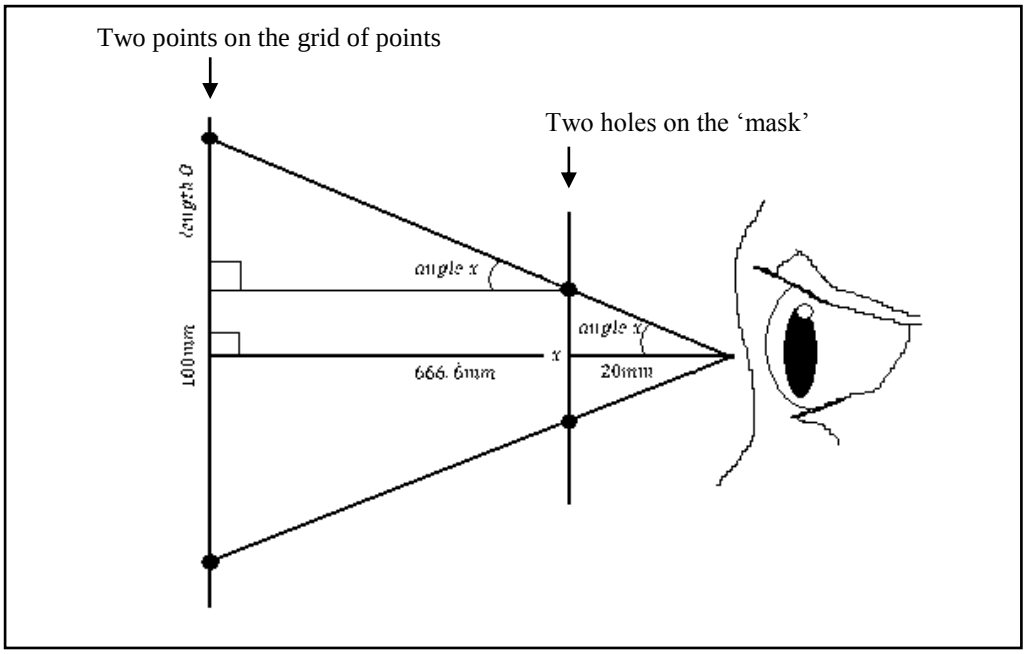


Figure 3.7. Illustrates the dimensions for the trigonometry calculations, converting the Hess test grid of points to the holes on the 'mask' for the focimeter.

3.3.2 Measurement

The ‘mask’ was placed on the lens, and each hole was tested using the focimeter. The prismatic displacement was recorded in Δ dioptres, and converted to mm of displacement (dioptre × 666.6 ÷ 100 = “mm of displacement”). Both the right and left PAL were recorded and the right PAL was again inverted and averaged with the left PALs results. The focimeter results were used to check the validity of the Hess test experiment and for comparison of the objective vertical/horizontal prismatic displacement effect.

3.4 Results – the Hess test

The results were from 10 volunteers, testing both their eyes. By inverting the right PALs results it could be superimposed and averaged with the left PALs results, consequently a total of 20 trials were conducted.

Figure 3.8 depicts the horizontal displacement for an average left PAL. The figure shows large displacements moving outward in the bottom corners of the lens, in the section mapped of the PAL (Figure 3.4). The largest displacement at position [100, 0] is 14.5mm (SD, 10.6) in a leftward direction, and the largest displacement at position [1100, 0] is 5.9mm (SD, 14.9) in a rightward direction. There is minimal horizontal displacements seen in the centre of the PAL, graphically shows an ‘elephant trunk’ shaped area.

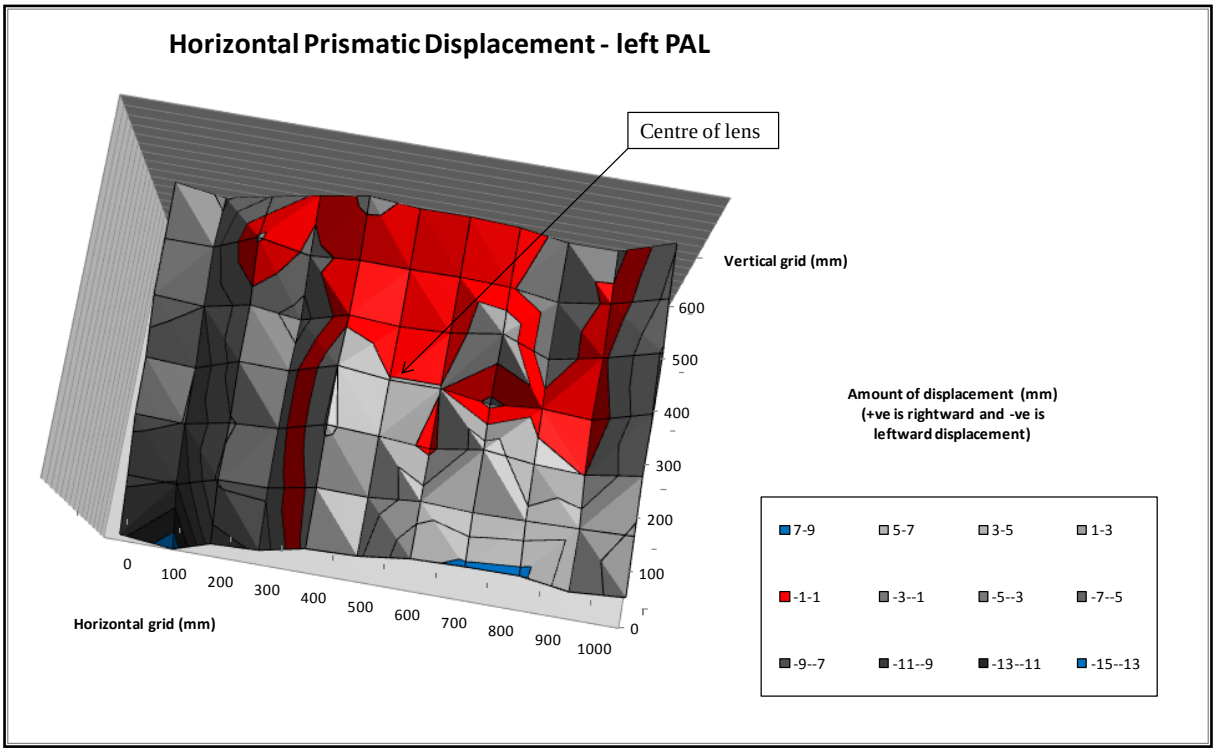


Figure 3.8. Horizontal prismatic displacement measured by the Hess test. The different colours correspond to the degree (mm) and direction (+ve/-ve) of displacement [see legend].

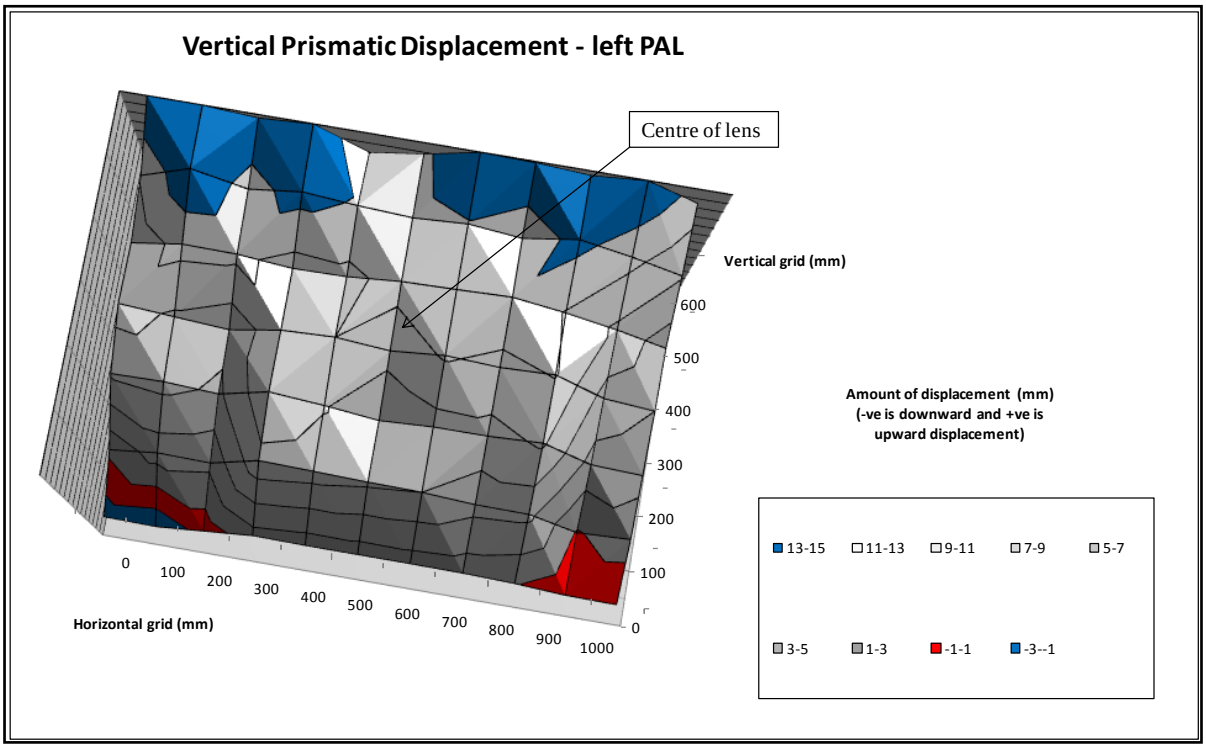


Figure 3.9. Vertical prismatic displacement measured by the Hess test. The different colours correspond to the degree (mm) and direction (+ve/-ve) of displacement [see legend].

Figure 3.9 depicts the vertical displacement for a left PAL. This figure shows large upward displacements at the top left and right corners, 16.2mm (SD, 6.7) and 12mm (SD, 12.1), respectively. The bottom right and left corners show minimal vertical displacement.

3.5 Results – the focimeter

Figures 3.10 and 3.11 illustrate the results for the prismatic displacement effect measured by the focimeter. The results are for a left PAL, as mentioned, the right PAL has been inverted and averaged with the left PAL measurements. Figure 3.10 depicts the horizontal displacement of the section of lens measured on the left PAL (Figure 3.4). Similar to the Hess test results there is a displacement seen in the right and left bottom corners, extending away from the centre of the lens. The maximal measurable displacement in the left corner is 13.3 (SD 0) mm and the right is 13.3 (SD 0) mm. There is an area in the middle of the PAL with no or minimal displacement.

The focimeter results show that the most irregular prismatic displacement is at the peripheral edges of the section of PAL examined. The horizontal displacement shows the image displacing outwards from the centre of the lens, and as the section of the PAL is closer to the peripheral edge, the degree of displacement becomes larger. There appears to be an ‘elephant trunk’ shaped section in the middle of the PAL that has no displacement.

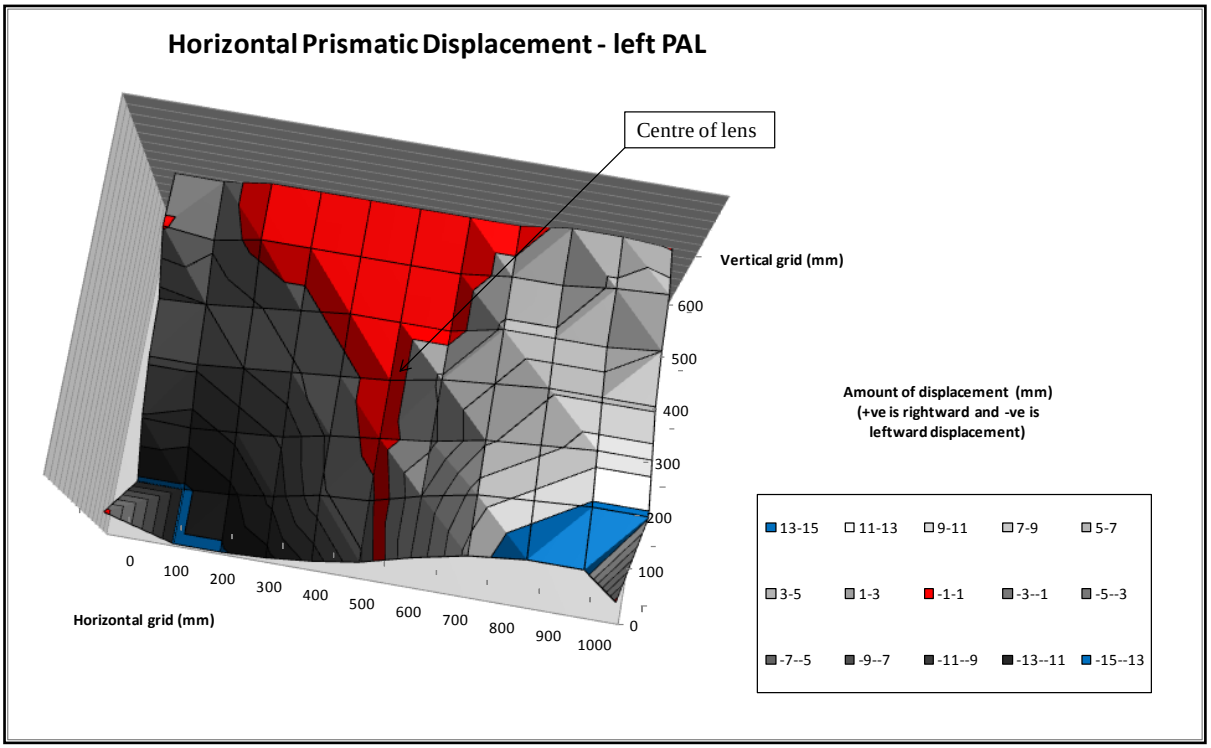


Figure 3.10. Horizontal prismatic displacement measured by the focimeter. The different colours correspond to the degree (mm) and direction (+ve/-ve) of displacement [see legend].

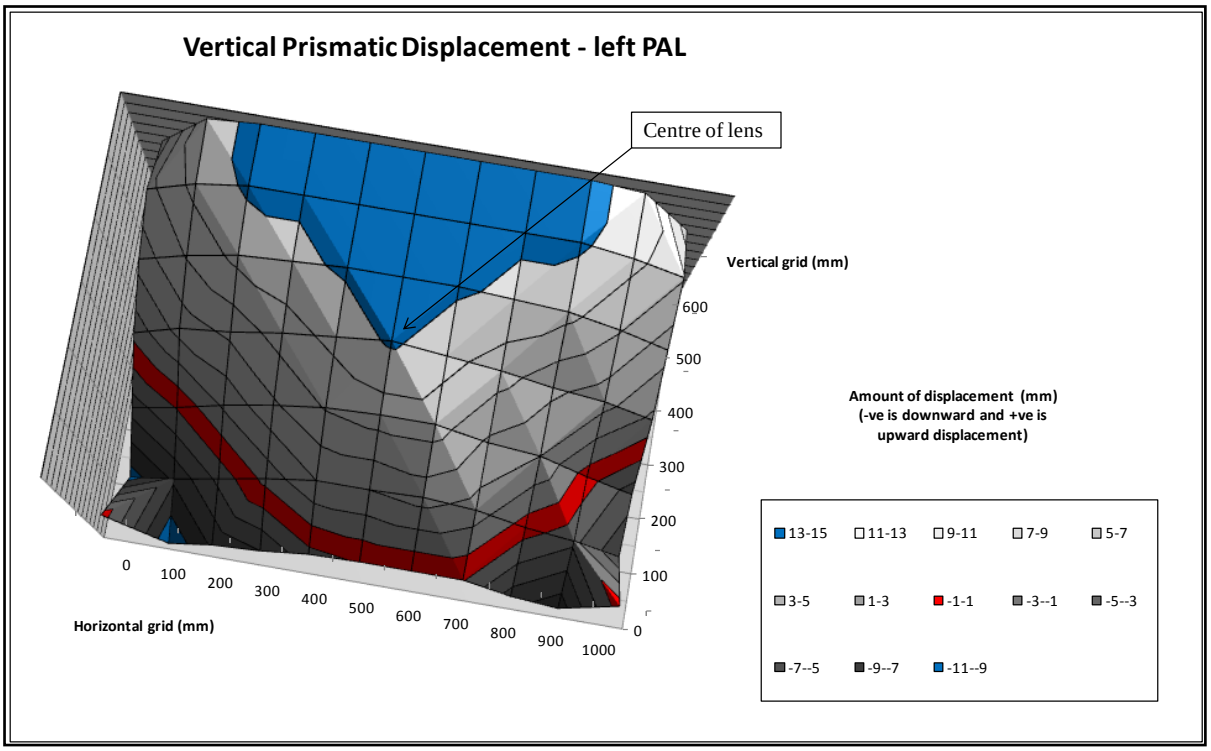


Figure 3.11. Vertical prismatic displacement measured by the focimeter. The different colours correspond to the degree (mm) and direction (+ve/-ve) of displacement [see legend].

The vertical displacement in Figure 3.11 shows an increasing upward displacement when progressing up the section of PAL tested and a slight downward displacement at the very bottom corners of the section. The maximal prismatic displacement upwards at the top of the lens is 13.3 (SD 0) mm and the maximal downward displacement is 10.8 (SD 1.2) mm and 8.3 (SD 2.4) mm in the left and right bottom edge, respectively. There is a small strip arcing along the bottom of the section of this lens that does not have any prismatic displacement effect, depicted in red.

3.6 Discussion

Both the subjective and objective prismatic displacement effect of a left and right PAL was measured by 1) the Hess test and, 2) the focimeter, respectively. This is, to my knowledge, the first map of the subjective prismatic displacement effect of a PAL.

Using the Hess test to map the prismatic displacement effect of a PAL showed a similar pattern to the focimeter results. It is inferred that if enough individuals were tested with the Hess test, it would show similar results to the focimeter. In other words, the focimeter mapped the prismatic displacement effect similar to which the subject would see through the PAL.

It has been postulated that adaptation of glasses for an older person occurs over a long period, possibly a month [35]. Graham *et al.* compared 10 young and 10 old participants (mean age 22.3 (SD 4.6) years and 74.5 (SD 4.3) years, respectively) in changes in gait when stepping up onto a block height of varying size when changing refractive power lenses (binocular magnification of $\pm 1\%, \pm 2\%, \pm 3\%,$ and $\pm 5\%$),. They concluded that age and a time period of 1 minute did not allow adaptation to the different lenses for gait [85]. The results from this study are largely consistent with my results in that volunteers did not adapt to the prismatic displacement of the PAL, illustrated by the similar results found with the Hess test and focimeter.

The main finding from the study is both the Hess test and focimeter results show the most variation in prismatic displacement at the edge of the section of PAL examined. The horizontal displacement seen with both graphs shows the image displacing outwards from the centre of the lens, and as the section of the lens becomes closer to the periphery the degree of displacement is larger. The maximal horizontal displacement taken from the focimeter is between 13-15mm either side of the bottom of the edge of the section of lens examined.

The middle of the lens for the horizontal displacement is an ‘elephant trunk’ shaped section that has minimal prismatic displacement. This corresponds to the area preferentially chosen to view through, and utilized for ADL. This area, depending on the model, can vary between progressive multifocal glasses. If this area is smaller, then it may increase falls, and I hypothesize that the larger this area is, the better older people are able to protect themselves from a fall and the less likely they are to have a trip, slip or loss of balance.

Current guidelines recommend that older people do not remove their glasses, as unaided distance refractive error is a significant risk factor for falls [3]. So a comparison of progressive multifocal glasses must be made to single distance vision glasses. It is postulated that the points of maximal prismatic displacement with PALs will be larger than with the single vision (distance) glasses. Furthermore, these areas of prismatic displacement will vary depending on the position of gaze.

There are other methods of subjectively measuring the prismatic displacement effect, for instance the modified Thorington technique; however, the Hess test is simple to perform in the multiple locations chosen and should give similar results.

3.7 Limitations

Indeed, with the Hess test, on some occasions slight head movement did occur because the volunteer could not physically visualise the light pointer. Because of this, the edges of the section of PAL mapped would be a poor representation of the degree of displacement that does occur; and also showed the preference of the volunteer to fixate through the middle section of the lens, which is the area with the least variation of displacement. This may explain the small prismatic displacement results with the Hess test in the periphery of the lens, compared to the focimeter. Possibly a neck cuff fixed on the volunteers could have reduced this effect by reducing movement of their head, and so forcing the participant to view through the outer edge of the PAL.

The focimeter measurements are more precise compared to the Hess test results. Nevertheless there are limitations to the focimeter. The very bottom left and right areas could not be measured because this correlated to the edge of the lens. However, the general extrapolated pattern of prismatic displacement progressing down the PAL appears to increase in size. So, if a larger PAL and ‘mask’ were used, the results would possibly show larger displacements in the two bottom corners. Because of this limitation, the possibly largest

prismatic displacement was not measured, and utilized for the studies reported in Chapters 5 and 6. However, due to the possibility that if the equipment, reported in Chapters 5 and 6, was placed outside of the section of PAL mapped, the equipment may be outside the participant's glasses' field of vision. So the results from this chapter will be utilized for the following study, and not extrapolated.

Due to time limitations the prismatic displacement effect of a range of differently manufactured PALs could not be mapped, and compared to single vision (distance) lenses. Furthermore, what specifically creates the prismatic displacement within a PAL was not deduced, and could be questions for further study.

3.8 Conclusion

Both the Hess test and the focimeter demonstrate a possibly clinically important prismatic displacement effect of PALs. The largest variation of prismatic displacement was seen in; 1) the lower periphery for horizontal displacement, increasing outwards when progressing to the edge of the lens (Figure 3.10); 2) centre for vertical displacement increasing upwards when progressing from the bottom to the top of the section of lens examined (Figure 3.11). Although, the prismatic displacement effect of multifocal glasses is alluded to as a potential reason for falls [2, 5, 60, 77, 79] no one, as of yet, has tested this effect. Based on the more accurate focimeter results, the following studies reported in Chapters 5 and 6 will target the areas of greatest prismatic displacement in an effort to understand its effect on falls, and the protective response when a fall occurs.

Chapter 4 – Equipment and methods

4.1 Overview of studies

The main objectives were to 1) measure the prismatic displacement of PALs, 2) test whether the prismatic displacement effect impairs the protective response to a slip, trip or loss of balance, and 3) test whether PALs alter stability when relying solely on vision to stay up-right.

The hypothesis is that PALs have a large and variable prismatic displacement effect, and this was confirmed by a modified Hess test and focimeter measuring a section of a PAL, reported in Chapter 3. By placing a bar or a black line in areas of largest prismatic displacement, reaction time and accuracy was compared between PALs and single vision (distance) glasses. If the participant hesitates when fixating through the largest prismatic displacement zone(s) of the glasses, and is slow and inaccurate with grasping the equipment; then this could be considered a proxy for someone visualising a support rail through large prismatic displacements and be less likely to grab for support if a slip, trip or loss of balance occurs. Because PALs affect vision in a number of ways, by removing proprioception and vestibular function (the other two senses known to help us stay up-right), PALs effect on vision and balance can be assessed. The amount of AP deviation from centre of mass will be measured, and compared between PALs and single vision (distance) glasses. Consequently, this will then show whether PALs have any effect on the ability to stay up-right.

4.2 Equipment

4.2.1 Power lab data acquisition system

The PowerLab® data acquisition system along with the LabChart® programme [86] was used to measure reaction time and accuracy. The system sent a timed light source and received an input, which is seen as a voltage spike on the main LabChart® programme display (Figure 4.1). The LabChart® programme then analysed these data for time to grasp the bar and push the black line, and which switch was pushed under the foam pad.

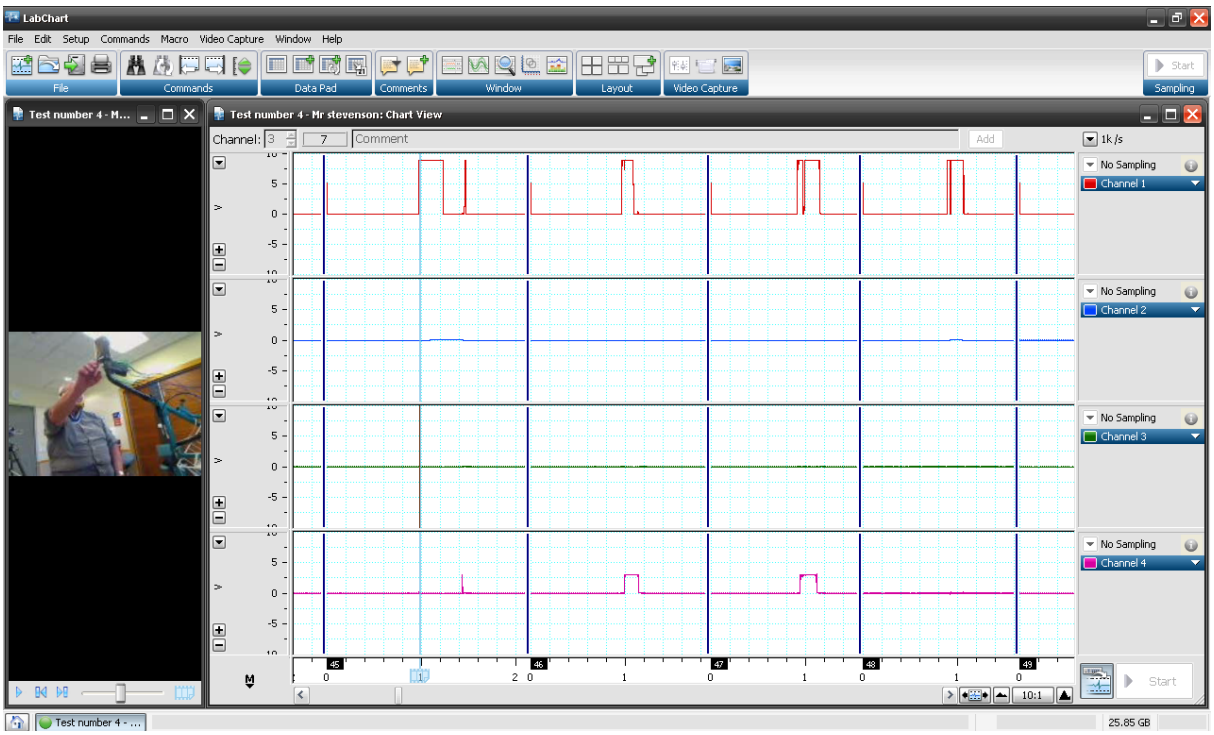


Figure 4.1. LabChart® display window. Left is the playback of video capture, and centrally and right-hand side is the feedback from inputs and outputs over time, are displayed. Note that the output in channel 1 is 9V, the output in channel 4 is 3V. By modulating the ouput voltage, effectively more channels could be simultaneously utilized.

The PowerLab® system used was a 4 input and 2 output device. However, part of the study required 9 separate switches, therefore 9 inputs. By using a 9, 6 and 3 volt battery supply, the different voltage spikes could be distinguished on the LabChart® system, and effectively transforming the PowerLab® system from 4 inputs into a 12 input device.

The Video Capture Module® [86] provides the ability to capture and synchronize video in Windows Media Player® format together with the LabChart® data recorded on a PowerLab® data acquisition system (Figure 4.1). A video camera on a tripod directly in front of the participant recorded the participant's hand movements.

4.2.2 Reaction time and accuracy equipment

A Mobilis® Quad Walking Frame was modified for the purpose of this study. The brake on the walking frame was the bar to grasp. A push switch was connected to the brake pad on the wheel of the walking frame, which sent a signal to the PowerLab® acquisition system (Figure 4.2). The input to the PowerLab® acquisition system, when grasping the brake, was a 9 volt battery connected in series, which represented a voltage spike of 9 volts on the LabChart® programme.

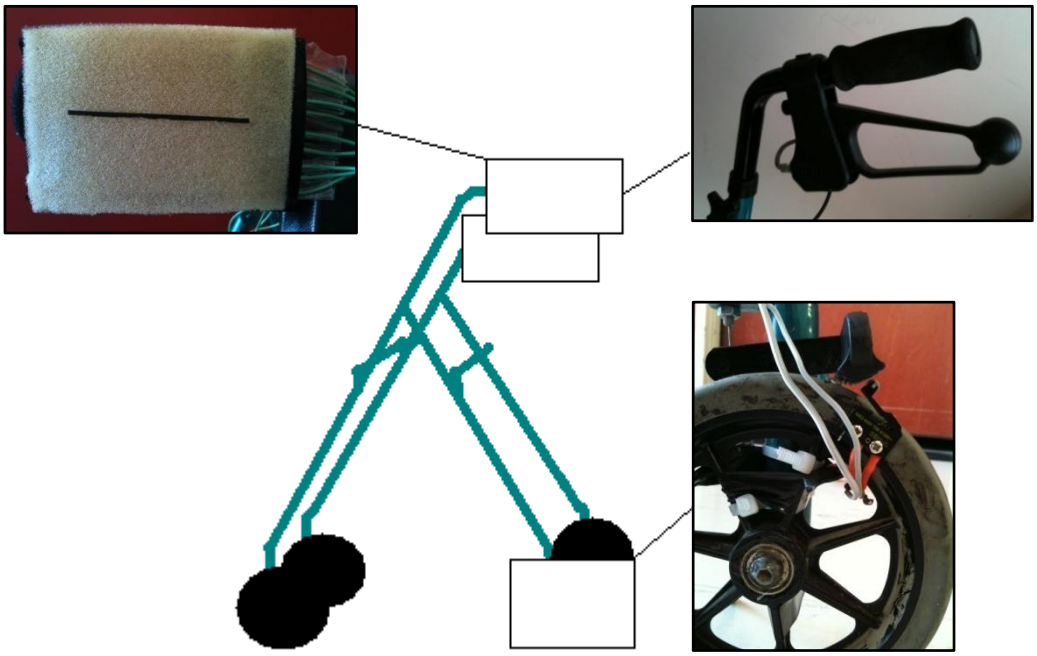


Figure 4.2. The modified Mobilis® Quad Walking Frame. This diagram illustrates the walking frame and the three major components attached to the frame: top left is a picture of the black line on the foam pad, top right is the bar to grasp, and bottom right is the switch on the brake pad.

Accuracy and reaction time were tested by grasping the brake and pressing the black line after a light signal. Figure 4.3 illustrates the nine wire switch schematic on a veroboard. The extreme top and bottom, and centre (which is where the black line under the foam pad is) switches on the veroboard were wired with a 9 V battery, the top three switches were connected with a 6 V battery, and the three bottom switches were connected with a 3 V battery. Each switch connected to a different channel on the PowerLab® system (Figure 4.3). The line on the foam pad was a 1mm wide strip of black masking tape 68mm long.

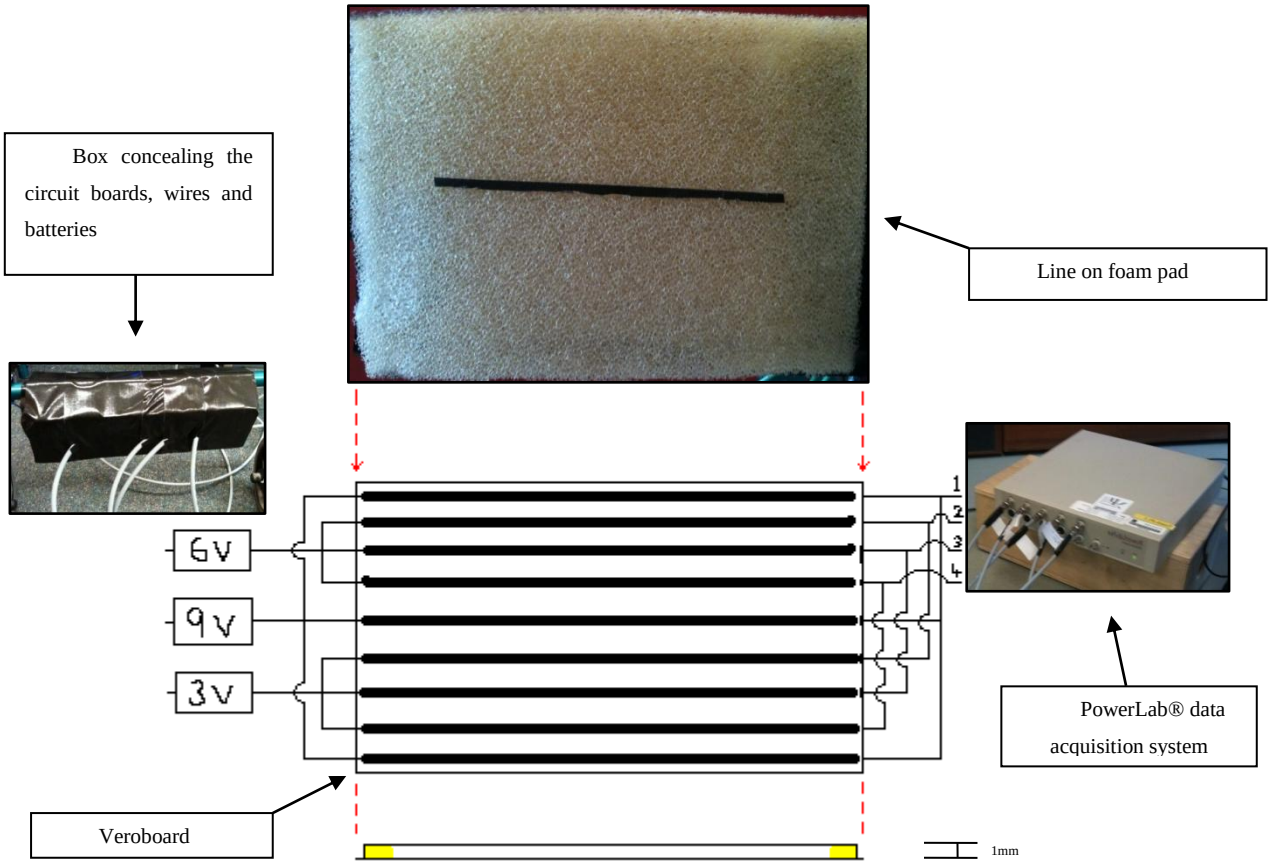


Figure 4.3. A veroboard containing 9 switches (represented by the thick black lines) with a line on a foam pad placed on top of it. This diagram represented the different voltage input to each switch and which channel on the PowerLab® data acquisition system and LabChart® the input were sent to. Height and length of the veroboard was 75mm and 130mm, respectively. Switches were raised above the veroboard, and spaced 7mm apart. The foam pad covering the switches was 5mm thick, and the black line placed on it is 1mm thick black masking tape and 68mm long.

To be able to adjust the height of the bar on the walking frame and the black line on a foam pad in relation to the participant, a wooden structure, an adjustable walking frame, and an adjustable seat were utilised. The wooden structure was designed to sit the walking frame on it and raise the walking frame by 380mm, see Figure 4.4. The wooden structure was also designed to raise the back wheels by 250 mm, so that the brake could be reversed and placed in a vertical position. The brake and black line could be placed horizontally or vertically on the walking frame, and there were 7 possible adjustable heights, see Table 4.1. The seat height could be adjusted from 450 mm to 690 mm, and fixated by three Velcro straps that held the stool in one place. This system enabled adjustments of the stool height to be made without compromising the fixed position of the subject, because significant movement would have affected the ocular fixation through the particular zone(s) of the glasses.

Table 4.1. Adjustable heights of walking frame for horizontally and vertically placed bar/line to the ground.

	Horizontal Heights (mm)	Vertical Heights (mm)
Top	935	1025
Penultimate from the top	910	1010
Antepenultimate from the top	890	1000
Middle	865	990
Antepenultimate from the bottom	840	975
Penultimate from the bottom	820	965
Bottom	800	950

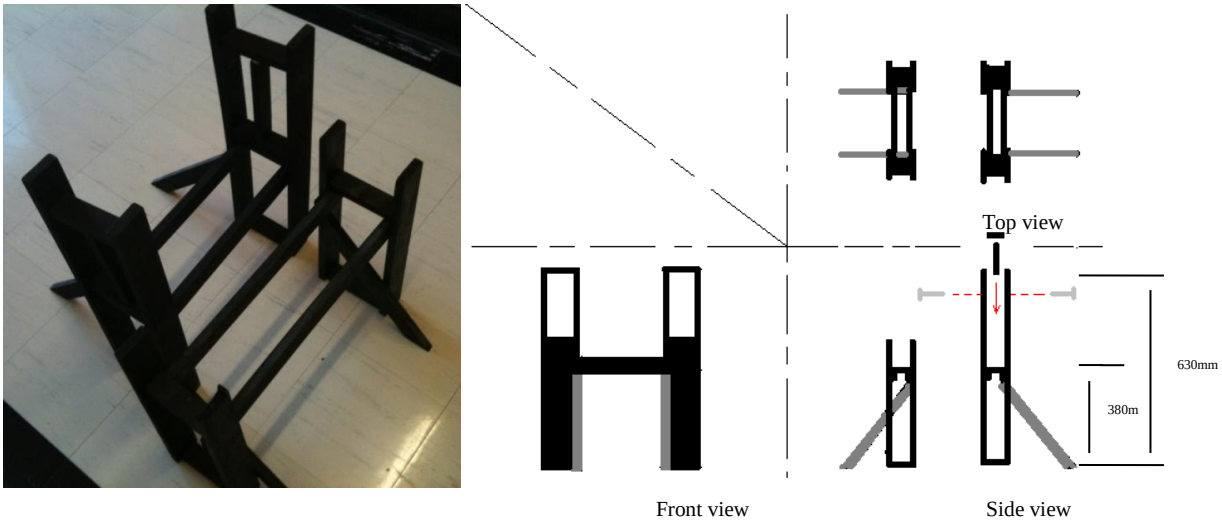


Figure 4.4. Wooden frame; photograph on the left, schematic/dimensions on the right.

4.2.3 BalanceMaster®/In VISION® system

The BalanceMaster® and In VISION® system together can isolate the visual aspect required for balance. The BalanceMaster® is a booth with a visual landscape and a platform that the participant stands on. The platform takes 100 measurements every second of each foot, in the x, z and y axis for both degree of deviation and velocity. The In VISION® system is a gyroscope head-wear, which can measure the participant's head angle and velocity, for pitch, yaw and roll head movements. All of these inputs and measurements were captured on the BalanceMaster's® computer system. Each participant wore a harness for the duration of the test and was connected to straps above the participant on the BalanceMaster®, which provided support if the participant lost balance. The harness also included a handle at the back for the investigator to provide additional support.

4.2.4 General equipment

Other equipment included a neck cuff to keep the head in a neutral position, and a black dot on a 100 x 100 mm plain white square paper for the participant to fixate on whilst in the BalanceMaster®.

The participant acquired their single vision (distance) glasses on testing day, so they did not have any time to adapt to this pair of glasses. Each new prescription of single vision glasses was identical and matched to the distant part of the individual's PAL and frame style. Where this was not possible due to a lack of supply; make, model, size and style of frame was matched as close as possible to the participant's chosen frame. The single vision glasses were not matched for scratch resistant lens coating and/or transitional tints, due to budget constraints. However, this was deemed unlikely to affect performance in the trials.

4.3 Methods

4.3.1 Recruitment

Thirty-one community-dwelling participants were recruited through optometrical practices in Dunedin.

4.3.2 Exclusion/Inclusion criteria

Participants aged ≥75 years from the Dunedin and Mosgiel communities who required a new/updated prescription of their PAL within the last 12 months were recruited. Testing occurred within 12 months of acquiring the participant's new/updated PAL.

Exclusion criteria were kept to a minimum to enable generalization of the results: 1) poorer than 6/12 vision in each eye or 6/12 with binocular vision when corrected with glasses [87], 2) ocular/retinal problems, 3) >2 dioptre difference of spherical anisometropia, 4) >4 dioptre of oblique astigmatism, 5) deformities of the arms, neck or head, 6) inability to stand, 7) suffering from dizziness or a recent injury or medical condition that affects coordination and ability to grasp, 8) not able to understand the study requirements, and 9) Mini Mental State Examination (MMSE) of <26.

Information for exclusion was collected through the participant's optometrist notes and a home visit conducted by the investigator.

4.3.3 Flow of participants through the study

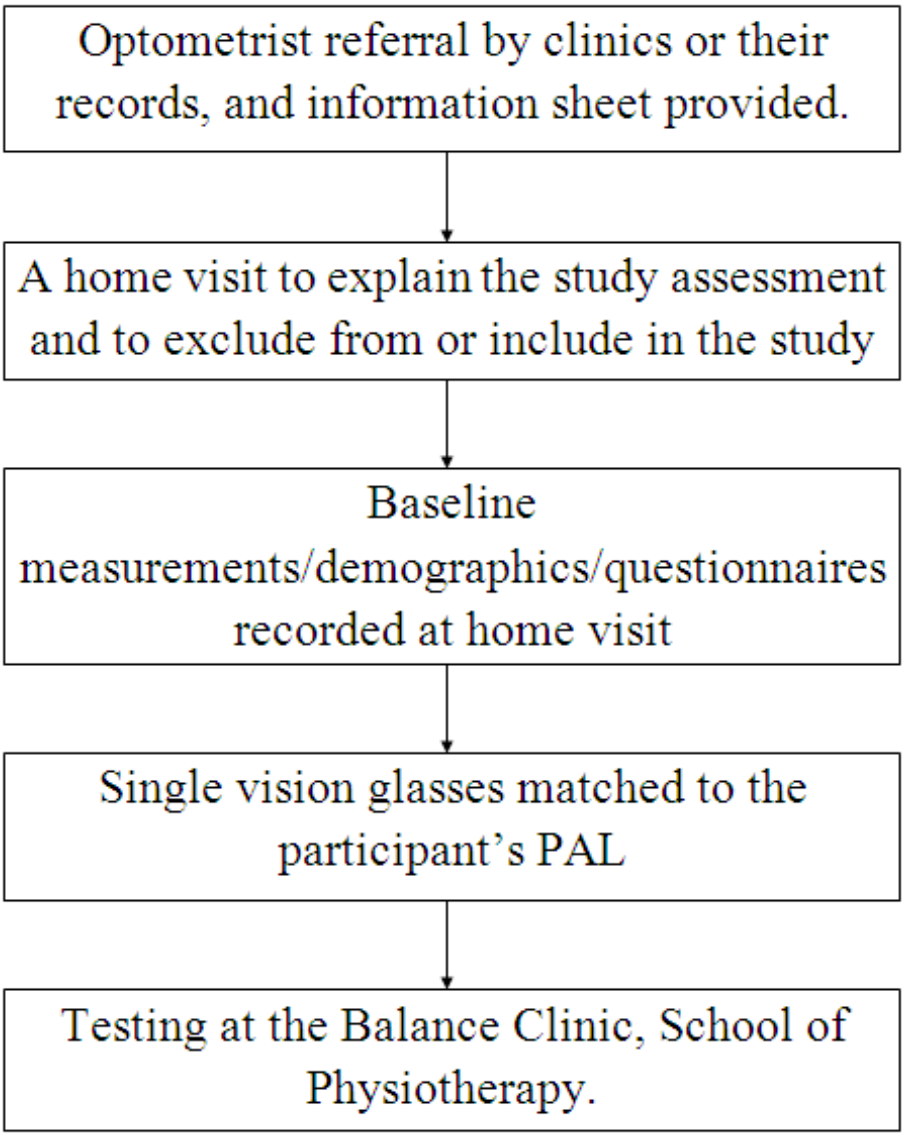


Figure 4.5. Flow of participants through the study.

4.3.4 Initial assessment

Demographic data (age, ethnic group, and living situation), current medication, medical conditions, MMSE, fear of falling (Falls Efficacy Scale – International (FES-I) questionnaire [88]), physical activity level (Adelaide Activities Profile (AAP) questionnaire [89]), a history of falls and injuries, and a review of their ocular capabilities and balance [see appendix for questionnaires] were documented at a home visit prior to ordering their single vision glasses and testing.

To verify that the prismatic displacement effect of a PAL, mapped in Chapter 3, was significantly greater than single vision glasses; the six specific points of fixation on the

glasses used during the trial, were measured with the focimeter. Paired T test was used to compare the prismatic displacement for PALs to single vision glasses at these points. The points of fixation used during the trial were within the zones of the glasses.

4.3.5 Consent

Written consent was obtained prior to testing and these studies were carried out with the approval of the - Lower South Regional Ethics Committee.

4.3.6 Randomisation

The order of the tests of the two types of glasses was randomised, with the investigator blinded to the order. In other words, whether each test started with PALs or single vision glasses were in random order. A statistician not involved with the study procedures prepared a computer generated randomisation and opaque envelopes with instructions as to the order of glasses to be worn. The schedule was made available on testing day and explained to the participant by a person independent from the study, in order to preserve blinding of the investigator.

Whether the bar or black line was positioned in an area of maximal or minimal prismatic displacement was randomized, sequence generation was by a computer random number generator prepared by the investigator.

So overall, the glasses and position of the bar or black line was randomized so that learning was kept to a minimum, and order effect was further analysed by repeated measures.

4.3.7 Blinding

PALs by design are inconspicuous and appear to be one constant power to an observer. It is almost impossible for an observer to tell if the glasses are PALs or single vision glasses (Figure 4.6). One of the reasons people choose PALs over bi/tri-focal glasses is because PALs make it difficult to tell the person’s age when presbyopia develops (Figure 4.7). Because of the design of PALs, this study was able to blind the investigator and subsequent analysis of the order of glasses. Consent and adjustment of the participant’s new single vision glasses occurred before blinding, and the schedule was made available in the Balance Clinic for each test day only.

Figure 4.6. Illustrating the two types of glasses; single vision (distance) glasses on the left and PALs on the right.

Figure 4.7. Demonstrating single vision (distance) glasses and PALs on a participant. Left photo is the participant wearing a single vision glasses, and the right photo demonstrates the participant wearing a PAL.

Randomisation/blinding were performed by giving the participants a sequentially numbered opaque and sealed envelope with a letter inside. This letter informed the participant which glasses to wear first and second. After consent and adjustment of the new single vision glasses had been acquired, the opaque envelope was opened and the randomisation procedure explained to the participant by a person independent from the study. Numbered tags were placed on the frames of each pair of glasses to allow the participant to wear the glasses in the correct order. The investigator then re-explained to the participant the need to 'refrain from describing the glasses as progressives or single distance as it is imperative that the investigator does not know the order during and after the test'.

4.4 Test 1 – Reaction time/Accuracy

Measurements of reaction time and accuracy were recorded by the LabChart® with the PowerLab® data acquisition system [86]. This system recorded the participant's reaction time and accuracy when grabbing a stationary bar and pushing a black line on a foam pad. In this project a fall is defined as a light stimulus and not the usual definition of a fall, 'an event which results in a person coming to rest inadvertently on the ground or floor or other lower level' [90].

4.4.1 Equipment set-up

See appendix for prepared instructions based on the participant's upper body height, which allowed the correct chair and walking frame height to be placed in accordance to different areas of fixation of the prismatic displacement of the glasses. The participant's height was measured at the home visit with Uzit™ Tape Measure 5 metres, while they sat on a solid chair and told to sit away from the back rest; a measurement was taken from the top of the seat to a point halfway up their glasses. Participants were placed in a neck cuff for the trials and fitted by the investigator with the investigator's fingers as a reference of neck length. The neck cuff was adjusted to one of 4 settings - tall, regular, short and no-neck; so that head movement was kept to a minimum and ocular fixation occurred only through the particular zone(s) of the glasses.

Illumination of the reaction time and accuracy equipment was measured by a 'minilux' portable photoelectric photometer, Salford Electrical Instruments lux metre to be 101 Lux.

The body movements were reduced by: 1) Velcro straps held the stool in one place, and 2) the distance from the bar/black line to the participant's glasses was two thirds of a metre, which was at a distance less than the participant's arm length [91]. This distance was measured with a set square ruler. Body movement were reduced so that the participant did not need to move forward in order to grab the bar or push the black line.

Masking tape on the floor positioned centrally and 35 degrees to each side of centre marked where the bar/foam pad was in relation to the chair and participant. A plum line was used to place the bar/foam pad in line with the masking tape.

All of the participant's movements were monitored by a video camera placed 17.5 degrees from centre, between the peripherally and centrally placed equipment. This camera was where the output (light stimulus) was placed. This was to keep eye movement constant between the

central and peripheral placement of the equipment.

Before randomization and concealment occurred both pairs of glasses were adjusted for comfort and a standard 20mm away from the participant's eyes to increase the effectivity of the prismatic displacement.

Figure 4.8. Bar placed vertically in the top background and foam pad in bottom foreground.

4.4.2 Testing procedure

The ocular fixation through the particular zone(s) of the glasses were based on the focimeter measurements reported in Chapter 3 (Figures 3.10 and 3.11) and using these data to place the equipment in the area of maximal and minimal prismatic displacement to determine if this had an effect on the participant's reaction time and accuracy. The particular points used, based on the focimeter results, were the co-ordinations [500, 300], [100, 100], [100, 200], [900, 100], [900, 200], and [500, 0].

[500, 300] is the centre of the lens and has no displacement horizontally but maximal displacement vertically. [100, 100] and [900, 100] are left and right respectively, which have no vertical displacement. Points [100, 200] and [900, 200] are left and right respectively and are areas with the biggest horizontal displacement. Lastly, [500, 0] is 300mm down from the centre of the lens and correlates to again no vertical prismatic displacement.

The bar was placed horizontally and vertically in front and to the dominant hand side of the participant, at a distance of 666.6mm away from them.

The bar was randomly placed vertically in either the:

i. Centre of the field of view (0 mm of horizontal displacement), or
ii. 35º to their dominant hand side and 200 mm down from centre (13.3 mm of outward horizontal displacement)

And, randomly placed horizontally in either the:

i. Centre of the field of view (13.3 mm of upward vertical displacement), or
ii. 35º to their dominant hand side and 100 mm down from centre (0.83 mm of downward vertical displacement)

The black line on a foam pad was randomly placed vertically in either:

i. Centre of the field of view (0 mm of horizontal displacement), or
ii. 35º to their dominant hand side and 200 mm down from centre (13.3 mm of outward horizontal displacement)

And, randomly placed horizontally either in the:

i. Centre of the field of view (13.3 mm of upward vertical displacement), or
ii. 300 mm down from the centre (0.83 mm of upward vertical displacement)

Figure 4.9. The investigator demonstrating the reaction time test.

In summary, the study measured the reaction time and accuracy with grabbing a bar and pushing a black line in the area of maximal vertical and horizontal displacement, and this was compared to the areas of minimal vertical and horizontal displacement.

A video camera placed in front of the participant was synchronised with their hand movements to grab the bar and push the black line for interpretation of the results.

Participants were asked to sit comfortably on a chair with their arm by their side in a neutral position. They were instructed to relax and stare at a light emitting diode (LED) in front of them, and when it turned on to reach out with their dominant hand and grab the whole bar or push the black line with their index finger, as quickly as possible. Enough strength to grip the bar or push the black line was needed to generate an input to the LabChart® and end the test.

The room was at mesopic conditions and there was time to rest after each test.

4.4.3 Outcomes

The main outcomes were reaction time and accuracy when pushing a bar at different points of fixation through the glasses as described above. Each test was repeated three times and the fastest time and associated accuracy were used in the analyses.

4.4.4 Validation of measure of accuracy

The participant's finger movements when pushing a line on a foam pad was recorded by a video camera behind them. The camera view was used to compare if the 9 wire switches were measuring accurately where the participant's index finger was placed.

4.5 Test 2 – Balance

The BalanceMaster® and In VISION® system was used to measure the participant's stability. This test assessed postural stability when wearing the two different types of glasses, at the same time removed proprioception and stressed the vestibular system, so that the visual aspect of balance was isolated.

4.5.1 Equipment set-up

Masking tape was placed on the BalanceMaster® platform that correlated to 14° of external rotation of the long axis of each foot, and stance width equal to 11% of the participant's height. This was the most stable stance for balance [92]. A camera was placed on the top of the BalanceMaster®, viewed from a 'bird's eye view' angle and recorded the participant's head, arm and body movements.

A black dot target was placed on the front of the booth of the BalanceMaster®. The height of the dot represented the line of vision on the ground 1.35 m away, which represented two steps and the distance required to view hazards [77].

A harness was fitted to the participant and strapped to the BalanceMaster® with enough tension to allow sufficient movement but provide support if a fall ensued.

4.5.2 Testing procedure

The testing procedure was explained to the participant before starting the test, and demonstrated by the investigator.

The person was instructed to stand in the BalanceMaster® machine and look at a dot above the ground with the head in neutral position. They were instructed to wear the In VISION® system and move the head from side to side, in a yaw direction. This was at a constant rate of 100 degrees/second between angles of 30 degrees, each side of the neutral head position, which correlated to the same areas tested with the reaction time and accuracy study, and the areas of maximal variation in prismatic displacement reported in Chapter 3 (Figures 3.10 and 3.11). The In VISION® system signalled the rate by a series of tones and

this movement was intended to stress the vestibular system [78]. When the participant was comfortable with this movement, the test began and required them to balance on a platform, and measurements of body sway were recorded. Trials lasted 20 seconds to minimise fatigue and there was time to rest after each test, if needed. Each trial was repeated three times for each pair of glasses, and glasses were again randomized by order. Throughout the tests the participant was in a harness and the investigator with a current medical first aid certificate was present to support the participant if they became unsteady.

Participants were barefoot through the test, and were instructed to place their feet with the big toe and heel on the masking tape, and the medial malleolus in line with the black markings on the platform of the BalanceMaster®. This was checked by the investigator.

Accuracy of fixation of the dot was not monitored because of equipment limitations (Figure 4.10). However, the investigator explained what was required of the participant before starting the test and throughout testing the investigator kept reminding the participant to fix their eyes on the dot.

The visual landscape on the booth of the BalanceMaster® in the participant's field of vision was similar to an outdoor environment (Figure 4.10). It was assumed that the booth would be distorted due to the prismatic displacement effect and affect the ability to stabilise when proprioception and vestibular function was removed.

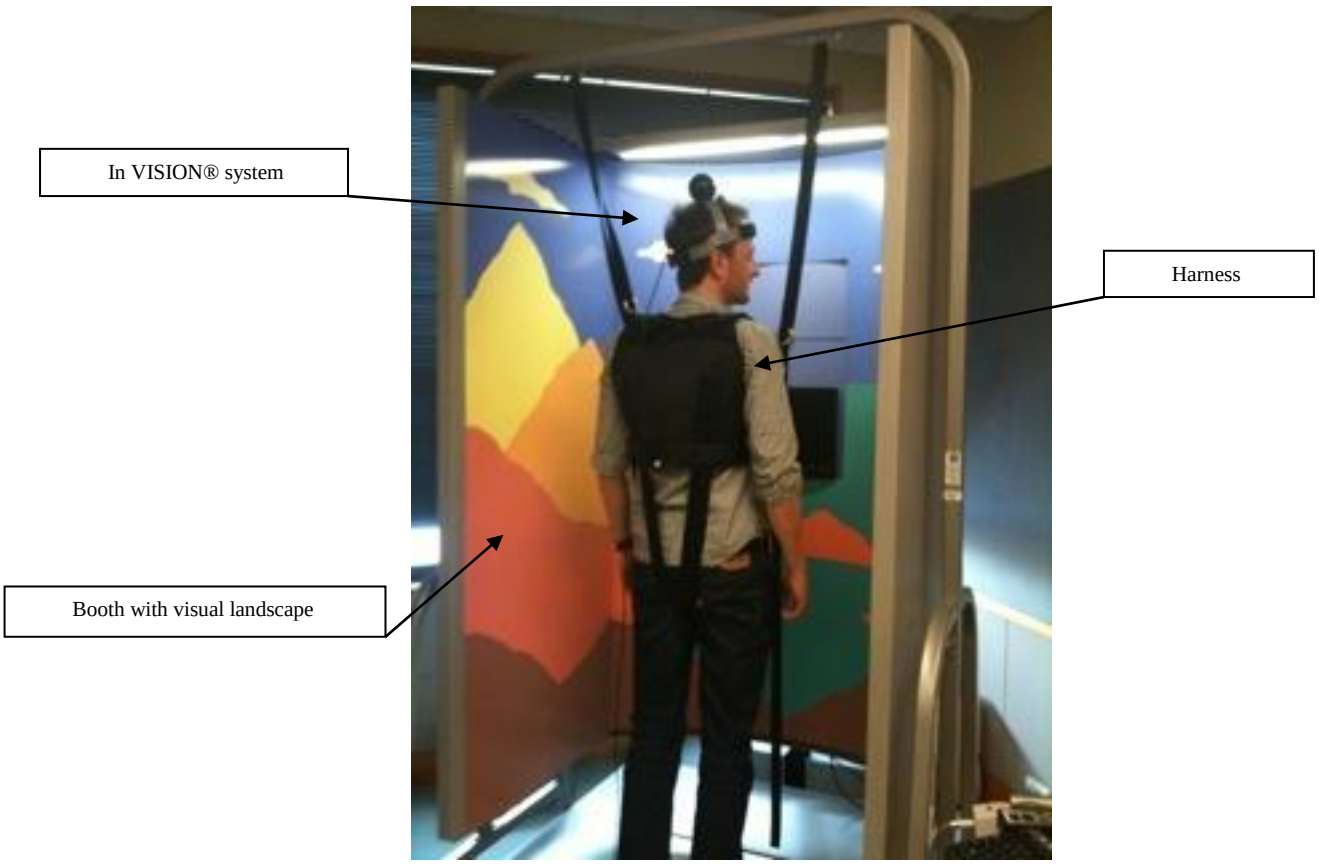


Figure 4.10. Illustrating the In VISION® (on investigators head) and BalanceMaster® system. Notice the booth with visual landscapes and the limitation for viewing the participant with a camera.

4.5.3 Outcomes

Primary outcome was the EQ score, which is the AP peak-to-peak sway angle, θ (in degrees), using the equation EQ = 100 x (1 – (θ/12.5), where 12.5 is the maximum theoretical peak-to-peak sway in the sagittal plane. For θ ≥ 12.5, which is scored as a fall, the EQ score is zero [93], comparing PALs to single vision (distance) glasses. Measurements were made through the balance platform and the BalanceMaster's® computer system calculated the EQ score.

Secondary outcomes were on the velocity of the participant's head in the yaw direction, the average pitch of the participant's head, and how many supports the participant required throughout testing based on video 'bird's eye view' camera recordings.

4.6 Subjective questionnaire about comfort

After test 1 and 2, the participant was asked about how they felt when wearing the two different glasses. The question asked was: 'out of a scale of 10, 10 being the most comfortable and 0 being the least, how did you feel when wearing the number 1 glasses'. This question

was then repeated for the 2nd pair of glasses. When the participant could not decide between two numbers the highest number was recorded, and half numbers were round up to the nearest whole number. This question was asked straight after each testing procedure and the participant was pre-warned at the start of testing that this question would be asked.

Response bias could have affected this questionnaire as the participant knew which glasses they wore, and no steps were taken to reduce this. However, the investigator was not biased in how the question was asked, as he was blinded to the type of glasses.

4.7 Sample size

Sample size calculation was based on a within patient standard deviation of reaction time of 58 ms (0.97 s) [2] and a difference between the two glasses of 45 ms (0.75 s). At a significance level of 0.05 and a power of 0.8, 29 participants were needed for this crossover trial. As this is a descriptive (pilot) study, 29 participants will give useful information to be the basis for further larger studies.

4.8 Statistical analysis

Data were analysed using the Statistical Package for the Social Sciences (SPSS) version 18 and presented as mean (SD), mean difference (95% CI) or number (percentage). To test whether each measure of reaction time, accuracy and stability differed between the two types of glasses, paired t-test or repeated measures analysis of variance and covariance were used. Repeated measures was used to analyse 1) reaction time, controlling for length of time since updating their glasses, prismatic displacement and order of glasses; and 2) stability, controlling for length of time since updating their glasses, order of glasses, and velocity of head movement. Accuracy measurements were analysed using the chi squared McNemar test. The LabChart® measurements were verified from the video recordings, to confirm whether the participant pushed the black line. The remainder of the secondary measures were analysed using paired t-tests.

Chapter 5 – Reaction time and accuracy of the protective response

5.1 Introduction

This study examined whether reaction time and accuracy when grabbing a bar and pushing a black line is effected by wearing PALs, compared with single vision (distance) glasses. As described in Chapter 3 the maximal and minimal prismatic displacement effects of a PAL on reaching out and grasping the equipment were measured. Reaction time and accuracy is a proxy outcome for whether wearing PALs affects stabilising oneself if a slip, trip or loss of balance occurs. No other studies have previously established whether the protective response in relation to a slip, trip or loss of balance is compromised by the prismatic displacement of PALs.

5.2 Methods

The equipment and details of this trial were described in Chapter 4. Participants aged ≥75 years with no ophthalmological or other health concerns were recruited for this trial.

The outcomes of interest were participants' reaction times and attempts to grab a bar and push a black line in their field of vision and were assessed with multifocal and single vision glasses, which were worn in random order. The bar and line were placed in the areas of maximal and minimal prismatic displacement, which was determined by the measurements of this effect for a PAL as reported in Chapter 3.

The measurements were of two variables: 1) the time from the light turning on until the participant squeezed the bar or pushed the black line with enough pressure to record a trace on the LabChart®; 2) the accuracy with which the participant pushed the black line, assessed by switches under and either side of the black line spaced 7mm apart, and a video recording of the participant's finger movements. Each test was carried out three times with each pair of glasses for each position of the bar and black line and the fastest time of this set of three was analysed to reduce learning bias. SPSS version 18 was used to analyse the prismatic displacement difference between the two glasses at specific points using repeated measures analysis of variance, and accuracy was analysed with the McNemar chi square test. Accuracy

measurements were recorded by which switch was pushed first and whether the participant's finger touched the black line or missed on the video recording.

5.3 Results

5.3.1 Sample recruitment

Figure 5.1 illustrates the recruitment of the cohort of older people, included in this study (n = 31). 54 potentially eligible participants were approached, 15 were excluded because they were not contactable, declined participation or one of the exclusion criteria. 31 (57.4%) participants were included in this study.

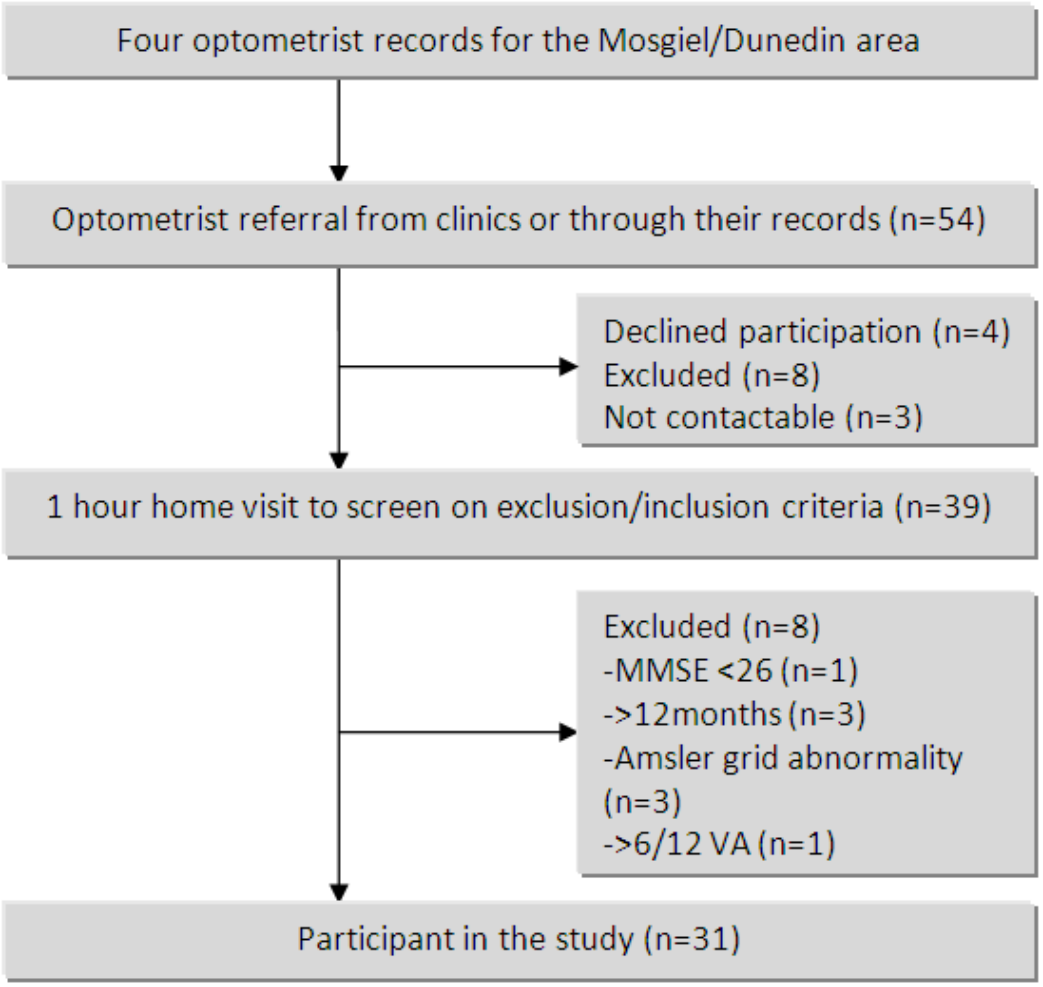


Figure 5.1. Participant recruitment.

5.3.2 Participant characteristics

Table 5.1 shows the baseline demographics, level of independence, cognition, health, visual function, activity, and physical performance of the participants. It illustrates that the majority of the cohort were healthy, active, and independent with ADL.

Table 5.1. Baseline characteristics of participants. Values are numbers (percentages) unless otherwise stated

Demographic factors	
Mean (SD) age (yrs)	79 (3.4)
Men	12 (38.7)
NZ European	29 (93.5)
Living arrangements	
Own home	28 (90.3)
Living alone	13 (41.9)
>1hr home help, per week	3 (9.7)
Meals on wheels	2 (6.5)
Medical conditions	
Mean (SD) MMSE* score [1]	27.7 (1.1)
One or more falls in previous year	12 (38.7)
No of falls with PALs	11 (45.8)
≥average subjective health†	27 (87.1)
Stroke	4 (12.9)
Parkinson's disease	1 (3.2)
Hip fracture	1 (3.2)
Hip/knee pain	6 (19.4)
Diabetes	4 (12.9)
Other medical problems	10 (32.3)
Medication use	
Four or more medications	20 (35.5)
Psychotropic medications	3 (9.7)
Vision and physical function	
Mean (SD) visual acuity (MAR‡)	1.38§ (0.38)
Mean (SD) edge contrast sensitivity (dB)	15 (2.4)
Mean (SD) sit to stand five times test (s)	17 (7.7)
Mean (SD) FICSIT 4 score [2]	4.0 (1.1)
Mean (SD) FES-I fall anxiety score ll [3]	23.0 (5.4)
Mean (SD) AAP score ¶ [4]	61.4 (8.7)
Mean (SD) length of time with PALs (yrs)	11.8 (10.7)

* Mini Mental State Examination; † ≥ average subjective health = ≥ good, rang from excellent, very good, good, fair, poor; ‡minimum angle resolvable in Minutes of Arc, § approx. Snellen equivalent 6/9 to 6/6; ll not anxious about falls (16 not anxious, 64 very anxious); ¶ Middle for activity level (21 unfit – 84 fit).

Abbreviations: s = seconds, dB = decibels, FICSIT 4 = Falls and Injuries: Cooperative Studies of Intervention Techniques, FES – I= Falls Efficacy Scale – International, AAP = Adelaide activities profile, PAL = progressive attenuated lens, yrs = years

5.3.3 Prismatic displacement measurements at specific points of the glasses

Table 5.2 shows the prismatic displacement at the specific positions tested, comparing the participant's PAL with their new pair of single vision glasses. The points measured by the focimeter on the participant's glasses are the points with maximal and minimal prismatic displacement, as defined in Chapter 3.

The results show a significant vertical displacement difference between the two glasses at the centre of lens, significant difference in horizontal displacement at 35^0 peripherally and down 200 mm from the centre, and a significant difference in vertical displacement at 35^0 peripherally and 100 mm down from the centre. The two central axis points showed a non-significant difference between the two glasses, that is, horizontal displacement at the centre, and vertical displacement at 300 mm down from the centre of the glasses. Furthermore, at all the points tested, PALs had larger prismatic displacement compared with single vision glasses.

Vertical displacement at 35º peripherally, 100 mm down from the centre was the second largest displacement measured. The vertical displacement at 35^0 peripherally, 200mm down from centre showed a small insignificant difference between the two glasses, mean 1.02mm (CI, 95%, -0.64 to 2.69), the minimal vertical displacement at 35° peripherally is either between 100mm to 200mm down from centre or further than 200mm down the lens.

Table 5.2. Ocular fixation zones of PALs compared with matched single vision (distance) glasses, prismatic displacement (mm) at 666mm from the lens.

	No	PALs Mean (SD)	Matched single vision distance glasses Mean (SD)	Mean difference (95% CI)	P-value
Vertical displacement – centre of lens	31	9.73 (4.20)	1.59 (1.84)	8.15 (6.54 to 9.75)	<.001
Horizontal displacement – centre of lens	31	4.92 (3.72)	4.35 (3.16)	0.56 (-0.46 to 1.59)	.271
Vertical displacement – 300mm down from centre of lens	31	10.67 (7.57)	9.70 (7.06)	0.97 (-0.75 to 2.68)	.258
Vertical displacement – peripheral 35 degrees, 100mm down from central	31	6.32 (3.33)	4.49 (3.38)	1.83 (0.52 to 3.14)	.008
Horizontal displacement – peripheral 35 degrees, 200mm down from central	31	15.54 (10.22)	13.31 (9.50)	2.23 (0.37 to 4.09)	.020

Abbreviations: PAL = progressive attenuated lens, SD = standard deviation, CI = confidence interval

Table 5.3 illustrates that repeated measures analysis of the distance between lenses of the participants' PALs compared with the specific points of displacement between each lens of

the glasses was not statistically significant. The average focal length of the reading portion of the participant's PALs is, mean 398.0 mm; 95% CI, 384.9 to 411.1.

Table 5.3. P value associated with relationship for distance between lenses and prismatic displacement between each lens of the PAL.

	Focimeter difference	Vertical central	Horizontal central	Vertical 300mm	Vertical 100mm	Horizontal 200mm
Distance between lenses		.364	.126	.765	.621	.309

5.3.4 Difference in reaction time between progressive addition lens and single vision glasses

Table 5.4 shows the reaction time measures for the different points localised through the glasses for both the bar and the black line, comparing PALs with single vision glasses. All 31 participants completed the trial but 3 areas of fixation tested did not record measurements of reaction time for all 31 participants. Blinding of the investigator was maintained through-out the trial and afterwards during analysis.

Most of the differences in reaction time measures were not statistically significant when wearing the two glasses. However, the horizontal black line placed 300mm down from the centre was significant P = 0.007 (repeated measures for order effect, time to update their PALs and prismatic displacement), and reaction time is faster when wearing PALs by 0.08 of a second. The other significant result is the horizontal bar at the centre of the glasses and PALs are faster by 0.101 of a second, P = 0.011 (repeated measures for order effect, time to update their PALs and prismatic displacement).

Table 5.4. Reaction times in seconds for the various points of fixation through the glasses, comparing PALs with single vision glasses

Deviation from centre (degrees)	Position of bar or line			Progressive multifocal glasses		Single vision distance glasses	Mean Difference (95% CI)	P value*
				No	Mean (SD)	Mean (SD)		
0	Centre of lens	Horizontal	bar	31	1.105 (0.332)	1.206 (0.340)	-0.101 (-0.203 to <0.001)	.011
			line	31	1.181 (0.478)	1.154 (0.358)	0.027 (-0.054 to 0.107)	.963
		Vertical	bar	30	1.223 (0.326)	1.232 (0.266)	-0.009 (-0.063 to 0.044)	.224
			line	31	1.063 (0.321)	1.089 (0.281)	-0.026 (-0.070 to 0.018)	.413
	300mm down from centre of lens	Horizontal	line	31	1.032 (0.279)	1.112 (0.049)	-0.080 (-0.113 to -0.046)	.007
35	100mm down from centre of lens		bar	30	1.080 (0.269)	1.117 (0.278)	-0.037 (-0.110 to 0.036)	.444
	200mm down from centre of lens	Vertical	bar	31	1.152 (0.280)	1.145 (0.319)	0.007 (-0.059 to 0.100)	.558
			line	30	0.959 (0.239)	0.953 (0.221)	0.006 (-0.043 to 0.054)	.714

*P value associated with repeated measures, controlling for order effect, time since new PALs, and amount of prismatic displacement

Figures 5.2 and 5.3 represent a graphical interpretation of the reaction time measurements, and illustrate the significant differences between the two glasses in the central visual axis. Differences in peripheral measurements were not statistically significant.

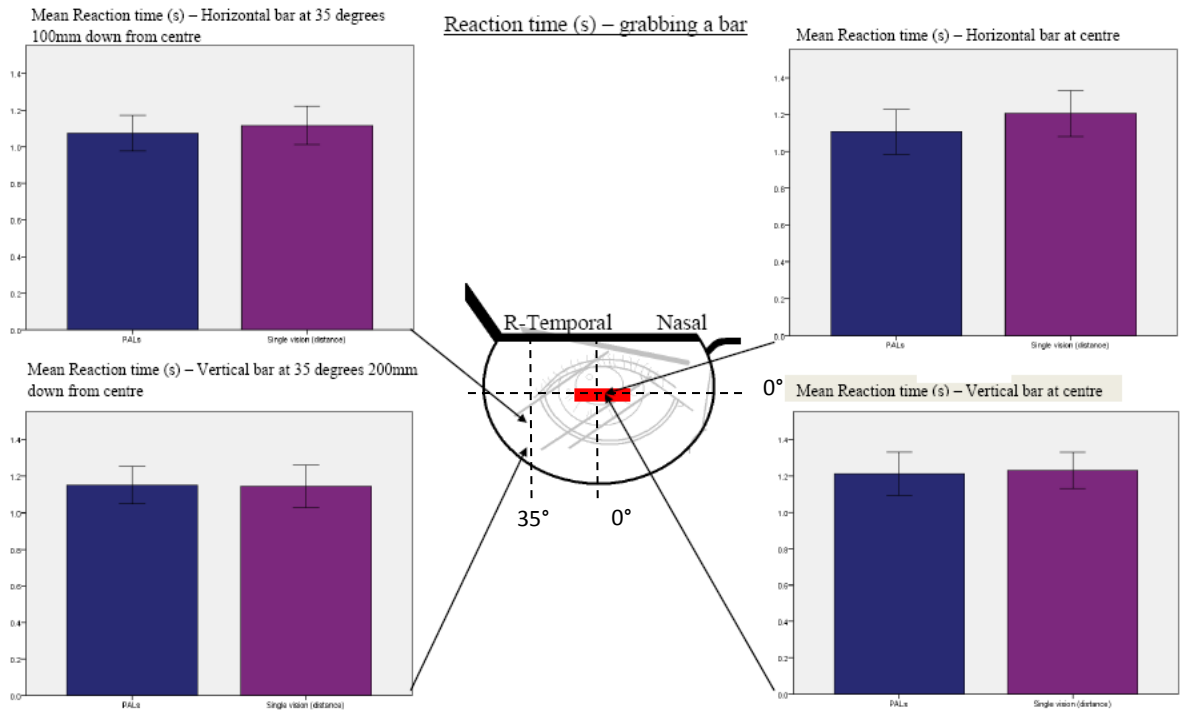


Figure 5.2. Reaction time measurements for grasping a bar at the various points of fixation while wearing the two glasses. The red line on the glasses illustrates a significant difference of reaction time and orientation of the equipment. Blue represents PALs and maroon represents single vision (distance) glasses.

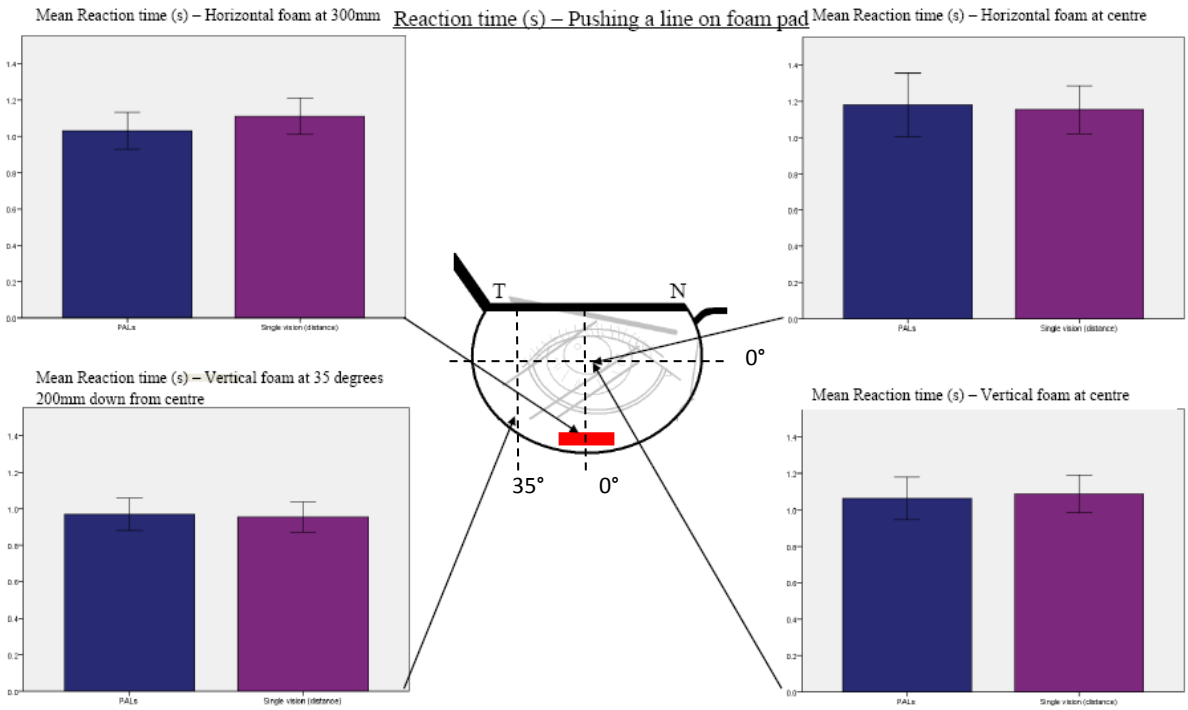


Figure 5.3. Reaction time measurements for pushing a black line at the various points of fixation while wearing the two glasses. The red line on the glasses illustrates a significant difference of reaction time and orientation of the equipment. Blue represents PALs and maroon represents single vision (distance) glasses.

5.3.5 Accuracy measurements for pushing a black line wearing progressive addition lens compared with single vision glasses

The Tables 5.5 to 5.8 illustrate the results for accuracy in pushing a black line when wearing PALs and single vision glasses. Figure 5.4 illustrates accuracy at the specific points that participants localised through the lens. Differences between measurements did not reach statistical significance; however participants showed a tendency to be more inaccurate whilst wearing PALs compared with single vision glasses at the edges of the glasses. At the centre of the lens, PALs showed a trend to be more accurate when the black line was placed vertically, and accuracy between the two glasses was similar when the black line was placed horizontally. Figure 5.5 illustrates the same results but in a pie graph form. The video tape recordings of the foam pad with a black line on it endorsed the findings of the switches using the LabChart® and PowerLab data acquisition system®.

Table 5.5. Accuracy, horizontal black line at centre[1]

		Single vision (distance) glasses		Total
		Accurate	Not accurate	
PALs	Accurate	7 (23%)	5 (16%)	12 (39%)
	Not accurate	6 (19%)	13 (42%)	19 (61%)
Total		13 (42%)	18 (58%)	31 (100%)

McNemar Test *P* = 1.000 (binomial distribution used)

Table 5.6. Accuracy, vertical black line at centre[2]

		Single vision (distance) glasses		Total
		Accurate	Not accurate	
PALs	Accurate	3 (10%)	10 (32%)	13 (42%)
	Not accurate	3 (10%)	15 (48%)	18 (58%)
Total		6 (19%)	25 (81%)	31 (100%)

McNemar Test *P* = .092 (binomial distribution used)

Table 5.7. Accuracy, horizontal black line 300mm down from centre[3]

		Single vision (distance) glasses		Total
		Accurate	Not accurate	
PALs	Accurate	6 (19%)	3 (10%)	9 (29%)
	Not accurate	8 (26%)	14 (45%)	22 (71%)
Total		14 (45%)	17 (55%)	31 (100%)

McNemar Test *P* = 0.227 (binomial distribution used)

Table 5.8. Accuracy, vertical black line at 35º peripherally at 200mm down from centre[4]

		Single vision (distance) glasses		Total
		Accurate	Not accurate	
PALs	Accurate	7 (23%)	2 (7%)	9 (30%)
	Not accurate	6 (20%)	15 (50%)	21 (70%)
Total		13 (43%)	17 (57%)	30 (100%)

McNemar Test $P = 0.289$ (binomial distribution used)

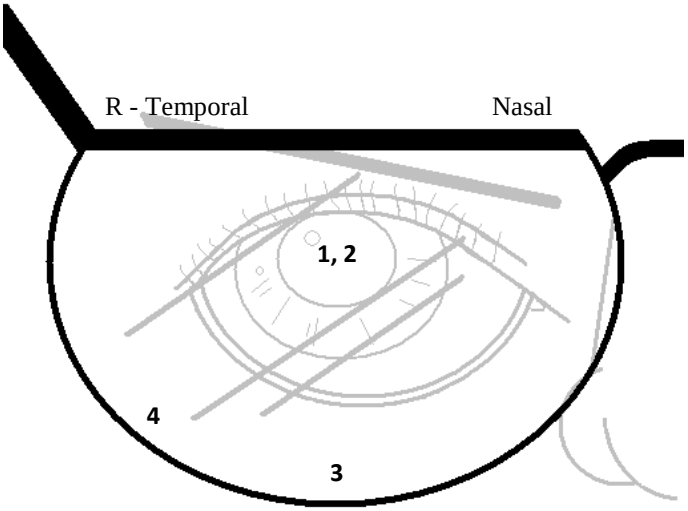


Figure 5.4. The right lens of the glasses and. Numbers represent the accuracy between the two glasses at the various points of fixation and are linked to the superscript on tables 5.5 to 5.8.

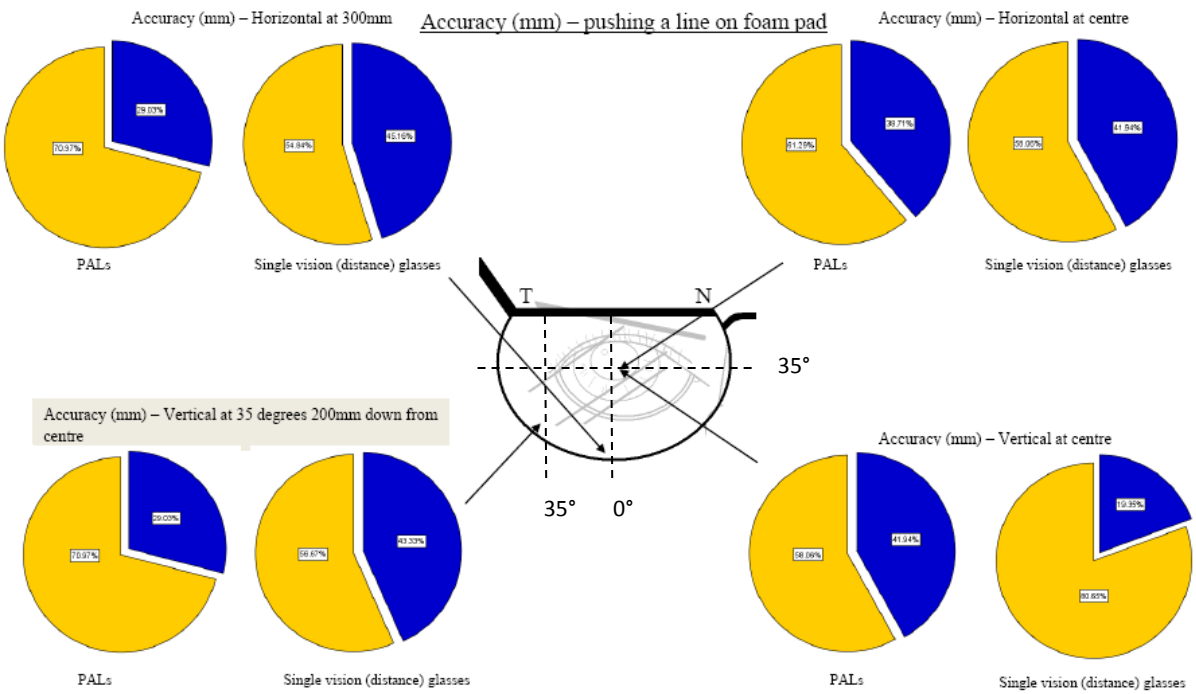


Figure 5.5. Accuracy measurements. The pie graphs represent accuracy of the participant to push the black line on a foam pad at the various points of fixation. Blue = pushed the black line and yellow = missed the black line.

5.4 Discussion

5.4.1 Principle findings consistent with previous research

The principal findings of this study showed that when wearing PALs, participants have a significantly faster reaction time when compared with single vision glasses and in two specific positions: 1) 300mm down from the centre pushing a black line; 2) centre of the lens grasping a horizontal bar. This study found no overall statistically significant result on accuracy and reaction time for pushing a black line and grasping a bar in the other positions of the glasses, when comparing PALs with single vision glasses. However, overall there is a trend for PALs to be less accurate at the edges of the glasses, but for most areas tested through the glasses, reaction time for PALs were faster. It is interesting to note that when the black line was placed at the centre of the lens there was no difference in reaction time, but there was a difference when grasping a bar at this position.

This result is consistent with the study of Lord *et al.* on wearers of multifocal glasses and the risk of falls. In which one of the secondary measures was reaction time. The study showed that participants who wore multifocal glasses were faster to react compared with non-multifocal glasses wearers, mean (SD) 276 (57) and 288 (58) ms, respectively [2]. However, the methods of that study were not comparable to the study reported in this thesis.

Results from this study are also consistent with the VISIBLE trial, which suggests that swapping multifocal glasses with single vision distance glasses had no overall effect on falls prevention (incidence rate ratio (IRR) 0.92, 95% CI 0.73 to 1.16) [5]. Additionally, by replacing multifocal with single vision glasses there was a significant increase in falls in older frail people compared with controls who continued wearing their multifocal glasses, especially in an unfamiliar environment (incidence rate ratio (IRR) 1.56; 95% CI, 1.11 to 2.19) [5]. The possible reason for this effect may be that frail older people cannot adapt quickly to the prismatic displacement of a new pair of glasses, which results in new stored visual-spatial information (VSI) and is inaccurate due to the reverse adaptation of the central prismatic displacement. This concept will be explained further in the next section.

5.4.2 Adaptation to the prismatic displacement effect and swapping glasses

Anecdotal evidence suggests that when first prescribed multifocal glasses there is a significant undulating effect, which takes time to become accustomed to. This undulating effect is due to the prismatic displacement, and people have the unique ability to adjust and

compensate for this effect. Hess, Shipman (1965), and Sperry (1943) have demonstrated that animals do not have this ability to adapt to a change in visual perception [81].

Inferences can be made from Cummings *et al.'s* trial (2007) and the VISIBLE trial with regard to adaptation to the effect of multifocal glasses [5, 35]. Cumming *et al.* looked at updating participants' glasses and an ophthalmological review if needed, and found that those in the intervention group, over a 12 month period, increased their risk of having a fall. This increase in fall rate was most prominent in the first 3 months of updating their glasses [35]. However, no one has specifically defined the length of time needed to adapt to multifocal glasses.

Indeed, by training older adults with visual perceptual-motor mismatch for 20 minutes, they performed better in balance and locomotor control, which was retained for 4 weeks [98]. Furthermore, it is shown that people can adjust to glasses that are inverted and once these are removed, they adjust back. It is suggested that this is due to the brain accommodating to the change, through recalibration of hand placement and extra-retinal eye movements, rather than a correction of the vision [83]. Therefore, participants who wear PALs frequently may be able to react quicker than with single vision glasses because they have adapted to the prismatic displacement of PALs. Subsequently, by reversing this effect by replacing the glasses, the participant is required to re-adjust to this change. In addition, the study reported in this chapter may have illustrated this effect because participants who already have adapted to their PALs were then given a new pair of single vision glasses at the time of testing. By swapping to glasses with less prismatic displacement i.e. single vision glasses, the prismatic displacement direction and magnitude changed relative to their usual glasses. The participants now hesitated and were slower and possibly less accurate with the new glasses because presumably the participants have not had time to adapt to the relative change in displacement. It is not unreasonable to postulate that this effect may work in reverse but would need further study to prove this.

5.4.3 Central visual axis of vision and the difference in reaction time

Participants who wore PALs compared with single vision glasses were faster at grasping a bar and pushing a black line when placed in the central visual axis. Conversely, there was no statistically significant difference seen between the two pairs of glasses at 35° peripherally. The central part of the lens is described as the corridor of clear vision through the progression zone, where the astigmatism does not exceed +1.00D [99]. There are two main types of progressive lenses with regards to this area: soft and hard designs. The soft design has the

least amount of prismatic displacement and astigmatism but with less of a clear corridor of vision, while the hard design has a larger area of clear vision but more extreme variations of prismatic displacement and astigmatism in the periphery see Figure 5.6. This corridor of clear vision is important because it is the area of the lens which is the area of vision used for ADL. Subsequently, anything that affects vision in this area may have a significant effect on falls as opposed to the edge of the glasses, which was initially hypothesised because of the larger variation in prismatic displacement. The results from this present study demonstrated no significant difference in reaction time or accuracy in the periphery of the glasses, even though the largest variation in prismatic displacement is found at the edge of the glasses. The prismatic displacement difference between the two glasses in the centre of the lens was large at around 8.15mm of vertical displacement, and a position in the periphery of the glasses that was tested was small, around 2.23mm of horizontal displacement. Therefore, testing in areas of larger prismatic displacement in the periphery could potentially show a significant difference between the two glasses. However, there was a trade-off to avoid testing outside the frames of the glasses.

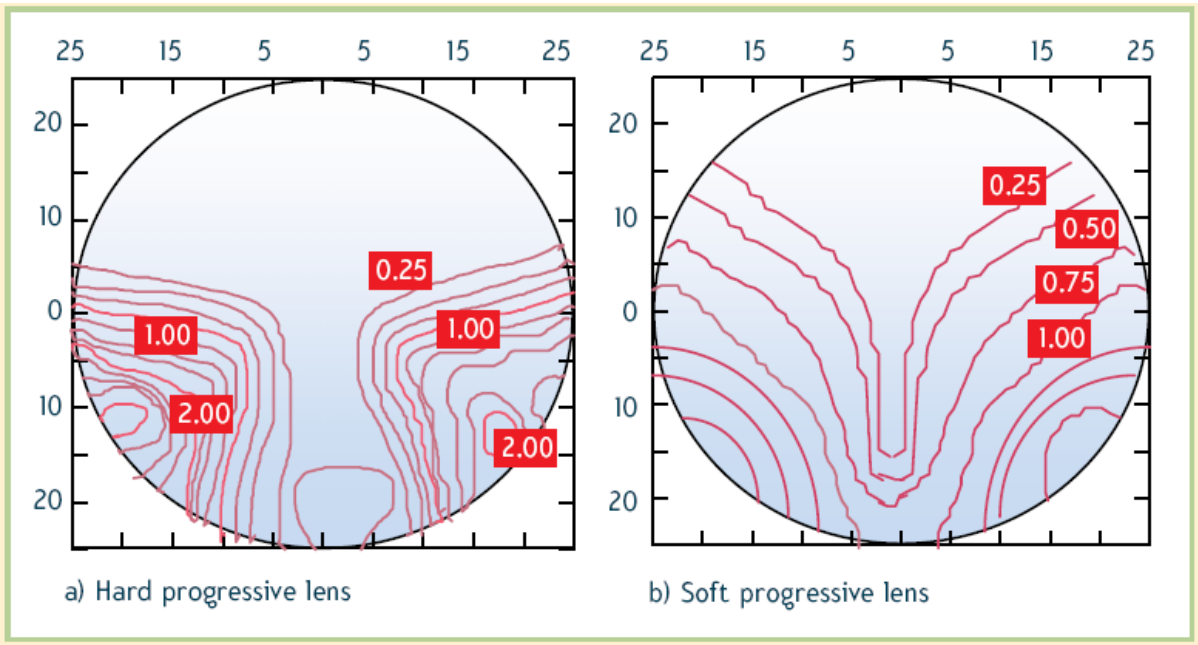


Figure 5.6. Comparison of isocylinder lines for hard and soft progressive lens designs of power, plano add +2.00D [99].

Whilst there was no significant difference in reaction time and accuracy in the periphery, there was a significant difference between the two glasses in the centre axis of the lens. In addition, the observed effect of the body position on a perturbation was that the arms reflexively moved out to the side with the head and eyes in a central position, which will be discussed further in Chapter 6. Therefore, anything affecting peripheral vision may not have an effect on the protective response of a trip, slip, or loss of balance. The possible explanation

behind the effect seen centrally may be due to the relative change and adaptation to the prismatic displacement effect when replacing glasses.

5.4.4 Prismatic displacement affects the visual-spatial stored information

Factors which affect the central axis portion of PALs may affect the protective response to a trip, slip, or loss of balance. This may occur both directly, through inaccurate visual feedback during a fall, or indirectly, through altered stored VSI. King *et al.* (2010) studied the startle response and whether young healthy volunteers look to where they place their hand when a perturbation throws them off balance [100]. They found that participants did not look at where they placed their hands, but even so, the participants knew where the bar was to grasp it. This seems plausible, as the time required for saccade initiation is at least 90 ms, and the execution of the eye movements will require an additional 40-70 ms, possibly requiring multiple saccades to find a suitable object to grasp and each saccade would add further delays of 50 ms or more per saccade [101]. Therefore, it is not surprising that the participants did not look for a support object when the perturbation did occur. They postulated that this 'knowing' where, without looking at the support rail, may be due to either stored central VSI because 7 out of the 11 healthy young participants looked at the support rail when entering the room, and/or stored peripheral information. Alternately not looking directly at the support rail could be due to online peripheral information, which 4 of the 11 subjects may have relied on because the rail did not reach within central 5º of the visual fields prior and post perturbation. There was sufficient power for the stored central VSI hypothesis but the group studied was small, so strong conclusions cannot be drawn as to whether reaching is guided by the peripheral vision.

The study reported in this chapter found no significant difference in reaction time and accuracy in the peripheral areas of the lens. So, possibly the effect of PALs on VSI could explain why wearing multifocal glasses increases the risk of a fall in Lord *et al.'s* study [2], because in the study reported in this chapter the central part of the lens has a significant affect on reaction time and has a significant upward prismatic displacement. The upward displacement is due to the base down thinning of PALs when they are manufactured and it is possible that participants adapt to the upward prismatic displacement with their current PALs. Hence, when the participant acquires a new pair of single vision glasses, the prismatic displacement effect is reversed and the participant, initially, has not adapted to this change. Indeed, the stored central VSI is incorrect and when an older person walks into an unfamiliar environment, he/she stores the potential support objects in the wrong place in space [100].

Therefore, when a perturbation does occur and the older person needs to rely on that stored information, the older person may miss the support. According to my study, this only would be true for the vertical displacement in the centre and the horizontal bar placed at this position for reaction time. However, the results found at positions of the black line at 300mm down from centre cannot be explained by the prismatic displacement effect.

5.4.5 Reaction time difference in the reading portion of progressive addition lens

As mentioned previously, the reaction time was significantly faster when the position of the horizontal black line was at 300mm down from centre and this could have a similar explanation as the central visual axis. However, this point cannot be explained solely in terms of the prismatic displacement effect because there was no statistically significant vertical displacement between the two glasses at this point (mean difference 0.97mm; 95% CI, -0.75 to 2.68), $P = 0.258$ (paired *t*-test)).

Alternatively, the results for the black line at 300mm down from centre in the central visual axis could be explained by the reading portion of PALs because the black line was placed at 666.6mm away from the participants. This is the optimal focus - around 600mm, for the reading power of multifocal glasses [2]. Furthermore, on average the participants' PALs had a reading power of 2.5 (SD 0.2) dioptres, consequently a focal length of 400 (SD 0.04) mm. Therefore, the positive power lens may bring the line closer to the participant and the resolution may be clearer, enabling the participant to push the line quickly.

5.4.6 Accuracy measurements linked to prismatic displacement

The accuracy results showed that at the peripheral edges of the glasses the participants were less accurate with PALs, and this may suggest that the prismatic displacement of PALs does affect accuracy especially in the periphery. The accuracy results in the centre gave mixed results; PALs were more accurate when the line was placed vertically and there was no difference between the glasses when the line was placed horizontally. This result does not relate with the prismatic displacement, and could solely be due to chance.

One limitation with this study and possible reason for not seeing an effect of the prismatic displacement in particular areas of the glasses in relation to the protective response is that the methods used did not correspond to an actual fall; the study used a light to 'simulate' a fall. Therefore, there was no heightened awareness through a fight-flight state. The participants were in a relaxed state, which is not a high anxiety situation for a fall, and possibly a one off

trail which involved a perturbation would be a better method to test this hypothesis [100, 102].

5.5 Summary

The main findings of this study indicate that there was a significant difference in reaction time between the two types of glasses in the central visual axis and for reaction time to be faster when wearing PALs. Furthermore, reaction time was faster and less accurate in the peripheries of PALs, although this did not reach significance, possibly due to a small sample size. In addition, it is possible that the participants had adapted to the prismatic displacement of the central clear corridor of vision, which is used for ADL, and by swapping glasses the participants possibly did not adapted to the relative change in displacement. This lack of adaption would affect the stored central VSI and therefore the protective response if a fall did occur, especially in an unfamiliar environment.

Chapter 6 – Ability to balance while wearing progressive addition lens

6.1 Introduction

As we age we rely more heavily on vision to stay upright and because multifocal glasses obscure vision, they could potentially alter stability [2]. The reading portion of PALs is known to affect both contrast sensitivity and depth perception [2], and as mentioned in Chapter 3, it is shown to contribute to the variation in prismatic displacement. The ability to walk without conscious thought is an astounding human ability. However, when this complex mechanism is overwhelmed by various environmental stresses a fall may possibly ensue with dire consequences, especially on an elderly person. Balance requires active muscle contraction coordinated by visual, vestibular, and proprioceptive input, and by experience and foreknowledge, all acting together [31]. It is widely accepted that postural instability is a risk factor for a fall in older people [77]. Prevention of falls is imperative to reduce associated morbidity and mortality, and maintain independence in the older population.

The aim of the study reported in this chapter was 1) to analyse the effect PALs have on stability when solely relying on vision to stay upright.

6.2 Methods

The equipment and setup of this trial is described in Chapter 4. The participants were the same as those taking part in the research study described in Chapter 5. Postural stability was assessed by removing proprioception and stressing the vestibular system achieved by using the BalanceMaster® and In VISION® system. Therefore, vision was the only sense relied on to stay upright. Then wearing PALs was compared with wearing single vision glasses in a single blinded, crossover trial.

Trials were 20 seconds long to minimise fatigue and participants were tested three times wearing each pair of glasses. Trials two and three have been used for analysis using the AP sway angle measurements, in degrees, which was used to calculate the EQ score, EQ =100 x (1 – (θ/12.5)) [78]. The clinically accepted EQ score represents instability as the maximum peak-to-peak sway about the "equilibrium point" [103]. 12.5° is the maximum theoretical peak-to-peak sway in the AP direction. If the AP angle goes beyond 12.5° then a ‘fall’ will

ensue and the EQ score is zero [78]. Each participant swung their head at 30 degrees either side of them because this corresponded to the largest variation in prismatic displacement for both vertical and horizontal displacement previously found in the research reported in Chapter 3. Trials two and three were used to analyse head velocity and head pitch. A 'bird's eye view' video camera recorded the participant's movements throughout testing, and movements from all three trials were analysed by the investigator subjectively for the startle response and number of supports required by the investigator. The startle response was a perturbation requiring self-stabilisation and number of supports was when the investigator had to grab the participant's harness. A questionnaire was used after testing to measure the participant's comfort level with the two glasses. SPSS version 18 was used for all analyses.

6.3 Results

Thirty one participants were tested in this study, and baseline characteristics and flow of participants through the study are detailed in Chapter 5 (see Table 5.1 and Figure 5.1). Blinding of the investigator was maintained through-out the trial and afterwards for the analyses.

6.3.1 Stability measurements

Table 6.1 shows the EQ score, frequency of assists, level of comfort, head velocity and head pitch when wearing PALs and single vision glasses. Figure 6.1 demonstrates the EQ score difference between PALs and single vision glasses. Not all the participants completed the 3 trials for each pair of glasses; all three trials were completed with PALs by 28 and were completed with single vision glasses by 27 participants.

There was no statistically significant difference in EQ score between trials with PALs and single vision glasses. The EQ score for balance was favourable towards multifocal glasses i.e. participants were more stable with multifocal glasses. However, the results were widely variable and did not reach significance. Differences in frequency of assists, level of comfort, and head pitch did not reach significance. Finally, there was no difference in the participants' head velocity between trials with the two types of glasses.

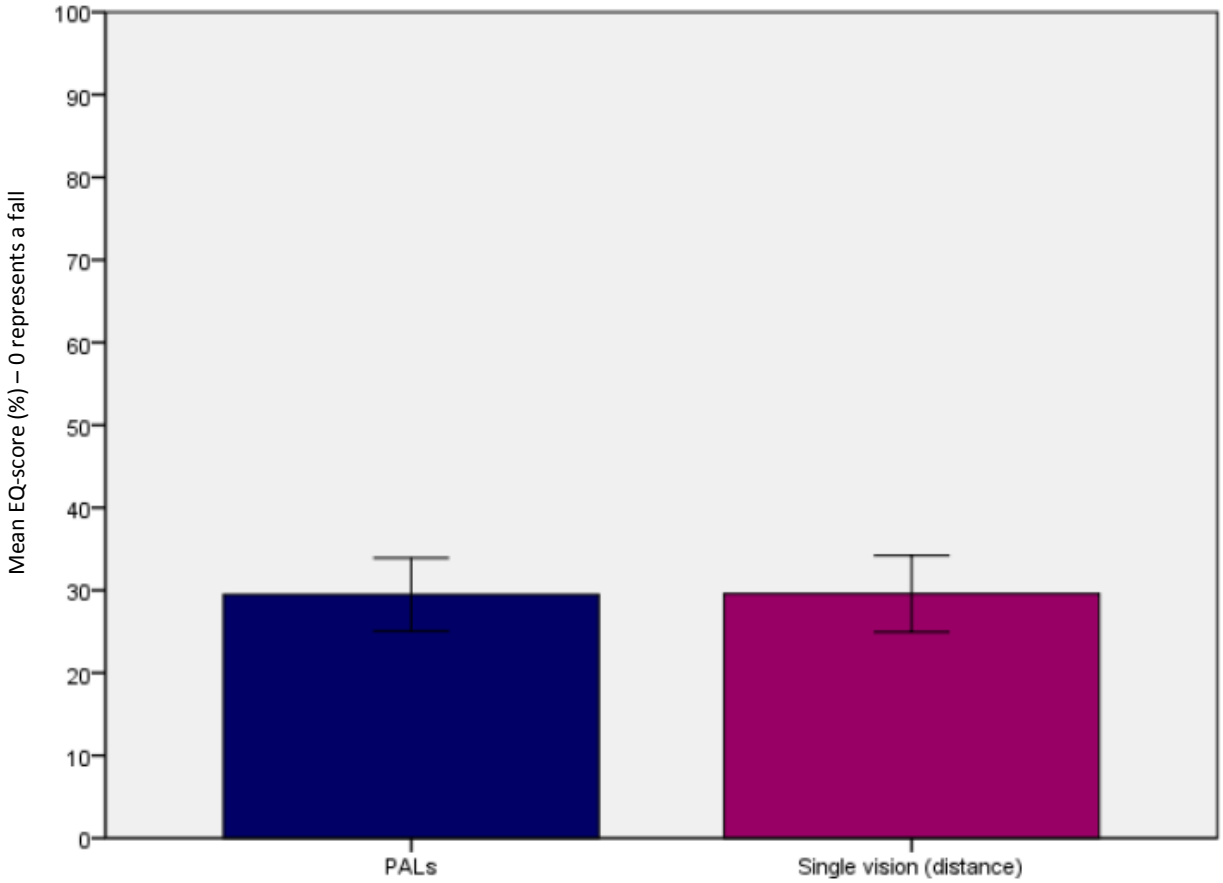
Table 6.1. Balance results and measurements of head movement

	Progressive multifocal glasses		Single distance vision glasses		
	No	Mean (SD)	Mean (SD)	Mean difference (95% CI)	P value*
EQ score	53	30.49 (16.55)	30.11 (16.95)	0.377 (-4.162 to 4.917)	.754
Frequency of assists	62	1.50 (1.54)	1.37 (1.54)	0.129 (-0.220 to 0.478)	.462
Level of comfort†	26	7.54 (1.84)	7.31 (1.87)	1.142 (-0.231 to 0.692)	.313
Head velocity (degrees/sec)	58	91.79 (34.25)	91.34 (37.32)	0.448 (-5.674 to 6.571)	.884
Head pitch (degrees)‡	62	0.48 (6.94)	-0.53 (10.80)	1.013 (-1.957 to 3.984)	.498

*P value for EQ score associated with repeated measures by order, number of days since PALs were updated, and head velocity; remainders associated with paired t-test

†Range of scale from 0 to 10, higher score indicates more comfortable

‡Positive means above and negative means below the horizontal plane



Footnote: EQ score = the AP peak-to-peak sway angle, θ (in degrees), using the equation EQ = 100 x (1 – (θ/12.5), where 12.5 is the maximum theoretical peak-to-peak sway in the sagittal plane. For θ ≥ 12.5, which is scored as a fall, the EQ score is zero [14]

Figure 6.1. A bar graph of the EQ scores comparing PALs (royal blue) with single vision glasses (maroon)

6.3.2 Kinematic startle response results

Table 6.2 illustrates the head position and hand response for all the perturbations observed on the BalanceMaster®, which are incidental findings. A perturbation of a participant is defined as a loss of balance requiring self-support. Ninety five perturbations occurred in total and an average of about 4 perturbations occurred for each participant. It was found that the

majority of participants held their head centrally and reflexively moved their arms out for support when a perturbation occurred. The remaining participants only moved their head slightly to one side, and their arms out in front or only one arm moved to the side.

Table 6.2. The participants' kinematic movements with a perturbation

	Count (percentage) (n = 95)
Arm movements – both arms moved to the side	51 (53.7)
Head position – central	63 (66.3)
Type of glasses - PALs	49 (51.6)
Mean (SD) perturbations per participant	3.52 (2.87)
Trial number one out of three	44 (46.3)

6.4 Discussion

6.4.1 Principal findings and relationship to previous research

The principal finding was that wearing PALs compared with single vision glasses did not alter stability, even when relying solely on vision to stay upright. Results showed wide between subject variation and a small difference between the glasses, which suggested PALs do not have an effect on balance, and the results of this study are largely consistent with Johnson *et al.'s* study comparing multifocal and single vision (distance) glasses [77]. The general consensus is that even though multifocal glasses affect contrast sensitivity, depth perception, and visual fields, and furthermore sway is affected by poor visual acuity and contrast sensitivity alone [53, 71]; multifocal glasses compared with single vision glasses do not affect sway in the older population.

Johnson *et al.* found no effect on balance with multifocal glasses compared with single vision glasses, however, they did find an effect of the participant's head and eye position on balance [77]. Participants were more unstable with head-forward/eyes-down and most stable with head and eyes forward. The expectation was that participants would flex their head more when looking at a dot on average 76.8 (SD 5.4) mm above the ground in the study reported in this chapter, which is below the horizontal eye level. Therefore, participants are not looking through the reading section, which causes poor contrast sensitivity, depth perception, and restricts the field of view. However, results from the candidate study suggested a trend that participants wearing PALs on the BalanceMaster® were more likely to extend their head slightly and focus on the dot through the reading portion. Although this difference was not statistically significant, this trend might be due to the participants avoiding the significant upward prismatic displacement effect in the centre of the lens, and possibly the prismatic

displacement is more of a threat than the reading portion influence on vision e.g. depth perception, and edge-contrast sensitivity [2].

6.4.2 Head movement and arm placement with the Startle response

The participants' head movements were in the yaw direction for this study, which matches areas of the glasses with the maximal variation in prismatic displacement, inferred using the focimeter of a typical PAL, as described in Chapter 3. The BalanceMaster® booth had a painted landscape on it similar to an outdoor environment where a fall may occur. The participant's vision was focused through the areas of maximal prismatic displacement and it was assumed that the booth would be distorted due to the prismatic displacement effect and affect the ability to stabilize when proprioception and vestibular function were removed. The participant's head movements were thought to fit with the chaos which happens with a fall. However, by reviewing the 'bird's eye view' video of the participants when they do have a perturbation, the majority of participants kept their head in a central position and the arms reflexively moved outward without looking directly at their arms, which is in keeping with previous research [100].

The reflex reaction of grasping to the sides when a perturbation occurs looks strikingly like the Moro reflex in a new-born baby. However, the average human being loses this reflex within the first 3-6 months of life; persistence beyond the 6th month indicates pathology [104]. Moreover, the startle reflex, which is one of the most important defensive reactions in the animal world, is a flexor reflex due to a nociceptor stimulus [105]. The startle reflex has the same characteristic appearance to the Moro reflex, but the startle reflex uses a different area of the brain and lasts into adulthood. The startle reflex is controlled in the brain stem, reticular system, and vestibular system [106]. While the Moro reflex is mediated only through the brainstem [105].

The startle response means central fixation is forward and does not lead the hand when grabbing a bar. King *et al.* [100] looked at the startle response with a perturbation of the floor and whether young healthy volunteers visualise where they grasp. King *et al.* found that participants did not look to where they put their hands and mentioned that the participants still knew where the bar was. King *et al.* concluded that this 'knowing' without fixating on the support rail was because of either stored central VSI or stored/online peripheral information. Furthermore, the majority of the participants (8 out of 11) maintained or redirected gaze at objects relevant to the task they were told to perform [100]. Older adults also have this ability to store VSI when guiding compensatory stepping responses prior to a perturbation [107]. By

comparing 12 older adults (61-73 years) with 12 young adults (22-29 years), they showed that older adults did not look down at an obstacle whilst stepping over it and when a perturbation occurs, which suggests an internal 'spatial map' of the obstacle prior to the perturbation occurring. There was no difference between young and old [107]. This means that anything that affects the central visual axis, for example replacing PALs with single vision glasses, might possibly affect the response to a trip, slip, or loss of balance.

6.4.3 Why the head keeps a central position when a perturbation occurs

The findings from the 'bird's eye view' video of the participants in the BalanceMaster® showed that the head stays central, and by keeping the head and eye movements stationary whilst a perturbation occurs may be particularly important to stabilize ones-self in a number of ways [107]: 1) it avoids instability with the egocentric system [37, 108]; 2) it stabilizes the visual and vestibular feedback system so they can perform at their optimum in real time [109-111]; 3) the cervical sensors are kept constant so that body position is controlled [106]; 4) it promotes acquisition of self-motion with moving visual cues [112]; and 5) it reduces the need to update the VSI because of the change in reference frames [113, 114]. In other words, the head is a reference point for all the sensory inputs during a fall and relies on being stationary to enable the person to regain balance. Because complicated processing is occurring in the brain during a perturbation an additional task such as looking at where to grasp for support would make maintaining balance in this dynamic situation even more difficult.

6.5 Summary

Wearing PALs compared with single vision glasses show no difference to the effects on balance in a situation where the person is solely relying on vision to stay upright. Other research suggests that elderly people do rely heavily on vision to stay upright but reduced contrast sensitivity, restricted field of view, poor depth perception, and the prismatic displacement effect of multifocal glasses do not influence stability. The results from this study are largely consistent with previous work comparing the two kinds of glasses. Finally, this study found that the head stays central and the arms reflexively move to the side with the majority of perturbations. Therefore, vision during the startle response of a fall does not appear to guide the hands to find support.

Chapter 7 – General discussion

7.1 Overview of the thesis

The studies were designed to elucidate the effect of wearing PALs and the risk of a fall in older people. It is known that multifocal glasses increase the risk of a fall [2] and the studies reported in this thesis investigated the effect multifocal glasses have on fall risk, particularly focusing on PALs. Poor contrast sensitivity, visual acuity, depth perception and visual field loss are possible visual contributors to falls in elderly people, [2] and PALs influence these variables. This study illustrated that prismatic displacement of PALs may also affect fall risk with regard to reaction time and accuracy of the protective response. Furthermore, updating or repeatedly changing glasses should be approached with caution. Potentially, the studies in this thesis will enable better patient education about wearing PALs, and may affect the way multifocal glasses are designed and manufactured so the glasses do not displace objects within the visual field.

7.2 PALs displace the visual field, to both subjective and objective viewers

It has been demonstrated that PALs have large areas of prismatic displacement with some areas showing a false projection of about 1.5 cm at two thirds of a metre away. In preparation for later chapters in this thesis both objective measurements of prismatic displacement using the focimeter and the subjective measurements using a modified Hess test were performed, and both illustrated similar patterns and results. Therefore, the prismatic displacement is experienced by participants. The participants in the Hess test also favoured using the clear corridor of vision through the progression zone, and avoided the large areas of displacement and astigmatism in the bottom corners of the lens. This was illustrated with a dulling of the prismatic displacement effect seen in the areas of maximal displacement of the Hess test graphs (Figure 3.8 and 3.9) and was potentially caused by the participants moving their head when performing the Hess test.

Due to limitations of the methods to map the prismatic displacement i.e. areas beyond the section of interest, there is the potential to show larger areas of prismatic displacement than what was measured. It was difficult to acquire a reading from the focimeter in the right and

left bottom corners because this was situated on the edge of the lens. I would assume that there are large areas of displacement at the edge of the glasses due to the general trend of increasing horizontal displacement progressing out towards the corners of the section of the lens mapped. Vertical displacement also illustrates this effect.

7.3 Startle response and kinematic movements of a fall

The study reported in Chapter 6, with regard to the 'bird's eye view' recordings of the participants in the BalanceMaster®, observed that the majority of the participants held their head central and their hands reflexively moved out to the sides for support. This movement appeared similar to the Moro reflex; however, the Moro reflex is lost in the first 3 to 6 months of life [104]. Conversely, the startle reflex persists through adulthood and is controlled by different areas of the brain [105]. When a perturbation occurs King *et al.* illustrated that healthy young participants do not fixate on a rail when grasping for support [100]. Moreover, no central fixation of the support rail occurs with the startle response because the head stays central for a number of reasons: 1) it avoids instability with the egocentric system; 2) it stabilizes the visual and vestibular feedback system so they can perform at their optimum; 3) the cervical sensors are kept constant so that body position is controlled; 4) it promotes acquisition of self-motion information via visual optic-flow cues; 5) it reduces the need to update the visual-spatial information because of the change in reference frames [107]. In short, when a slip, trip or loss of balance occurs the head stays central and the arms reflexively move to the side for support.

7.4 Adaptive response to change in prismatic displacement

Studies reported in Chapter 5 demonstrated that there was a difference in reaction time comparing PALs with single vision glasses in the central visual axis, which was contrary to the initial hypothesis. What was initially hypothesised was that the participants wearing PALs would be slower and less accurate in the peripheral edges of the lens because the prismatic displacement is greatest, and this is in an area where one would grab for a support object. Accuracy and reaction time did show a trend towards PALs being less accurate and possibly slower in the periphery but this did not reach significance. However, reaction time in the central visual axis did show a significant difference between the two glasses. Furthermore, whilst wearing PALs, participants were quicker to grasp the equipment – bar and black line.

This effect was possibly due to the participants being long term PAL wearers (mean 228 (SD 146) days) and then swapping to new single vision (distance) glasses. For this trial this means that participants had to re-adapt to the relative change in prismatic displacement between the two glasses. Adaptation to the change in prismatic displacement effect could occur through adjustment of the extra-retinal eye movements (egocentric and oculocenteric visual directions) or re-calibration of the proprioception receptors in the upper and lower limbs [82, 83].

7.5 Change in stored visual spatial information by replacing glasses and its effect on the protective response and foot step misplacement

Stores VSI is a theory which describes the ability to move into a room and map consciously and/or unconsciously all of the surroundings in that room. This VSI is utilised if a perturbation occurs and the need to reach for support is required. This is especially true in unfamiliar environments. Chapter 6 suggests that when a perturbation occurs the head stays central and the arms reflexively move out, which means that possibly a visual 'spatial map' of the surroundings is required, so that the person can grab the support rail without fixating on it [100]. To illustrate this in another way, when a perturbation occurs the participant's head stays central and therefore there is no central fixation of the support bar.

Studies reported in Chapter 3 showed that the largest areas of displacement were in the centre and at the edges of the lens, vertical and horizontal displacement respectively. Studies reported in Chapter 5 illustrated that there was a significant difference in reaction time in the central visual axis and not the periphery. This could indicate that older people visualise their surroundings through the central visual axis, which has a base down prism creating large upward displacement areas and affects VSI. Therefore, participants cannot adapt to the change in displacement when replacing PALs for single vision glasses. Consequently, when a perturbation does occur in an unfamiliar surrounding, the older person is too slow to react and grab for support. Subsequently, to miss a support rail when a slip, trip or loss of balance occurs would result in a fall. Indeed, when a pole is placed in front of older participants, the maximal reach for this pole is associated with having a fall [115].

There is a tendency for PALs to have more astigmatism and prismatic displacement at the edges of the lens compared with single vision glasses. So if the general trend of accuracy is correct, then the older person's online/stored peripheral vision may also be affected when grabbing for a support. This possibly illustrates a propensity to miss a support rail at the side

of the participant, while wearing PALs. Nonetheless, a larger sample size would be needed to confirm this relationship.

Replacing multifocal glasses with single vision glasses could be dangerous. In the VISIBLE trial secondary measures of non-fall related injury e.g. laceration, lifting or twisting injury, burn/scald, eye injury, collision and pedestrian injuries were compared between the intervention of replacing multifocal glasses with single vision glasses, and controls who did not swap their multifocal glasses. They found that 26% of the intervention group compared to 17% of controls (P= 0.01) had a non-fall related injury [29]. This effect could be due to the convenience of multifocal glasses when carrying out everyday tasks such as cooking, driving, shopping, or other such tasks. Conversely, the result may be due to the participants in the intervention arm leaving their glasses off because of the inconvenience with changing between glasses, or using the wrong pair of glasses.

7.6 Progressive addition lens effect on stability

It is suggested in Lords *et al's (2002)* paper that people wearing multifocal glasses have more stability compared with wearing single vision glasses, however, this difference did not reach significance [2]. Studies reported in Chapter 6 showed that when wearing PALs compared with single vision distance glasses there was no significant difference with stability, even when relying solely on vision to stay upright. This is also illustrated in Johnson *et al's* (2009) study looking at multifocal glasses compared with single vision (distance) glasses, in which they also concluded that multifocal glasses do not affect stability in elderly people [77].

7.7 Limitations

It is acknowledged that the studies in this thesis had a number of limitations. The studies were not powered to find a difference between the two glasses because it was a descriptive (pilot) study and no data on the effect size of these measures were available. Furthermore, the study in this thesis recruited healthy participants who were active which is not the general older population at greatest risk of a fall. It was shown in a sub-group analysis of the VISIBLE trial that compared to active older people; non-active older people have an increase in falls outside, which should be the population that is reviewed with regards to replacing glasses.

The technique used to map the prismatic displacement was limited to the mask used to map the section of the lens. There was a balance between mapping the largest prismatic displacement at the edge of the glasses, while testing had to occur within the glasses frame. Therefore, the equipment could potentially have been in a more extreme position at the edge of the glasses compared to what was tested, without testing beyond the frame of the glasses.

Another limitation with this study is that it was simulating a fall, which was not a real fall situation. Participants in the study reported in Chapter 5 were seated and the stimulus was a light, which is not the high anxiety and stressful situation a fall produces. Lastly, measuring stability with PALs compared with single vision glasses was limited due to the equipment and the ability to observe the participants' central fixation, which meant fixating on the target dot could not be accounted for.

7.8 Future directions

Based on the theory that the change in relative prismatic displacement and adaptation to this is what is contributing to falls in elderly people who wear multifocal glasses. Further research is required to illustrate how long it takes to adapt to a change in visual perception? Furthermore, more research is required to understand how long it takes for frail, non-active older people who go outside, to adapt to the change in visual perception created by glasses? Frail older people are defined as those who have cognitive dysfunction, a low activity profile, co-morbidities and require home help. Moreover, this cohort of people has cognitively declined and whether they can adapt to a change in perception would be an interesting question? Finally, a reverse study looking at the change from single vision glasses to PALs would clarify whether the results in this thesis are a true association of reaction time with replacing glasses.

7.9 Conclusion

The main result from these studies is that when replacing from PALs to new matched single vision glasses, reaction time is slower in the central visual axis. Furthermore, stability is not effected when replacing the glasses. It is suggested that older people take time to adapt to the prismatic displacement effect when replacing or updating glasses. So caution is advised with swapping long term PAL wearers with single distance vision glasses. In conclusion, updating glasses could possibly occur more often in the elderly (especially those who are frail and unable to go outdoors), or a hard design lens would possibly be more beneficial to use

than a soft design, or the lens should not be thinned with a base down prism. On the whole, this study may affect the way multifocal glasses are designed, manufactured and prescribed, so that they decrease the displacement of objects within the visual field. Further research is required to answer the question as to the length of time required to adapt to the visual perception of multifocal glasses, so that recommendations can be made when updating, acquiring or replacing glasses.

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Appendix A – Questionnaires for initial home visit

Effect of multifocal glasses on reaction time and balance
Baseline information

Participant number: ☐☐

Date: ☐/☐☐/☐☐

Place an X in the relevant boxes below

1. Male ☐ Female ☐
2. What is your date of birth? ...../...../.....
3. What is your age? .....
4. Which ethnic group do you belong to?
   Place an X in one or more boxes

   New Zealand European ☐ Maori ☐ Samoan ☐ Cook Island Maori ☐

   Tongan ☐ Niuean ☐ Chinese ☐ Indian ☐

   Other (such as Dutch, Japanese, Tokelauan), please state.....
5. Are you of Māori descent (that is, did you have a Māori birth parent, grandparent or great-grandparent, etc.)?

   Yes ☐ No ☐ Don't know ☐
6. Where do you live?

   Your own home ☐ Residential care ☐ With son/daughter/other ☐

   Retirement village ☐ Other.....
7. Do you live alone? Yes ☐ No ☐
8. Are you currently receiving home support services? Yes ☐ No ☐
   If yes,

   Home help – cleaning (enter hours per week) .....
   Home help – personal care (enter hours per week) .....

   Do you receive Meals on wheels? Yes ☐ No ☐

9. Medical history
   Do you suffer from or have you had any of the following:
   (Please tick if applicable)

   Parkinson's disease ☐ Stroke ☐ Hip fracture ☐

   Do you have pain in your hip or knee (such that it limits you in your daily activities)? ☐

   Diabetes Mellitus ☐ or any other medical problem …….

10. Do you take any medications? Yes ☐ No ☐

    (If no, move on to question 12)

11. What current medications are you taking (including tablets for sleep) and dose of medication (if known)?
    ……
    ……
    ……
    ……
    ……
    ……

12. In general, would you say your health is:

    Excellent ☐ Very good ☐ Good ☐ Fair ☐ Poor ☐

13. Have you had a fall in the last 12 months? (if no, go to question 18)

    Yes ☐ No ☐

14. Over the last 12 months,
    How many falls were indoors? ……

    How many falls were outdoors? ……

15. Please describe any injury from the fall(s)?
    ……
    ……
    ……
    ……

16. Were you wearing glasses at the time of any of these fall(s)? Yes ☐ No ☐

17. If yes, what type of glasses were they and how many falls were associated with the type of glasses?

    Single lens distance glasses …….. Reading glasses …….. Bifocal glasses ……..

    Trifocal glasses …….. Progressive multifocal glasses …….. Sunglasses ……..

18. Is this your first pair of progressive multifocal glasses? Yes ☐ No ☐
19. If yes, what did you have before hand?

    Single lens distance glasses ☐ Reading glasses ☐ Bifocal glasses ☐

    Trifocal glasses ☐ I did not need glasses (excluding sunglasses) ☐

20. How long have you been wearing progressive multifocal glasses?

    ……days …….weeks ……years

21. How long ago did you obtain your updated/new pair of progressive multifocal glasses?

    ……days …….weeks

Effect of multifocal glasses on reaction time and balance
Baseline information

Participants number: ☐☐

Date: ☐☐/☐☐/☐☐

---

1. High contrast acuity (with glasses) Right ……./…… Left ……./……
   Start at 4 metres

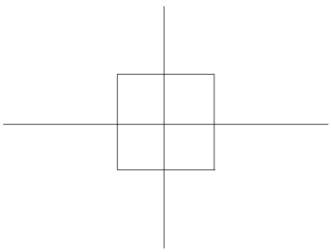
2. Low contrast acuity (with glasses) Right ……./…… Left ……./……
   Start at 4 metres

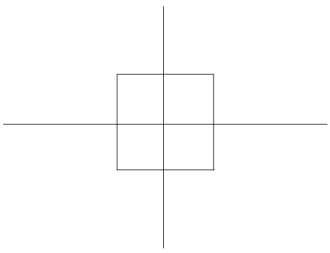
3. Melbourne edge test (with glasses)
   Assess at 25cm. Enter last successful edge identified Right …… Left ……

4. Near vision (with glasses)
   Assess at 35cm. Enter smallest number read Right …… Left ……

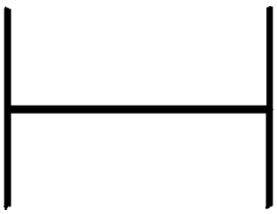
5. Amsler grid normal (with glasses) Abnormal ☐ Normal ☐
   Assess at 33cm.

6. Peripheral field test (with glasses)

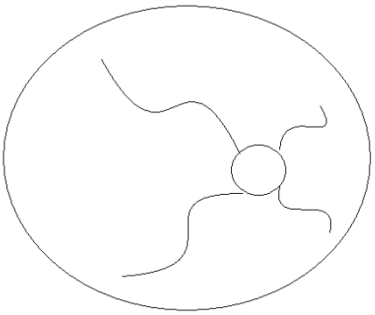




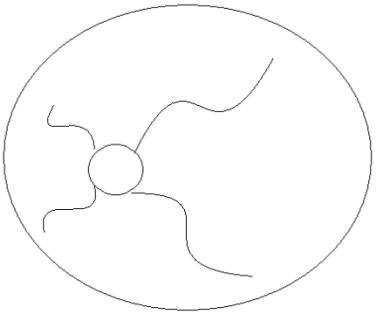
7. Extra-ocular eye movements (mark diplopia with an X)



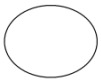
8. Direct ophthalmoscope

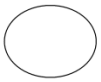


D/C ratio…….



D/C ratio…….

Red reflex 

Red reflex 

9. Eye problems

Age related macular degeneration (double check with amsler grid) ☐

Cataract (double check with red reflex) ☐

Diabetic retinopathy (double check with direct ophthalmoscope) ☐

Glaucoma (double check with pressing on the globes) ☐

Eye surgery ☐

Other …….. ☐

10. FICSIT 4-test balance scale
Enter seconds = 0 if task not attempted because of failure at an earlier task.
Enter seconds = 1 if task was attempted but participant lost balance immediately.

Stand with feet together in side-by-side position (maximum of 10 seconds) ☐

Stand with feet together in semi-tandem (one foot to the side of other foot's toe) position (maximum of 10 seconds)

☐

Stand with feet together in tandem (one foot in front of the other) position (maximum of 10 seconds)

☐

Stand on one foot (maximum of 30 seconds) ☐

11. Their height ……mm

12. Height of body when sitting down (from the seat to vertically half-way up the glasses) ……mm

13. Sit to stand
    Ask the participant to fold their arms across the chest and stand up from the chair one time.

    Successful ☐

    If successful, ask the participant to fold their arms across the chest and stand up and down 5 times as quickly as possible. Allow a maximum time of 2 minutes.
    Enter time (in minutes and seconds) from the initial sitting position to the final standing position at the end of the 5th stand. Leave the boxes blank if less than 5 stands are completed successfully in 2 minutes. ☐/☐☐min☐☐sec

    Enter number of stands completed successfully within 2 minutes ☐

14. Do they have any deformities of the arm, neck or head that would prevent them from participating in this study

    Yes ☐ No ☐

15. Which is your dominant hand? Right ☐ Left ☐
    (If ambidextrous hand them a pencil)

16. Arm length (from acromion to their index finger of dominant hand – with arm at 90º) ……mm

17. Monofilament 10g force sensation in

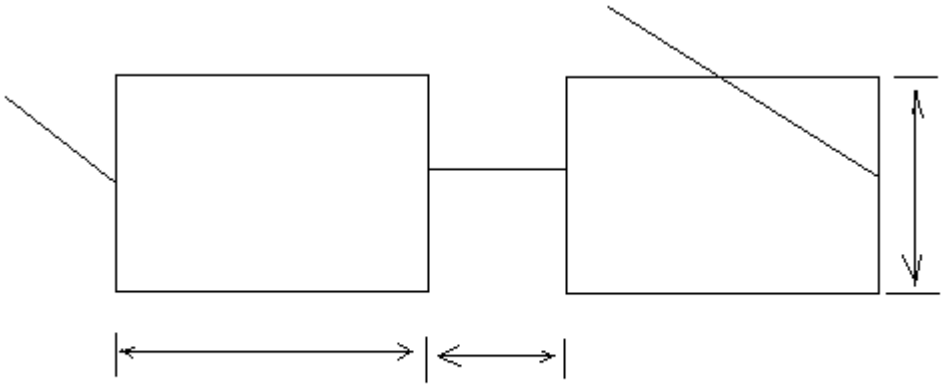
    R: Hallux ☐ 1st metatarsal ☐ L: Hallux ☐ 1st metatarsal ☐

    2nd metatarsal ☐ 5th metatarsal ☐ 2nd metatarsal ☐ 5th metatarsal ☐

    Heel ☐ Heel ☐

18. Date of updated/new prescription of progressive multifocal glasses? ……./……./…….

19. Frame dimensions – fill in the gaps (mm) and take a photo to ascertain style of the frame.



20. Record points on focimeter for progressive multifocal glasses (dioptre, place arrow for direction)

R: Centre	– Vertical …….	Horizontal …….
300mm down from centre	– Vertical …….	Horizontal …….
Left 100mm down from centre	– Vertical …….	Horizontal …….
Left 200mm down from centre	– Vertical …….	Horizontal …….
Right 100mm down from centre	– Vertical …….	Horizontal …….
Right 200mm down from centre	– Vertical …….	Horizontal …….

L: Centre	– Vertical …….	Horizontal …….
300mm down from centre	– Vertical …….	Horizontal …….
Left 100mm down from centre	– Vertical …….	Horizontal …….
Left 200mm down from centre	– Vertical …….	Horizontal …….
Right 100mm down from centre	– Vertical …….	Horizontal …….
Right 200mm down from centre	– Vertical …….	Horizontal …….

Ask the participant "On a scale of nought to 10, how comfortable did you feel while wearing the glasses"

Not at all comfortable — Fairly comfortable — Completely comfortable

0 1 2 3 4 5 6 7 8 9 10

Test 1 (precision and accuracy): A = glasses trial 1 ☐☐ B = glasses trial 2 ☐☐

Test 2 (stability): A = glasses trial 1 ☐☐ B = glasses trial 2 ☐☐

21. Record points on focimeter for single distance glasses (dioptre, place arrow for direction)

R: Centre	– Vertical …….	Horizontal …….
300mm down from centre	– Vertical …….	Horizontal …….
Left 100mm down from centre	– Vertical …….	Horizontal …….
Left 200mm down from centre	– Vertical …….	Horizontal …….
Right 100mm down from centre	– Vertical …….	Horizontal …….

Right 200mm down from centre	– Vertical …….	Horizontal …….
L: Centre	– Vertical …….	Horizontal …….
300mm down from centre	– Vertical …….	Horizontal …….
Left 100mm down from centre	– Vertical …….	Horizontal …….
Left 200mm down from centre	– Vertical …….	Horizontal …….
Right 100mm down from centre	– Vertical …….	Horizontal …….
Right 200mm down from centre	– Vertical …….	Horizontal …….

Appendix B – Testing schedule for bar and black line placement

02		Horizontal bar at 35°			Foam pad - central			Vertical bar at 35°		
		chair height	zimmer frame setting		chair height	zimmer frame setting		chair height	zimmer frame setting	
	2 Peripheral	***52cm up from bottom***	***bottom***		***45cm up from bottom***	***2nd down from top (no box)***		***45cm up from bottom***	***2nd hole down from top (no box)***	
		Horizontal bar			Foam pad			Vertical bar		
		chair height	zimmer frame setting		chair height	zimmer frame setting		chair height	zimmer frame setting	
	Central	***55.5cm up from bottom***	***top***		***55.5cm up from bottom***	***top***		***57cm up from bottom***	***bottom***	
	BalanceMaster	Height of dot = 77cm	Distance of feet (b/w malleolus)=	17.6			32.1	at 30cm		14 degrees
03		Horizontal bar at 35°			Foam pad - central			Vertical bar at 35°		
		chair height	zimmer frame setting		chair height	zimmer frame setting		chair height	zimmer frame setting	
	2 Peripheral	***55.5cm up from bottom***	***bottom***		***48.5cm up from bottom***	***2nd down from top (no box)***		***48.5cm up from bottom***	***2nd hole down from top (no box)***	
		Horizontal bar			Foam pad			Vertical bar		
		chair height	zimmer frame setting		chair height	zimmer frame setting		chair height	zimmer frame setting	
	Central	***59cm up from bottom***	***top***		***59cm up from bottom***	***top***		***60.5cm up from bottom***	***bottom***	
	BalanceMaster	Height of dot = 87.3cm	Distance of feet (b/w malleolus)=	19.9			34.4	at 30cm		14 degrees

	vertical foam pad at 35°	
zimmer frame setting	chair height	zimmer frame setting
2nd hole down from top (no box)	***45cm up from bottom***	***2nd hole down from top (no box)***
	Vertical foam pad	
zimmer frame setting	chair height	block height to device
bottom	***57cm up from bottom***	***bottom***
14 degrees		
	vertical foam pad at 35°	
zimmer frame setting	chair height	zimmer frame setting
2nd hole down from top (no box)	***48.5cm up from bottom***	***2nd hole down from top (no box)***
	Vertical foam pad	
zimmer frame setting	chair height	block height to device
bottom	***60.5cm up from bottom***	***bottom***
14 degrees		

Appendix B – Competitions attended

Poster competition **–** Division of Health Sciences Research Forum 2011: Innovation through collaboration, student poster competition.

Speech competition – 210th scientific meeting of the Otago Medical School Research Society: MSc/Honours student speaker awards.

Abstract – Ellison A, Campbell J, Robertson C, & Sanderson G. (2011). Prismatic effect of progressive multifocal glasses on falls in elderly people. *New Zealand Medical Journal*, *124*(1346). (www.nzma.org.nz/journal/124-1346/4980/content.pdf)