THE ROLE OF VISION AND REFRACTIVE CORRECTION CHANGES IN DIZZINESS

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Abstract

Dizziness is a common, multifactorial problem that causes reductions in quality of life and is a major risk factor for falls, but the role of vision is a very under-researched area. This study aimed to investigate any link between dizziness and vision and to establish if changes in spectacle lens correction could elicit dizziness symptoms.

A link between dizziness and self-reported poor vision was indicated in the epidemiological literature as shown by a systematic review, provided light-headedness was not included in the definition of dizziness. Cases of individuals who reported vision-related dizziness were investigated to determine potential areas of research for this thesis and subsequently two studies investigated the effects of refractive correction changes on dizziness status. The first study was limited by logistical problems, although it highlighted limitations in the short form of the Dizziness Handicap Inventory that was used to quantify dizziness. Results of an optometry practice recheck study found that oblique cylindrical changes were significantly more likely to be associated with dizziness symptoms than other spectacle lens changes. It also highlighted that optometrists do not ask/record about dizziness symptoms with only 4% of records including “dizziness” as a problem when 38% of patients reported dizziness symptoms when directly asked. All studies highlighted a need for a patient-reported outcome measure to be designed to assess vision-related dizziness. Literature review, interviews with experts and patients and focus groups led to the development of a pilot questionnaire and subsequently a 25-item Vision-Related Dizziness instrument, the VRD-25.

This was validated using responses from 223 respondents, with 79 participants completing the questionnaire a second time to provide test-retest data. Two subscales of VRD-12-frequency (VRD-12f) and VRD-13-severity (VRD-13s) were shown to be unidimensional and had good psychometric properties, convergent validity and test-retest repeatability. The VRD-25 is the only patient-reported outcome measure developed to date to assess vision-related dizziness and will hopefully provide the platform to further grow this under-researched area that seems likely to provide important clinical information.

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Chapter 1.

Introduction and literature review

Dizziness is common and has both physical and emotional consequences for the sufferer. It has been reported that 18% of people between the ages of 60 and 80 years increasing to 31% of those over 80 years (Olsson Möller et al. 2013) experience it. As the population ages, this problem will increase. Whether dizziness can be caused by refractive corrections and visual impairments is an under-researched area, with little evidence to support a link at the start of this thesis other than one pre-post cataract surgery cohort study (Supuk et al. 2016) and a possible link in two participants in a small sample study that actively blurred subjects (Atchison et al. 2001).

This thesis will investigate dizziness that could be attributed to vision and refractive correction changes (regardless of any other contributory factors such as vestibular disorders) to determine if manipulation of spectacle correction and/or other optometric interventions can reduce dizziness and improve quality of life for dizziness sufferers.

To fully understand the role of vision and refractive correction in patients with dizziness, it is important to be aware of the incidence, prevalence and aetiology of dizziness, and the consequences of having such issues.

1.1 Definition and classification

It is difficult to precisely define the term dizziness. The Collins English Dictionary's (2003) definition of dizziness is, "affected with a whirling or reeling sensation". Dorland (2012) defined dizziness as "a disturbed sense of relationship to space; a sensation of unsteadiness with a feeling of movement within the head". Black's Medical Dictionary (Marcovitch 2010) points out that the term dizziness has different meanings to different individuals and that practitioners should ascertain exactly what that person means when they use the expression. Yardley et al. (1998) described dizziness as a "non-specific symptom", as did Clark et al. (1994). Warner et al. (1992) described dizziness as 'an uncomfortable, disturbed state of spatial awareness'. It could be argued that this definition is suitably ambiguous as the term 'dizziness' may be used to describe a variety of often quite vague symptoms, making the condition difficult to assess and treat.

Patients use many different words to describe dizziness and may describe the same episode of dizziness in several different ways (Newman-Toker et al. 2007). An individual may refer to several coinciding sensations as an overall feeling of dizziness, indeed, patients frequently struggle to describe their own symptoms (Grill et al. 2013). Often practitioners use differing definitions of the same word and dizziness and vertigo seem to be terms which fall in to that category. Blakley and Goebel (2001) concluded that the definition of vertigo varied amongst professionals, and that the definition needed to be standardised to only include the illusion of spinning or turning of the environment in relation to the patient.

Practitioners should be aware of the following descriptions when trying to make sense of a patient's history and symptoms: light-headedness, swimming, floating, rocking, spinning, unsteadiness, giddiness, faintness, impending loss of consciousness, unreality, disorientation and imbalance - all may be used to describe a feeling of dizziness.

Studies that investigate dizziness also vary in their definitions of the condition. Many (Warner et al. 1992; Clark et al. 1994; Yardley et al. 1998; Tinetti et al. 2000; Jönsson et al. 2004; Dros et al. 2011) refer to dizziness as symptoms which fall within the subtypes described by Drachman and Hart (1972). These are as follows:

Vertigo. This is the feeling that either the individual or their surroundings are spinning. It often suggests a vestibular disorder (Murdin and Davies 2008).

Pre-syncope. This is a feeling of unsteadiness which is often described as the feeling that one is about to faint. Temporary reduced blood flow, causing lack of oxygen to the cerebral cortex is the cause of this sensation which may lead to a loss of consciousness. This condition may be associated with cardiovascular problems (Ham et al. 2007).

Disequilibrium. This is the feeling that an individual cannot keep their balance when they are standing still. This is often made to feel worse when the patient or the environment moves (Clark et al. 1994).

Light-headedness. This is a condition with no clear explanation which is used to describe dizziness which does not fall into the other categories. It is often associated with postural hypotension. Clark et al. (1994) indicated that this category of dizziness is often associated with stress or psychiatric problems.

Disequilibrium and vertigo are of particular interest to this study as they both

involve movement, the detection of which relies primarily on the visual system. It seems less likely that symptoms of light-headedness and pre-syncope would be linked with vision.

The Committee for the Classification of Vestibular Disorders of the Bárány Society has developed international classifications for vestibular complaints (Bisdorff et al. 2009). The first consensus document offered detailed criteria for the definition of symptoms and guidance on evaluation to help practitioners make the correct decision when classifying symptoms of dizziness and vertigo. This document was followed by diagnostic criteria for vestibular migraine (Lempert et al. 2012), benign paroxysmal positional vertigo (von Brevern et al. 2015) and Meniere's disease (Lopez-Escamez 2016). The International Classification of Vestibular Disorders (ICVD) document (Bisdorff et al. 2015) gave definitions for dizziness and vertigo.

These descriptions and definitions will enable practitioners to make diagnoses systematically and to be able to communicate with each other more effectively, however, these definitions are specific to patients with vestibular disorders, therefore are not wholly suitable for inclusion in this study.

1.2 Balance control

Balance control, postural control and postural stability are all terms used to describe the body's ability to successfully maintain balance. Good balance control is achieved when the visual, vestibular and proprioceptive systems are working successfully together (Yardley 1994). The control of balance is a process of which we are largely unaware. The body must be able to appreciate its spatial location, determine the speed and direction of any movement that it

makes, and make appropriate corrections to its posture to remain stable.

Balance is controlled by inputs to the motor system from the centrally integrated visual, vestibular and somatosensory systems. The visual system uses central and peripheral optic flow as well as retinal image and eye movements to monitor the body's position and movement in space (section 1.3). The vestibular system uses the vestibular apparatus in the inner ear to monitor head movements and acceleration. The vestibular apparatus comprises 3 semi-circular fluid-filled canals positioned in different planes combined with the utricle and saccule. The semi-circular canals each have an enlarged area (the ampulla) that contains hair cells which bend when the fluid (endolymph) moves in response to rotational head movements. Information about rate and direction of movement as well as the effect of gravity is detected by sensors in the utricle (horizontal movement) and saccule (vertical movement) and transmitted via the vestibular nerve to the vestibular nucleus and the cerebellum (Khan and Chang 2013). Figure 1.1 shows how these structures are arranged. Position and movement receptors throughout the body transmit information about the position and movement of body parts to the somatosensory system (Konrad et al. 1999). Information from these three systems is integrated to transmit impulses to the motor system which gives an individual an awareness of where the body is in space and whether and how it is moving, allowing for small movements to be initiated as needed to retain posture and balance (Waugh et al. 2014; Tortora and Derrickson 2014).

The balance system is constantly in use as the body is never truly immobile, since even when standing still, small movements are constantly present due to respiration (Winter et al. 1990). Figure 1.2 summarises the processes

involved in the maintenance of balance.

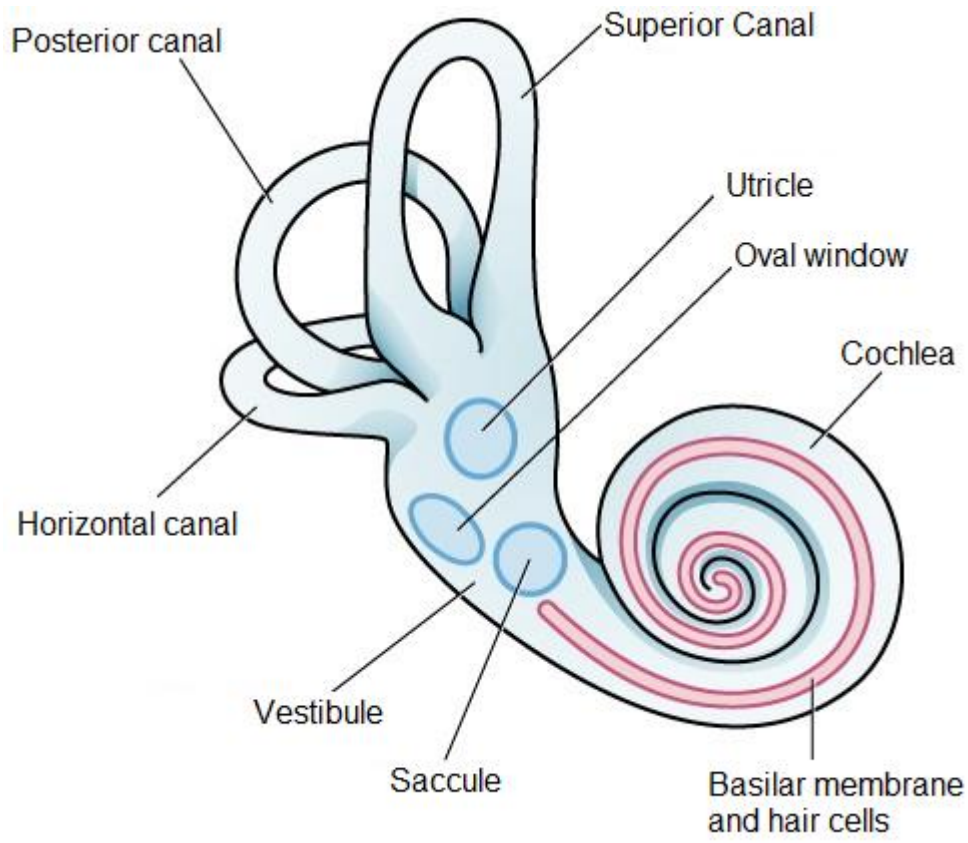


Figure 1.1 The structure of the inner ear

The major sensory organs of the vestibular system by Creative Commons https://courses.lumenlearning.com/msstate-waymaker-psychology/chapter/reading-the-vestibular-sense/ Accessed 4th May 2018.

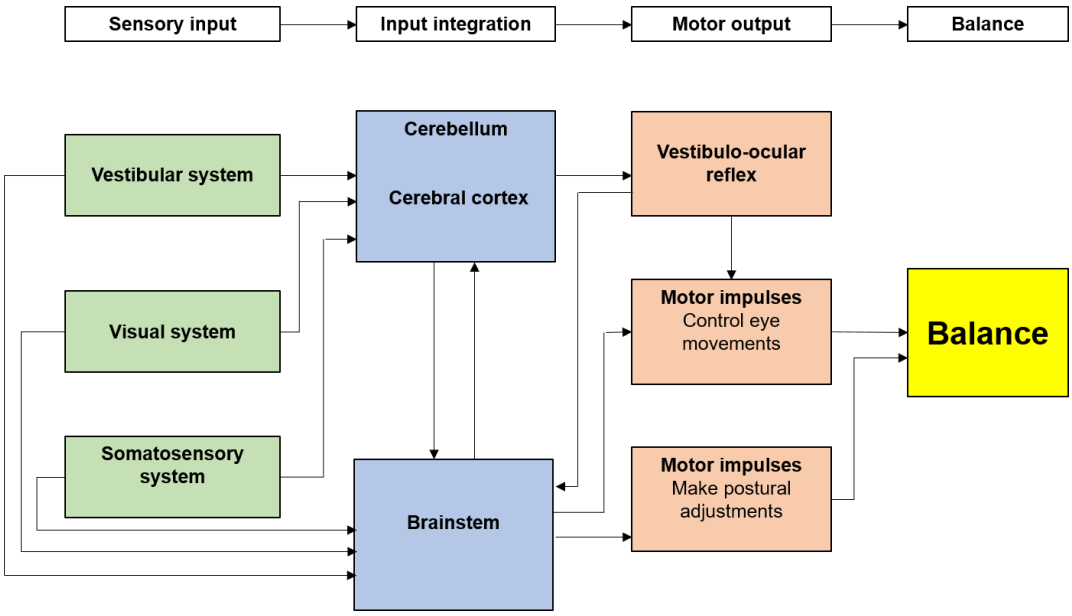


Figure 1.2 Diagram showing how the sensory and motor systems that control balance are connected *Adapted from* http://vestibular.org/understanding-vestibular-disorder/human-balance-system.

An impairment of one of these systems due to injury, disease or age, may result in reduced balance control. It has been shown that individuals who have impaired vestibular systems rely more heavily on their visual systems to maintain balance than those who have all three systems intact (Redfern et al. 2001). Likewise, those with an impairment of the proprioceptive system such as peripheral neuropathy, often rely more on visual and vestibular cues, to retain stability (Redfern and Furman 1994; Peterka and Benolken 1995). When an individual is subjected to motion, dizziness, disorientation nausea and vomiting may occur (Dai et al. 2007) even in healthy people. This is commonly known as motion sickness. It can occur when travelling by land, air, sea or during other forms of motion such as fairground rides. Inconsistency in the information received from the three systems involved in balance, creates a conflict of information being sent to the brain and may result in symptoms of

‘seasickness’ (Reason and Brand, 1975). When one is travelling in a boat, for example, the eyes tell the brain that the body is still, but the vestibular system detects movement. The brain can adapt to this conflict of information to reduce symptoms whilst at sea, as evidenced by some sailors suffering from ‘mal de debarquement’ – or sea sickness symptoms being present when being on dry land again (Bos et al. 2008). Watching 3D movies has been identified as a source of dizziness that is caused by moving scenes (Solimini 2013; Zeri and Livi 2015). This type of dizziness and discomfort is perhaps linked to the symptoms experienced during motion sickness where there is a mismatch in the movement detected by the eyes and the inactivity that the vestibular system perceived (Reason and Brand 1975).

1.3 The role of vision in balance

When standing still, the balance system is constantly making small adjustments to keep the centre of mass of that individual within the area of support which is provided by the feet, to compensate for tiny movements due to respiration (Winter et al. 1990). These tiny movements used to retain postural (or balance) control or stability, are known as postural sway and may be anterior-posterior or medial-lateral in direction.

The visual input for balance control is from optical flow information from the visual field and from retinal image movements (Guerraz and Bronstein 2008). Anterior-posterior body sway is monitored by retinal image movements, however retinal image movements from lateral body sway are unconsciously corrected by the eye movements initiated by the vestibulo-ocular reflex, therefore it is these eye movements that are used to monitor lateral body sway

(Elliott 2014b). It has been shown that eye movements influence the perception of body movements even in complete darkness (Clemens et al. 2017) as demonstrated by the Romberg test which compares postural sway of a subject standing with feet together with eyes open and then with eyes closed. A positive Romberg test is indicated by a significant increase in postural sway when the eyes are closed. (Lanska 2002). This highlights the importance of vision in the maintenance of postural control.

It has been shown that reduced vision decreases postural stability by increasing body sway (Ray et al. 2008; Paulus et al. 1984).

Similarly, it has been demonstrated that refractive blur and age-related eye disorders can adversely affect standing postural control in the elderly (Anand et al. 2003a, 2003b). Matheron and Kapoula (2011) demonstrated that an induced vertical heterophoria as small as one prism dioptre can be enough to cause the modification of postural control in healthy, young people.

1.4 The vestibulo-ocular reflex.

During brief head movements, an accurate vestibulo-ocular reflex (VOR) fixes images on the retina by means of equivalent eye movements in the opposite direction, in other words, the ratio (or VOR gain) of eye to head movement must be 1.0 to keep the retinal image stable. The process is rapid as there are only three neurons in the loop (figure 1.3), however, the visual input is slow so the system is primarily driven by the vestibular contribution. This is evidenced by the VOR remaining functional in the dark or when the eyes are closed (Daw 2012).

If there is a change in the VOR gain (for example a significant modification of spectacle power which results in the retinal image size changing considerably) eye movements must be re-calibrated to correctly adjust for head movements. ‘Catch-up saccades’ (rapid, jerky additional movements of the eyes which catch up with the target when viewing a moving object) may be necessary to retain a steady retinal image during adaptation and dizziness may be experienced if movement is not accurately determined by the brain The adaptation mechanism allows for some degree of protection from damage due to trauma, disease or ageing (Miles and Lisberger 1981). A decrease in VOR gain with age (Teggi et al. 2017), a prolonged latency of the linear VOR and use of more ‘catch up saccades’ to maintain a stable retinal image (Tian et al. 2002) and longer periods of dizziness following vestibular insult (Scheltinga et al. 2016) suggest that the elderly may be more prone to dizziness due to VOR errors. Adaptation of the VOR in man has been investigated using 2x magnifying spectacles (Gauthier and Robinson 1975), reversed visual tracking (Gonshor and Jones 1976a), and optical reversal using prisms (Gonshor and Jones 1976b). All three of these studies showed that adaptation of the VOR can be induced and that recovery takes place when the temporary, change-inducing lenses are removed. Small numbers of younger participants (one, seven and four respectively, age range 20-50) were used and the conditions induced were extreme – unlike the subtle changes in VOR gain that would be expected with a change in spectacle prescription. Collewijn et al. (1983) used changes in spectacle prescription (of 6-10 Dioptres) to investigate VOR adaptation in five subjects (ages not specified) and found that the adaptation to what they described as ‘modest’ changes in VOR gain took

minutes rather than the hours found in the three studies described above. It should be noted that in optometric practice, these dioptric changes to spectacle prescription would be described as ‘substantial’ (e.g., Cumming et al. 2007) rather than ‘modest’. This adaptation period may be accompanied by feelings of dizziness as the surroundings appear to move at a different pace to the head as detected by the vestibular system.

Manipulation of the VOR using spectacle correction has not been tested in elderly patients to date.

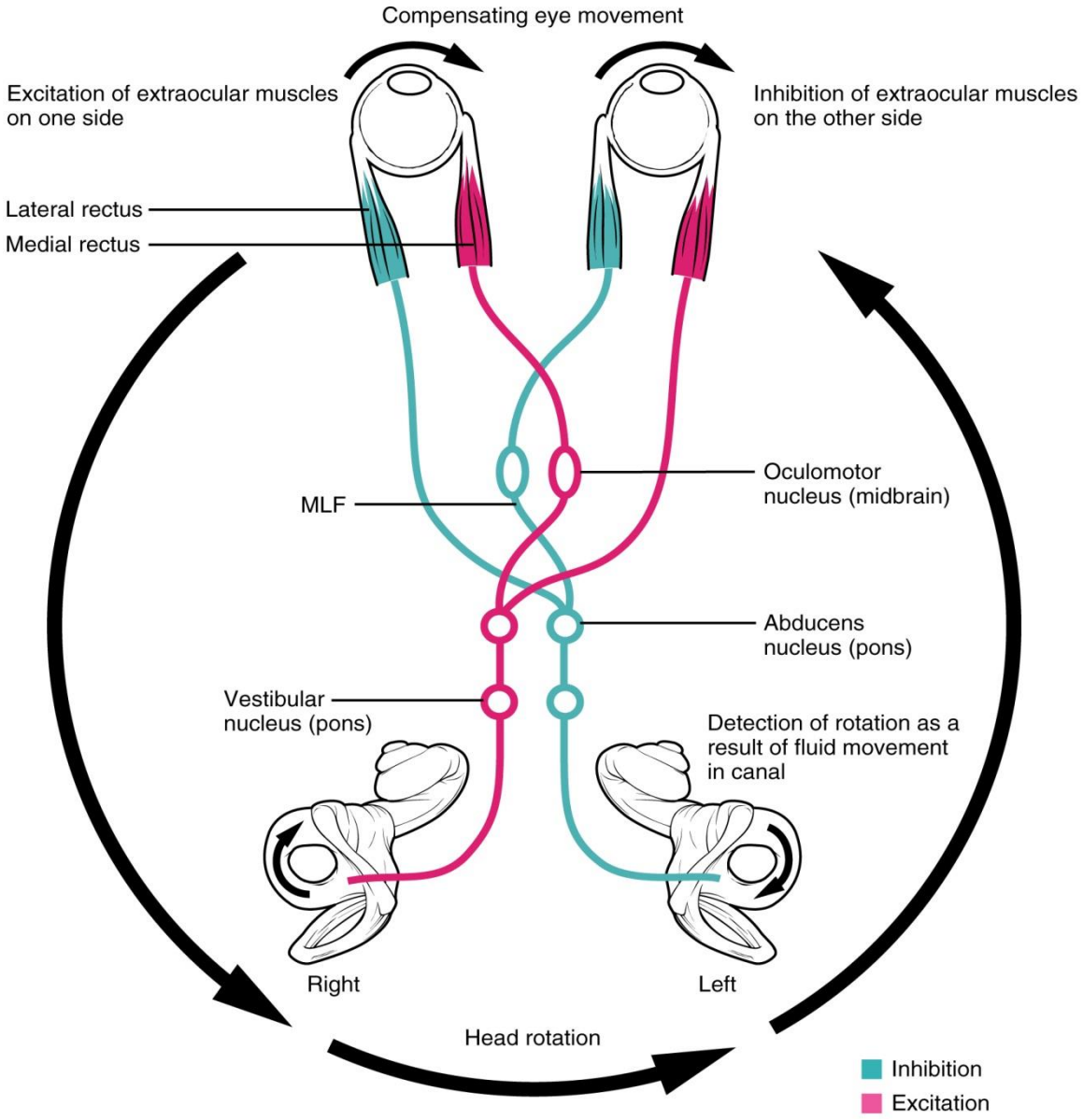


Figure 1.3 The vestibulo-ocular reflex. When there is head movement to the left, the eyes move to the right at exactly the same speed and for the same amount of distance to maintain a stable retinal image. A three-neuron loop is involved in this process, ensuring high speed feedback. MLF = medial longitudinal fasciculus. *(Reproduced from OpenStax, Anatomy and Physiology. Openstax CNX.* Accessed 30 Jul 2014 *http:??cnx.org/contents/14fb4ad7-30a1-4eee-ab6e-3ef2482e3e22@6.27.)*

1.5 Spectacle magnification and the VOR

Spectacles provide magnification by changing the path of the light as it passes through the lens. A convex, or positive lens, used for hyperopic correction converges rays of light to increase the size of the subtended angle, this in turn increases the image size on the retina (Figure 1.4). Conversely, a negative lens for myopic correction diverges rays of light, decreasing the subtended angle and causing minification, or negative magnification, of the retinal image.

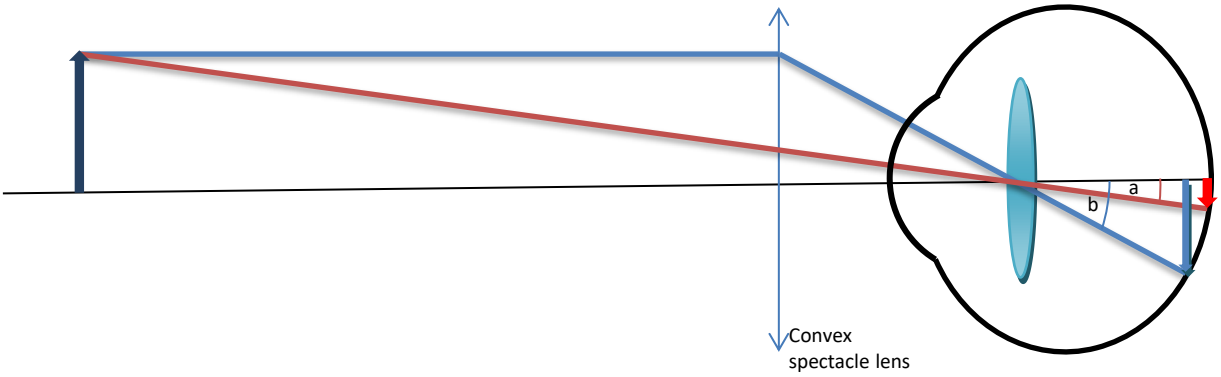


Figure 1.4 Spectacle magnification and the VOR. The red ray line shows how light passes through the eye to form an image when no spectacle lens is worn resulting in the image denoted by the red arrow. The blue ray line shows how light is converged by the convex lens, resulting in an increased angle of subtension (b) which in turn increases the image size (denoted by the blue arrow). *(Source: author)*

Spectacle magnification of a theoretically thin lens is calculated using the formula:

$Spectacle\ magnification$ = *retinal image size in a corrected eye*

retinal image size in an ametropic, uncorrected eye

(Rabbetts 2007)

Spectacle magnification (SM) of a real, 'thick' lens also depends on the thickness, material, front surface curvature (or form) of the spectacle lens and distance (or vertex distance) of that lens from the eye. This is calculated by the formula:

$$SM = \frac{1}{1 - (t / n_2)F_1} \times \frac{1}{1 - hF_v}$$

(Benjamin 2006)

Where t = thickness of spectacle lens (in metres)

n_2 = refractive index of the spectacle lens material

F_1= front surface power of the spectacle lens (in dioptres)

F_v = back vertex power of the spectacle lens (in dioptres)

h = distance from back surface of lens to the pupil entrance (in metres)

Magnification caused by spectacle lenses means that the eyes have to rotate more or less (depending on whether the lenses are of positive or negative power) to allow a stable retinal image to be formed during head movements (Crane and Demer 2000). The magnitude of this rotation is dependent upon the dioptric power of the spectacle lenses being worn. In addition, the eye must rotate (more with a positive lens, less with a negative lens) to compensate for the prismatic effect of looking through a spectacle lens at any point other than the principle meridian (Michaelides and Schutt 2014).

In a perfect situation, a stable retinal image would be maintained when the amount of eye movement is equal to the amount of head movement (but in opposite directions) when there is no refractive correction being worn. In other words, the ratio of head movement to eye movement should ideally be 1. This ratio is termed the VOR gain. If this VOR gain is changed due to the wearing of spectacle lenses, dizziness may occur until adaptation is achieved (Demer et al. 1989). A habitual spectacle wearer will be adapted to their usual VOR gain, however, if the spectacle power is adjusted such that the VOR gain changes, it seems reasonable to expect that adaptation will once again be necessary.

1.6 The opto-kinetic reflex (OKR)

The opto-kinetic reflex is an additional mechanism used to maintain clear vision. When the eyes track a large, moving scene, the optokinetic reflex provides visual back-up for the VOR in stabilizing the retinal image. The eyes rotate to follow the scene then quickly ‘snap’ back to their original central position where the process starts again. The eyes are observed to move from side to side in what is termed opto-kinetic nystagmus. The movements

required are similar to those used during smooth pursuit of an object, however the OKR is thought to be an automatic process whereas smooth pursuit requires the observer to choose to follow the object whilst paying significant attention to the task (Schweigart et al. 1997). At lower frequencies the OKR compensates for movement of the image on the retina (or retinal slip) of the image by constantly returning the eyes to the starting point of the movement. At higher velocities or accelerations, the OKR gain declines and the VOR becomes the principle contributor in fixing the retinal image.

1.7 Aetiology of dizziness

Practitioners have been pondering the causes of dizziness for many years. In terms of visual aetiologies, Harwood (1916) stated that unstable muscular mechanisms were the root of the cause, with reductions in visual acuity, especially those caused by astigmatism, enhancing the problem. He suggested that girls between 14 and 21 years of age who received a modern education would be highly likely to suffer from dizziness(!) as well as those who have recently given birth, had an operation or suffered from ‘shellshock’. These suggestions were purely anecdotal with no evidence offered to support the observations. Opinions have changed somewhat over the years however it is interesting to note the inclusion of astigmatism as associations between dizziness and astigmatism have since been supported by scientific evidence (Guyton 1977; Supuk et al. 2016).

Dizziness has many different causes ranging from the innocuous accumulation of excess ear wax to the often life-changing event of a brain stem stroke (Warner et al. 1992). There may be a definite cause for dizziness

in an individual, however, the practitioner often may not be able to identify a source (Belal and Glorig 1986). Those who suffer from motion sickness, or space and motion discomfort, frequently complain of dizziness (Redfern et al. 2001). Redfern and Furman (1994) found that patients who were diagnosed with vestibular problems or suffered from anxiety had an increased sensitivity to rapid changes in the visual surroundings, causing dizziness and disequilibrium. Anxiety was shown to have a similar effect by Jacob et al. (1995).

1.7.1 Aetiology of dizziness - visual vertigo

Situations such as fairground rides or flight simulators may elicit dizziness symptoms in normal subjects (Dichgans and Brandt 1978). Visual vertigo is a condition where certain visual conditions trigger or exacerbate dizziness (Bronstein 1995; Guerraz et al. 2001; Bronstein 2005; Jacob et al. 2009). Visual vertigo typically develops following an episode of vestibular disease or injury such as vestibular neuritis. Many people with past or present vestibular problems suffer from visual vertigo that is triggered when the individual views ‘busy’ moving scenes such as walking down a supermarket aisle or across a patterned floor (Bronstein 2005). It has been demonstrated that visual vertigo sufferers show excessive postural and perceptual responses to disorientating visual surroundings Guerraz et al. (2001) and are often more visually dependent for balance control than normal subjects (Guerraz et al. 2001; Bronstein 2005). A study of 101 vestibular migraine patients aged between 18 and 65 years (Vuralli et al, 2017) concluded that dizziness triggered by moving visual stimuli is common, with 71% of subjects reporting this as a factor for

inducing and/or exacerbating dizziness symptoms. Visual vertigo can lead to anxiety in susceptible individuals (Bronstein 2005), however neurological disorders are unlikely to be the cause in vestibular patients (Guerraz et al. 2001).

1.7.2 Aetiology of dizziness – refractive correction changes

Research on dizziness and spectacle correction is limited, however small amounts of spherical anisometropia (one subject with an additional +0.50DS monocularly and another with an additional monocular -0.50DS) have been shown to induce dizziness in two of 15 young subjects (Atchison et al. 2001). None of the subjects complained of dizziness with binocular additions of -0.50DS or +0.50DS or with +0.25DS in the right eye and -0.25DS in the left eye. Changes in oblique astigmatic correction have been identified as a cause of increased dizziness within a multivariate model after routine cataract surgery in 287 patients (Supuk et al. 2016) and prescribing guidance often includes advice to make only conservative changes to oblique cylindrical lens power to reduce the chances of the patient being dissatisfied with their spectacles without mentioning the word ‘dizziness’ (Guyton 1977; Werner and Press 2002; Elliott 2008, 2014b). In addition, refractive correction changes were shown to reduce dizziness symptoms in three, of the seventy- five dizzy subjects examined by Das et al. (2017) suggesting that there is value in carrying out further research in this area.

1.8 Reporting of dizziness

Documentation of dizziness usually relies on self-report by the patient. This

leads to the suggestion that dizziness may be underestimated due to inaccurate recall (as with the reporting of falls; Cummings et al. 1988) and the many different definitions of dizziness which are used. The results of any longitudinal study to investigate the prevalence and incidence of such a problem may be skewed by the patient reporting every tiny incidence of dizziness, whereas someone involved in a retrospective study may only recall symptoms if they caused significant imbalance or distress, with mild symptoms being disregarded. Reporting of the prevalence of dizziness may also be affected by the wording of the questions in the instrument used. A question such as 'have you ever suffered from dizziness?' may lead to the reporting of any small episode of dizziness regardless of whether it caused a problem (for example, looking up suddenly after a period of reading and experiencing a delay in the eyes focussing causing symptoms of dizziness which only last a few seconds). At the same time, asking a patient to recall over a long period of time could result in a patient only remembering episodes of dizziness which caused significant problems. Yardley et al. (1998) reported that only 40% of subjects who reported dizziness consulted their GP about their problem. This evidence suggests that many cases of dizziness are mild and don't cause activity limitation or distress, therefore, intervention might not be necessary. In addition, males attend their GP less often than females and often delay consulting their GP (Francome 2000; Banks 2001). This would skew the results of any study which documented the prevalence and severity of dizziness between the sexes.

1.9 Prevalence of dizziness

Studies investigating the prevalence of dizziness vary in their findings. Several papers agree on a prevalence being between 20 and 30% in the elderly population of over 65 years (Colledge et al. 1994; Yardley et al. 1998; Tinetti et al. 2000; Kao et al. 2001; Gassmann and Rupprecht 2009). Studies finding the prevalence of dizziness to be between 15% and 20% (Sloane et al. 1989; Gomez et al. 2011; Maarsingh et al. 2014) all had study populations of 60+ years suggesting that the inclusion of 60 - 64 year olds may have reduced the overall prevalence of dizziness. Two studies stand out as having very different results from the others. Menant et al. (2013) found a prevalence of 42% although the population studied was an older, elderly population with ages between 73 and 92. Since the prevalence of dizziness increases with age (Colledge et al. 1994) this could account for the difference between this and other studies. Aggarwal et al. (2000) found a very low prevalence of only 9.6% in the overall community elderly (65 years+) population with an increasing prevalence with age (6.6% in the 65 - 74 years age group rising to 18.4% in the ≥85 years group) however this study focussed on those who reported to have dizziness at least once per month with persons who had dizziness less frequently than monthly being categorized as not having dizziness. The same study found a prevalence of 41.4% when participants were asked if they had ‘ever’ suffered from dizziness or light-headedness.

The exclusion of patients with cognitive decline such that they would not understand the questions being asked, implies that dizziness in the elderly population may be underestimated. This problem is unavoidable since the inclusion of these individuals would reduce the efficacy of the data obtained.

Few studies focus on dizziness in the working age population. Yardley et al. (1998) found the prevalence of dizziness in those ages 18 - 64, in the United Kingdom, ranged from 20% to 25% depending on the location the sample was taken in. A lifetime prevalence of 40% was recorded. Studies on the general population are not as numerous as those on the elderly, and have demonstrated that between six and 21% of the general population are affected by dizziness (Nakashima et al. 1996; Hannaford et al. 2005; Neuhauser et al. 2005; Wojtczak 2017).

Many differences in methods and investigations are highlighted when evaluating studies investigating prevalence of dizziness, many studies don't define exactly what they mean by dizziness, the sample sizes used may differ significantly (from 262 to 15,788) and few use matching populations or similar methods of sampling (postal questionnaire, telephone interview or clinic sample) making it very difficult to make meaningful comparisons.

Table 1.1 summarizes some of the differences between these prevalence studies.

Table 1.1 Comparison of studies of the prevalence of dizziness in terms of dizziness definitions, sample population and exclusion criteria

Paper	Dizziness definition	Sample population	Exclusion criteria	Prevalence	Associated factors
Aggarwal et al. (2000)	None specified	Age 65+ USA N = 672	None	41.4% lifetime 9.6% regular	Dizziness prevalence increased with age
Colledge et al. (1994)	Not specified	Age 65+ UK N=900	Dementia, care home residents	30%	Prevalence increases with age
Gassman et al. (2009)	Not specified	Age 65+ Germany N = 620	Cases with missing data	29.2%	Dizziness often multifactorial.
Gomez et al. (2011)	Not specified	Age 60+ Colombia N = 1692	Significant cognitive and medical problems	15.2%	Dizziness multifactorial
Kao et al. (2001)	Not specified	Age 60+ USA N=262	Poor cognitive ability	21%	Increases with number of predisposing factors
Maarsingh et al. (2014)	Not specified	Age 60+ Holland N = 681	Not explained	18.4% at baseline 18.9% at 7 years 14.3% at 10 years	Rheumatoid arthritis, anxiety or depression, use of nitrates and impaired lower extremity function all predictors of dizziness
Menant et al. (2013)	Not specified	Age 73-92 Australia N=516	Dementia, developmental disability, neurological conditions. Non-ambulatory	42%	Anxiety linked to dizziness
Sloan et al. (1989)	Not specified	60+, USA N=1612	Institutionalised individuals	18.2% 1 year 29.3% lifetime	Perception of self as a nervous person, depression, neurologic disease, cardiac disease
Tinetti et al. (2000)	Dizzy, unsteady spinning or moving, light-headed or faint	72+ years, USA N=1087	Reduced cognitive ability, ambulation, and communication.	24%	Dizziness strongly associated with number of predisposing factors
Yardley et al. (1998)	Not specified	18-64 years N=2064	Not specified	23.3% (40% lifetime)	Increases with age and female sex

1.10 Risk factors and associated problems

Dizziness has been associated with many other health-related problems. Risk factors vary between studies since research projects have considered different factors in their investigations. For example, Colledge et al. (1994) considered physical factors such as angina, diabetes and falls in an elderly population whereas Yardley et al. (1998) was researching into the psychological problems of anxiety and avoidance behaviour in the working age population.

It has been shown that the probability of a patient experiencing dizziness is linked to the number of predisposing factors (Tinetti et al. 2000). This approach was supported by the results of the study by Kao et al. (2001) who found five independent risk factors for dizziness (depressive symptoms, balance impairment, postural hypotension, past myocardial infarction and the use of three or more medications). Tinetti et al. (2000) found the same five factors to be associated with dizziness in addition to impaired hearing and anxiety, with unsteadiness increasing with the number of risk factors identified in an individual. Participants who didn't report any of these risk factors reported no dizziness. 6% of patients with one risk factor reported dizziness and subjects with two, three and four or more risk factors, reported dizziness of 12%, 26% and 51% respectively. These studies appear to confirm each other's findings, however, the populations studied were different. Kao's study included those who had attended a geriatric assessment centre, which may have introduced selection bias as patients who present for examination are more likely to have a reason for suspecting a problem than those who do not attend. Tinetti's population was community based, so would probably contain

a more representative sample of non-dizzy elderly people. As with Kao's study, the percentage of the population who reported dizziness rose with the number of predisposing characteristics, with one, two, three, four and five or more risk factors corresponding with 18%, 27%, 33%, 50% and 68% of patients reporting dizziness, respectively.

1.10.1 Gender

Many studies show that gender has an influence on dizziness with females being more likely to report problems than males (Colledge et al. 1994; Yardley et al. 1998; Jönsson et al. 2004; Ödman and Maire 2008; Neuhauser et al. 2008; Stevens et al. 2008; Maarsingh et al. 2010a; Maarsingh et al. 2010b; Lai et al. 2011; Radtke et al. 2011; Bisdorff et al. 2013). All studies found that dizziness was more common in the female gender. Maarsingh et al. (2010b) noted that in the very elderly (85+years) prevalence was similar in both males and females.

1.10.2 Age

Increasing age is another risk factor for dizziness that has been documented in many studies (Colledge et al. 1994; Jönsson et al. 2004; Neuhauser et al. 2008; Maarsingh et al. 2010b; Lai et al. 2011). Bisdorff et al. (2013) found that dizziness had an approximately even occurrence throughout life in a large sample size (N=2987, age range 18-86 years, mean age 46 years) study that investigated dizziness in a general population. This may be because even occasional, short duration (<1 hour) episodes of dizziness were recorded. Many patients, especially the elderly, have numerous problems contributing

towards their dizziness, making differential diagnosis difficult. This is termed ‘multisensory dizziness' (Murdin and Davies 2008) and it has been suggested that dizziness in the elderly should be considered not as a symptom, but as a geriatric syndrome with many contributory factors (Tinetti et al. 2000). The word 'presbyastasis' was used by Belal and Glorig (1986) to describe the increasing likelihood of reporting symptoms of dizziness with age. It was suggested that, although some cases of dizziness are attributable to a specific cause, many cases have several origins due to the general reduction of function and processing capability with age.

1.10.3 Postural hypotension

Postural hypotension (a sudden change in blood pressure when moving to a more upright position) can precipitate dizziness and this has been a factor considered in many studies. It is often described as feeling of ‘light-headedness’. Radtke et al. (2011) conducted a study focussing on the problem of orthostatic dizziness on a large (N=4077) cross-sectional population with ages ranging from 18 to 89 years and found that this type of dizziness accounted for 42% of all dizziness found in the general population with females being more likely than males to report problems. The highest percentage of orthostatic dizziness was found in young adults with an age range of 18 to 29. The study also found that 55% of non-vestibular dizziness cases were of postural origin and that a fifth of the people with orthostatic dizziness had lost consciousness and almost as many had suffered a fall because of their dizziness. Colledge et al. (1994) found that a change of posture was the most common precipitant of dizziness in their study which

investigated a population of community dwelling over 65 year olds. Colledge et al. (1996), Kao et al. (2001) and Jönsson et al. (2004) all found links to postural hypotension while Tinetti et al. (2000) found that the relationship between dizziness and postural hypotension depended on the definition used by the researchers. (A relationship was found when the mean blood pressure measurement was used, but not when only the systolic pressure was used).

1.10.4 Vascular disease

Vascular disease has been found to be a risk factor for dizziness in numerous studies with papers investigating cerebrovascular disease (Colledge et al. 1994; Maarsingh et al. 2010a; Maarsingh et al. 2010b), the taking of medication for cardiovascular problems (Colledge et al. 1994), past myocardial infarction (Kao et al. 2001), past transient ischaemic attacks (Menant et al. 2013), the presence of cardiovascular disease and peripheral vascular disease (Maarsingh et al. 2010a; Maarsingh 2010b). Notably, all these reports were conducted on people over 65 years, possibly indicating that this may not be a risk factor for the younger population or that this is mainly a health problem associated with the older population.

1.10.5 Vestibular disease

Given that one of the inputs for balance is located in the inner ear, one might assume that dizziness is a problem with the ears and/or vestibular system. Drachman and Hart (1972) found 38% of patients in a dizziness clinic had problems of vestibular origin and Neuhauser et al. (2008) supported this claim by finding a third of dizziness to be vestibular. Kroenke et al. (1992) reported that vestibular disorders were the primary cause of dizziness in their study

with 40% of their dizzy patients identified as having vestibular origins for their problem.

1.10.6 Pharmacological risk factors

When an individual is taking many different medications (typically more than four) they are more likely to have problems with dizziness than someone who is taking

fewer or no medications (Colledge et al. 1996; Tinetti et al. 2000; Kao et al. 2001; Bisdorff et al. 2013). Medicines such as benzodiazepines (prescribed for sleeping and anxiety problems) and narcotic analgesics (such as co-codamol) have side effects such as dizziness indicating that this may be the cause (Longo and Johnson 2000; Furlan et al. 2006). However, the medical problems being treated by these drugs could also have symptoms of dizziness making it impossible to pinpoint the exact reason for the problem. Several studies have investigated whether regular alcohol consumption is associated with dizziness (Colledge et al. 1996; Tinetti et al. 2000; Kao et al. 2001; Stevens et al. 2008) and found that alcohol consumption did not have a statistically significant association with dizziness. Since it is known that even moderate consumption (0.4g/Kg of bodyweight) doses of alcohol can decrease postural stability (Wu et al. 2017), people who suffer from dizziness may moderate their intake or abstain from consumption to try to reduce their dizziness.

1.10.7 Anxiety

Anxiety has been shown to be a risk factor for dizziness as well as a consequence (Yardley et al. 1998; Yardley et al 2001). Being anxious or upset

has been reported to be associated with dizziness both in studies conducted on the elderly population (Colledge et al. 1996; Tinetti et al. 2000; Olsson Möller et al. 2013; Menant et al. 2013) and in those on the general population (Yardley et al. 1998; Ödman and Maire 2008; Bisdorff et al. 2013). Anxiety can also exacerbate and delay recovery from vestibular disorders (Yardley and Redfern 2001). Dizziness is often intermittent and dependent upon the situation that the sufferer finds themselves in. This can lead to anxiousness about if, and when it may recur. If a specific cause for the condition has not been found, if the patient fears falling, is embarrassed about what others may think of them when they are dizzy or has had to restrict activities due to their dizziness, this can lead to a feeling of helplessness which can trigger anxiety. Furman and Jacob (2001) investigated dizziness in patients who also suffered from panic disorders. They asked 94 people who had been diagnosed with panic attacks to identify their dizziness symptoms during a panic attack from a predetermined list. 70% of patients indicated that light-headedness was 'often' among their symptoms when a panic attack occurred. This, they suggested, was likely due to anxiety triggering hyperventilation which caused dizziness described as light-headedness. Dizziness may trigger anxiety (Yardley et al. 1998; Holmes and Padgham 2011) and anxiety may lead to dizziness, leaving the patient in a self-perpetuating condition that they may feel unable to escape from.

1.10.8 Summary

Since dizziness is often multifactorial (Kao et al. 2001) and may be categorized as a geriatric syndrome (Kao et al. 2001; Tinetti et al. 2000) it may

be that an individual has more than one source for their problem, meaning that percentages of patients with any particular cause may not be constrained to 100%. For example, if a patient has vestibular disease and takes multiple medications, they may be included in calculations for both risk factors.

Vascular disease has been found to be the most common independent risk factor for dizziness in the elderly (Colledge et al. 1996). Drachman and Hart (1972) found the most likely cause to be vestibular disease, while Tinetti et al. (2000) reported that there was no single factor with a strong relationship to dizziness. Clearly all these differing opinions cannot all be correct. The differences in findings are most likely explained by variations in study design and the populations used. Table 1.2 summarises the most common risk factors for dizziness.

Table 1.2 A summary of the most common risk factors for dizziness

	Sample population	**Main risk factor findings**
Kroenke et al. (1992)	20-62 years, dizzy patients in hospital out-patients clinic N= 134	40% Vestibular disorders 12% Psychiatric disorders 16%Multi-causal or unknown
Belal & Glorig (1986)	65+ years Ear clinic patients N = 740	79% no specific cause 8% Meniere's 2% Vascular disorders
Colledge et al. (1994)	65+ years Community dwelling N = 900	Dizzy group twice as likely to have angina or a myocardial infarction than non-dizzy group
Colledge et al. (1996)	79-90 years Sample of urban population N = 246	Dizzy group twice as likely to have ischaemic heart disease or ear disease than non-dizzy group. Dizzy group three times more likely to have eye disease than non-dizzy group
Yardley et al. (1998)	18-64 years Random selection, GP lists N = 2064	15.3% anxiety (other risk factors not investigated)
Tinetti et al. (2000)	72+ years Random selection, community N = 1087	Relative risk for dizziness was 1.38 for each additional risk factor
Kao et al. (2001)	60+ years Geriatric assessment centre N = 262	OR 6.6 (95%CI 1.7-25.0) myocardial infarction OR 5.3 (95%CI 2.2-12.9) cataracts OR 3.1 (95%CI 1.5-6.5) abnormal gait OR 2.8 (95%CI 1.4-5.5) depressive symptoms OR 2.5 (95%CI 1.1-5.8) diabetes OR 2.0 (95%CI 1.0-4.0) postural hypotension OR 1.6 (95%CI 0.7-3.6) 3+medications
Nauhauer et al. (2008)	18-79 years General population N = 4869	25% vestibular vertigo (other risk factors not investigated)
Maarsingh et al. (2010b)	65+ years Dizzy patients seeking GP care N = 3990	Cardiovascular disorders 14% Vestibular disorders 12% Psychiatric disorders 6%
Maarsingh et al. (2010a)	65-95 years Dizzy patients seeking GP care N = 417	Cardiovascular disease 57%, Vestibular disease 14%, Psychiatric illness 10%

1.11 Consequences of dizziness

Dizziness may cause the sufferer to change their day to day activities, even during periods when they are not experiencing the problem, since the fear of dizziness has an impact on how that individual behaves. A greater level of quality of life limitation is perceived by the patient if they have a negative view of the effects of dizziness with the patient subsequently introducing self-imposed limitations on behaviour, although treatment can reduce negative perception (Yardley et al. 2001).

Dizziness has both physical and emotional consequences. Headaches, unsteadiness, blurred vision, diplopia, paraesthesia (pins and needles), tinnitus, hearing loss, nausea and vomiting are all symptoms which may accompany the sensation of dizziness, (Colledge et al. 1994) however, these associated symptoms have not been found to be common (Jönsson et al. 2004). One of the more serious physical problems associated with the sensation of imbalance is the increased tendency to fall (Menant et al. 2013). Masud and Morris (2001) used the results of 12 studies and ranked 'dizziness / vertigo' as the third most likely cause of falls with a mean of 13% of falls reported to have been most probably caused by dizziness. Colledge et al. (1994) found that 10% of their study population had fallen while dizzy. The low percentage of dizzy patients who fell may be attributed to the sensation of dizziness being an ‘early warning’ which alerted patients to the need to sit down or hold on to something stable to prevent a fall. O'Loughlin et al. (1993) suggested that dizziness is an issue that is significantly associated with an increased rate of falls in the elderly population. Falls and the fear of falling lead to reduced quality of life due to activity restriction and anxiety. A patient

who has a fear of falling is more likely to be frail and have balance impairment, and this can lead to more falls (Arfken et al. 1994). Dros et al. (2011) found that dizziness in the elderly is associated with social isolation, functional disability, falls and placement in care homes. When an elderly person falls it may cause injury and hospitalization at a cost of reduced quality of life and loss of independence for the patient, as well as the financial implications of medical care (Masud and Morris, 2001).

Dizziness often leads to anxiety (Yardley et al. 1998; Holmes and Padgham 2011) and anxiety can lead to the feeling of dizziness, causing the patient to feel that they are trapped in an unpleasant cycle with no way out. Pollak et al. (2003) used the Hospital Anxiety and Depression Scale to compare the anxiety levels experienced by 30 adult patients with vestibular disturbances who were hospitalized in a neurologic department due to their first attack of vertigo, with 35 adult patients who had been hospitalized in the same department due to an acute onset non-vestibular neurological defect (including stroke, III nerve palsy, cerebrovascular accident, demyelination, myelitis, inter-nuclear ophthalmoplegia, Guillain-Barre syndrome or cranial polyneuritis). Self-estimation of anxiety levels prior to hospitalization were similar for both groups of patients. The study found that those with vestibular deficiencies suffered more from anxiety and felt “more handicapped” than non-vestibular patients. This was hypothesised to be probably due to connections between the vestibular system and the limbic system (which is responsible for emotion) in the brain, however, he concluded that this theory needed further investigation.

Neuhauser et al. (2008) conducted a study with a large sample size of 4869

adults aged 18-79. The sample was randomly selected from the German National Health Interview Study (2003) and was representative of the general population of Germany. The screening question of “did you ever experience moderate or severe dizziness or vertigo?” identified 1003 patients with symptoms which were evaluated to distinguish between those with vestibular dizziness and non-vestibular dizziness. An annual prevalence of 22.9% was found for dizziness with 24.2% of these dizzy individuals being categorised as having dizziness of vestibular origin. The adults who were identified as being dizzy were then interviewed by telephone using an instrument developed and validated by the authors (the instrument, however, was not detailed in the paper) to determine the character of the dizziness and the consequences of having such a problem. Dizzy patients' perception of their health-related quality of life was lower than that of non-dizzy people in all aspects investigated by the interview (physical functioning, vitality, pain, general health, social and emotional functioning and mental health). They found that, as well as the interruption of normal activities and the tendency to avoid leaving the home, dizziness also carried the economic consequences of having to take sick leave and medical consultation. This indicates that dizziness has costs for the community as well as for the individual.

Dizziness has been shown to compound other problems, with patients who suffer from anxiety disorders feeling more limited in day to day life by their dizziness than those who have not been previously diagnosed with such a problem (Eckhardt-Henn et al. 2003). Yardley et al. (2001) showed a relationship between symptom levels and the amount of quality of life limitation, and, that this relationship was influenced by a patient's negative

perception of the consequences of dizziness. The study involved recruiting patients over the age of 18 who attended their GP practice due to dizziness. 159 participants with dizziness of vestibular origin and who wouldn't be harmed by the movements involved in therapy were initially enrolled in the study, but a high level of withdrawal and patients who failed to return the questionnaires resulted in only 76 being included. Patients were randomly, assigned to the treatment group, or the control (no treatment) group. Patients who received treatment were shown to have fewer negative beliefs about dizziness than those in the control group and, consequently had reduced feeling of the level of limitations caused by their dizziness. There is no mention of using a placebo treatment for the 'no treatment' group, therefore, participants would know to which group they had been allocated, creating performance bias. In other words, the participants who knew they had received treatment may have had their perception of activity limitations influenced by the knowledge that they had received treatment, rather than by the effect of the treatment itself.

1.12 Assessment and measurement

When a patient describes their dizziness, they may give a detailed picture, or they may be very vague as symptoms may be subtle and difficult to describe accurately. Taking a patient's history is essential to any investigation; in the case of dizziness, the practitioner would be well advised to ascertain exactly what the patient means when they describe their dizziness. Information gathered during a thorough history should be used in conjunction with other tests to formulate a management plan.

1.12.1 Objective measurement of dizziness and balance

Measuring dizziness objectively using tests such as computerised dynamic posturography may be useful to clinicians who need to quantify dizziness pre- and post-treatment to determine if an intervention has been successful. These tests measure balance, or postural stability rather than dizziness. Quantifying the shortfall in function, however, may not be useful at deciding if a patient has a significant dizziness problem, or the impact of the dizziness on daily life as, what is intolerable to one individual, may be barely noticeable to another. In other words, the activity limitation or inconvenience caused by dizziness is a very subjective experience. It could be argued that the best way of quantifying a subjective experience would be to use a subjective test, such as a patient reported outcome questionnaire. Furthermore, objective and subjective assessments of dizziness have been shown to have only weak to moderate correlation with each other, depending on the tests used (Rossi-Izquierdo et al. 2014). This study of 37 patients over the age of 65 who had balance problems which were thought to be due only to advancing age and who presented a high risk of falling compared scores on the Dizziness Handicap Inventory with scores on objective balance tests (the Sensory Organisation Test, Computerised Dynamic Posturography, the Swaystar Balance Control Index and the Modified Timed Up and Go Test). They found no correlation with the static balance test and only weak to moderate correlation with dynamic balance tests.

1.12.2 Objective balance testing.

Computerised Dynamic Posturography. (CDP). This non-invasive objective test of postural stability was introduced by Neurocom in 1986. It has been described as the most superior existing test for investigating balance disorders and deficits (Lui et al. 2013). It consists of a platform that can move both horizontally and rotationally with a visual surround target (which can be made static or dynamic) in a three-sided enclosed box-like arrangement. A safety harness is used to guard against patients sustaining injuries if they lose their balance during the procedure. The platform contains pressure sensors which detect shifts in body weight (or sway) of the patient who stands on it without shoes. In this way an indirect measurement of the displacement of the patients' body can be obtained. The data collected is compared to an inbuilt database of values which compare age, height and weight of the patient. CDP is used to test sensory organisation, the limits of stability, motor control and adaptation.

The Sensory Organisation Test. The patient is asked to stand on the platform in the Romberg position (Standing upright with arms down by the side or folded in front). The patient must attempt to remain balanced on the platform in six different conditions. These conditions are:

1. Stationary platform and visual surround, eyes open.
2. Stationary platform, eyes closed.
3. Stationary platform, moving surround, eyes open.
4. Moving platform, stationary surround, eyes open.
5. Moving platform, eyes closed.
6. Moving platform, moving surround, eyes open.

An average balance score can be calculated using the mean values for the different conditions as well as isolated scores for visual, vestibular and somatosensory input. The degree of dependency on the visual system for balance maintenance (or visual preference) may also be determined (Rossi-Izquierdo et al. 2014).

Limits of Stability Test. This test assesses the ability to transfer weight away from the centre of gravity whilst maintaining balance. The patient is asked to move their trunk towards a target using their ankle joint as the pivot point for movement and keeping their trunk in a straight line. The target is presented at eight different positions 45˚ apart from each other, forming a circle around the patient. The point at which postural stability is lost is recorded and is compared to the theoretical maximum score for the patient's age. Directional control, reaction times, mean velocity of the movement and maximum reach may be recorded. This test may also be carried out using the Swaystar System (Rossi-Izquierdo et al. 2014).

Motor Control Test. This test measures how capable the patient is of recovering from a sudden, unexpected disruption to their postural control. This is simulated by having the platform move without warning in a horizontal plane. The size of the movements is scaled to the patient's height to ensure that the disturbance to postural control remains the same for each patient.

Adaptation test. The adaptation test assesses the patient's ability to stabilise the body when the supporting platform tilts in a toes up/down direction unexpectedly. In this way, it attempts to reproduce real life situations. Force needed to correct the instability caused by movement of the platform is

measured via the sensors in the platform.

The Swaystar System. (*Balance International Innovations GmbH, Switzerland*). This consists of a box-like device that is worn around the waist at lumbar level, close to the centre of mass. This device uses transducers to evaluate shifts in movement of the trunk and can measure both pitch (antero-posterior movement) and roll (latero-lateral movement). These measurements are compared to a database of normal, age-adjusted results. The apparatus calculates the angular deviation of the body, rather than using indirect estimations based on foot pressure (as used for the CDP) (Faraldo-García et al. 2013). The Swaystar System is portable, allowing it to be worn in real life situations such as stair climbing, however, this portability means that there is no safety harness, so the practitioner must stay close to the patient in case balance is lost. The Swaystar System and CDP only give comparable results when they are used in exactly the same test situations. This is thought to be due to the information received by balance system being very different depending on whether a visual surround or the whole room is used for visual feedback (Faraldo-García et al. 2013).

The Timed Up and Go Test. This simple test is used to assess the mobility of a patient whilst they are using both static and dynamic balance. The patient is asked to stand up from a chair, walk a distance of 3m at a comfortable pace, (wearing shoes and making use of any habitual walking aids) before turning through 180˚and returning to sit in the chair once again. The time taken to complete the task and the number of steps taken is analysed and compared against normal scores (Nordin et al. 2008).

Video Head Impulse Testing. This test, more commonly known as vHIT, is an updated version of the Head Impulse Test. It consists of a spectacle-like apparatus which contains a tiny camera. The camera is used to measure eye movements as the patient is asked to make saccades to follow a target. It is used to estimate how well the VOR is performing and to determine if there is any deficit in semi-circular canal function.

1.12.3 Subjective dizziness assessment.

Quantifying the overall shortfall in function for maintaining postural stability by measuring dizziness objectively may not be useful at deciding whether a patient has a significant problem which impacts on their day to day life since dizziness is a very individual experience. Furthermore, objective and subjective assessment of dizziness have been shown to have only weak to moderate correlation with each other, depending on the tests used (Rossi-Izquierdo et al. 2014).

Dizziness is a subjective sensation therefore it could be argued that the best way to quantify it is by using a subjective method. Questionnaires (or patient reported outcome measures) are routinely used for assessing dizziness status. For a questionnaire to be useful, it must have been validated and analysed to ensure the answers to the questions give meaningful, repeatable results. Such instruments are self-report which inevitably must exclude those who have reduced cognitive abilities. These subjects are among the patients who are suspected to be most likely to have multiple risk factors for dizziness due to their frailty (Tinetti et al., 2000), but research must exclude them due

to their inability to understand the questions being asked. Reporting bias must also be taken into consideration when using questionnaires as patients who are aware of a problem tend to over-report the consequences of their disability (Rubin et al. 2001). Another limitation of patient-reported outcome instruments is the ability of any patient to recall dizzy events, especially if a long time-scale (for example 'during the past year...') is used. Subjects are more likely to remember only major problems, and this, combined with poor memory recall in older people may lead to the under-reporting of dizziness, as it has with the recall of falls (Cummings et al. 1988).

The electronic databases of Medline (1944-2015) and Web of Science (1950-2015) were searched using the search terms dizz* OR vision OR 'refractive error' OR 'vision impairment' OR spectacle* OR 'quality of life' AND questionnaire OR evaluation OR survey to identify any PROMs that might be useful for research into vision-related dizziness

The four most frequently used instruments to assess dizziness symptoms and activity limitation are:

The Dizziness Handicap Inventory, which also has a short form version, the Vertigo Symptom Scale, the Activities-specific Balance Confidence Scale, and the Vertigo Visual Analogue Scale.

These instruments were assessed for relevance to the study of vision-related dizziness and rejected for various reasons which are detailed below.

1.12.3.1 The Dizziness Handicap Inventory and its short-form version

The Dizziness Handicap Inventory (DHI) (Appendix A1) is used to identify problems related to balance disorders in three domains – functional, physical and emotional. It is the most commonly used PROM in vestibular research. (Fong et al. 2015). Jacobson and Newman (1990) described the development of the DHI. It is a 25-item instrument used to measure the self-perceived activity limitation of patients with vestibular disease and is intended to be administered before and after treatment to quantify the effects of intervention. As well as quantifying the overall perceived limitations, specific problems may also be identified by the questions, enabling the clinician to identify areas where help is most needed. The three domains of the questions may help with patient management, for example, if the perceived activity limitation is mainly identified as emotional, for example, a psychological referral may be considered rather than an intervention focussing on physical problems. This categorisation of questions, however, may lead one to question the validity of the cumulative scores of the DHI (Tesio et al. 1999). The reliability of the DHI was measured using Cronbach's α coefficient analysis, however, this test assesses internal consistency as opposed to reliability (by finding the mean correlation coefficient of half the questions against the other half), and high Cronbach's α values suggest that the instrument has a high level of redundancy (Pesudovs et al. 2007). The test-retest reliability of the instrument was shown to be excellent using Pearson product-moment correlations, however, these have been shown to provide poor assessment of reliability, (Bland and Altman 1986; McAlinden et al. 2010), however, this could give misleading results as the time interval for test-retest was only a few hours and

the second set of data may have been influenced by the subjects remembering the responses they gave during the first test. Duracinsky et al. (2007) suggested that the time interval for the test-retest was too short and that the sample size was too small to achieve statistical significance. In addition, it has been shown that a high correlation coefficient value does not automatically mean that the first test scores agreed with the second test scores, as the correlation coefficient can depend upon the range of values used in the study (Haegerstrom-Portnoy et al. 2000). The intention of the authors of the DHI was to develop an instrument which would be able to determine if treatment had been successful. In the light of this, a test-retest time of several weeks or even months may have been preferable to more closely replicate the intended use of the instrument. The validity of the instrument was not determined as part of the development, however, Tesio et al. (1999) applied Rasch analysis to the DHI during the construction of the short form version (DHI(sf)) to identify and re-score any superfluous or badly fitting items with the aim of creating a simpler questionnaire with increased validity. The DHI(sf) consists of 13 questions or items. It asks patients to consider their symptoms 'during the last month' whereas the DHI does not specify a time scale for the questions, making answers for the short form of the questionnaire more representative of the patient's current symptoms. The short form only has two possible responses – 'yes' and 'no', further reducing respondent burden. A five-point scale may have given more precision, however, it would not have fulfilled the criteria of reducing respondent burden and creating a simpler instrument.

The study of visually-related dizziness needed a questionnaire that determined dizziness in a general population, therefore, there are several reasons why the DHI or its short form could not be used exclusively in the investigation of vision-related dizziness:

1. The instruments were intended for use on vestibular patients, not on a general population, therefore the questions are unlikely to be wholly appropriate (for example P11. Do quick movements of your head increase your problem? P25, Does bending over increase your problem?)
2. They measure activity limitation and not symptoms (for example, F14, Because of your problem, is it difficult for you to do strenuous housework or yardwork?)
3. They don't assess how much the patient feels that their quality of life is affected by their dizziness. The "yes/sometimes/no" answers don't attempt to quantify the problem.

1.12.3.2 The Vertigo Symptom Scale

The Vertigo Symptom Scale (VSS) (a short form version of 15 items is available) was developed by Yardley et al. (1992) and was intended to determine the extent of symptoms in all age groups of patients who present with vertigo. Its aim was to assess the frequency and number of vertigo symptoms without the results being affected by anxiety. It consists of 34 questions and is divided into two scales. The vertigo/balance sub-scale comprises 19 items asking about how often the respondent experiences

symptoms such as spinning, unsteadiness, vomiting etc. and the autonomic/anxiety sub-scale comprises 15 items asking about problems such as pains in the chest, hot or cold spells, tension in the muscles etc. Due to the intermittent nature of vertigo, patients are asked to recall symptoms experienced over the past twelve months. This recall period has been criticised as being too long by Duracinsky et al. (2007) as some patients are not able to accurately remember events for more than a few weeks, creating possible recall bias. (It should be pointed out that any questionnaire has the potential to have its results skewed by inaccurate recall by subjects). A second sample of only 44 patients was used to assess test-retest reliability of the instrument with the subjects being asked to complete the questionnaire again after a time interval of just 24 hours. This period may be viewed being as being too short as it is likely that the subjects would be able to remember the answers they gave only the day before. An interval of 1-3 weeks is advised by Duracinsky et al. (2007) for the results to be relevant however, if the instrument under development is likely to be used to measure the effect of an intervention, then the optimum test-retest time to select would be that which would occur when the developed instrument was being used in a clinical situation. A test-retest interval which more closely reflected a clinical intervention time was carried out by Tschan et al. (2008) during the validation of the German version of the Vertigo Symptom Scale. The test-retest reliability was determined on a group of 54 patients after 6 weeks had passed. The test-retest correlations were found to be r=0.75 for both the vertigo symptoms and anxiety scales. Reliability and repeatability measurement is discussed in 6.2.1.

Although this instrument measures dizziness in a wider age range than the DHI, it only assesses vertiginous symptoms, not quality of life related issues and modern psychometric techniques were not used in its development. It is for these reasons that the VSS is not suitable to assess visually-related dizziness exclusively. Many of the items, however may be useful, and these have been included in the development of the new questionnaire (Chapter 6).

1.12.3.3 The Activities-specific Balance Confidence Scale

The Activities-specific Balance Confidence (ABC) Scale is an expansion of the Falls Efficacy Scale and concentrates on the elderly population of 65 years and over (Powell and Myers, 1995). Many frequently used measures of dizziness and imbalance are aimed at assessing specifically vestibular patients, however, the ABC Scale is aimed at the general population. The ABC Scale examines the difficulties that older people face in day to day living activities with a focus on mobility issues. A much smaller number of patients carried out the retest (after an interval of two weeks) than were used for the initial assessment (21 versus 60). This may have been because the retest group also had to agree to balance testing, which in turn carries the possibility that less mobile subjects would decline because of the perceived difficulties of the examination, introducing bias to the process. Despite this, Fong et al. (2015) stated that this scale has good test-retest reliability. This retest sample size seems inadequate since to test repeatability to within 20% either side of the estimate for within subject standard deviation, a sample size of 48 subjects would have been required for accuracy (Bland 2010). The ABC scale has been used in further studies by Myers et al. (1998) whereby the subjects from

the development project were contacted and as many as possible were re-tested one year after the original test. Everyone was included unless the patient could not be reached, refused to take part, were hospitalized or had died, leaving 37 out of the initial 60 participants. Patients in the higher mobility group were found to have similar scores to those obtained in the development study, however, those with low mobility who were resident in nursing care homes showed significantly lower scores. This may indicate deterioration in health of the lower mobility group rather than any test-retest correlation problem. It is possible to use the ABC scale to differentiate between levels of mobility of patients, with a score of less than 50 indicating low mobility, 50 – 80 indicating moderate mobility and over 80 representing a high level of mobility. This scale has been shown to be useful for the study of balance and mobility in the general, elderly population, however, it is not specific to dizziness and is aimed at only the elderly, therefore was rejected for exclusive use in this study. Some of the items, however, were considered for inclusion in the development of the new questionnaire.

1.12.3.4 The Visual Vertigo Analogue Scale

The Visual Vertigo Analogue Scale (Appendix A2) (VVAS) is a nine-item instrument which is based on the Pain Visual Analogue Scale. It was intended to offer an alternative, quick way of assessing visual vertigo (chapter 1, section 1.7.1) by using a continuous scale to give an estimate of the degree of dizziness and individual experiences It involves the use of a 10cm line and asks the participant to rate the intensity of their vertigo symptoms during nine different everyday situations which often produce dizziness, for example

walking through a supermarket aisle, being a passenger in a car etc. A score of 0 indicates no symptoms increasing to 10 which corresponds with symptoms as severe as they could be (Dannenbaum et al. 2011). The points marked are measured to the nearest 0.5cm and summed then divided by the number of responded categories with the result multiplied by 10 to give an overall dizziness score. It was developed using a population of 203 adults of all ages who were attending a vestibular clinic (n=102) or an orthopaedic clinic (n=101). The instrument showed a moderate correlation between its results and those of the DHI (Spearman correlation coefficient r= 0.67). This visual analogue scale is useful in that it usually gives a unidimensional estimate of dizziness (usually severity) and it may be especially useful when assessing a multicultural population where communication may be difficult. The VVAS, however does not use modern psychometric techniques to assess patient responses and requires the patient to have suitable cognitive ability to be able to convert a complicated subjective experience into a visuospatial image (Carlsson 1983). Kremer et al. (1981) compared a visual analogue scale to a descriptive scale and found that 11% of the study population were unable to complete a visual analogue scale, however, all subjects could complete the descriptive scale. This, he concluded was due to the reduction in abstract ability with age (Albert et al. 1990). The development population, the lack of questions relating to how dizziness affects quality of life and the lack of modern psychometric techniques used in its development and assessment of patient responses make the VVAS unsuitable for being the sole instrument used in this project, however, its items were very useful during the development of the new instrument (Chapter 6).

1.12.3.5 Other dizziness questionnaires

Other, less commonly used dizziness specific questionnaires were identified during the search for dizziness questionnaires. They included the Vertigo Handicap Questionnaire (Yardley and Putman 1992) the Vertigo, Dizziness, Imbalance Questionnaire (Prieto et al. 1999), the Vestibular Disorders Activities of Daily Living Scale (Cohen and Kimball 2000), The Dizzy Factor Inventory (Hazlett et al. 1996) and the European Evaluation of Vertigo (Megnigbeto et al. 1999) These are all instruments that are used to assess symptoms and impairment and how they relate to the quality of life of the dizzy patient. They are not as widely used as the four studies discussed in Fong's paper.

1.12.4 Quality of life assessment

The subjective nature of dizziness means that an essential part of assessment is to ascertain the impact on quality of life. The same level of dizziness may be tolerable to one person, but highly debilitating in another. To investigate vision-related quality of life issues that may be influenced by refractive correction, (regardless of whether the patient had dizziness
symptoms) vision related quality of life questionnaires were valuable sources of information. The PROMs most relevant to research into dizziness-related quality of life in a general population are described below.

1.12.4.1 The Quality of Vision questionnaire

The Quality of Vision questionnaire is a 30-item, three scale PROM investigating 10 symptoms. It can be used to assess quality of vision issues caused by spectacle and contact lens correction, surgery and ocular disease.

It was validated on a population of 900 adults aged 21-78 years who wore spectacles, contact lenses, had had refractive laser surgery, had cataracts or had had intraocular lens implantation surgery. Uniquely, it asks how ‘bothersome’ (annoying or troublesome) a symptom is to the patient as well as determining the frequency and severity. Rasch analysis has shown the Quality of Vision Questionnaire to be valid, reliable and well targeted.

1.12.4.2 The Spectacle Adaptation Questionnaire

The Spectacle Adaptation Questionnaire is an 18-item instrument investigating the symptoms and difficulties experienced by patients who have a change in spectacle lens power (not for problems caused by adaptation to a different type of correction, for example, when changing from single vision to varifocal lenses, or for people who wear a spectacle correction for reading only). It uses a three-point Likert scale and was developed using the method for questionnaire development described by Pesudovs et al. (2007), involving a thorough literature review for item

selection, patient and professional focus groups for item reduction and pilot questionnaire data analysed using the Rasch model to identify the final necessary items and providing a scale to allow real measurement (Mallinson, 2007).

1.13 Conclusion

Research in the field of dizziness uses differing populations, definitions of dizziness and methods of data gathering, making it difficult to reach a meaningful conclusion when comparing studies, or to gain an overall view of current thinking. Many investigations were conducted on patients who

attended hospital vestibular clinics, so their results were not applicable to dizziness of non-vestibular origin. These vestibular patients were often elderly, again making the results inappropriate when comparing to a general population. Studies investigating dizziness should define what they mean by the term so that participants are in no doubt as to the sensation that researchers are referring to. Simply determining the presence or absence of dizziness seems an inadequate method of assessing the condition since dizziness may be mild or severe and can be intermittent or constant. This means that dizziness can have very different impacts on an individual's quality of life, depending on the nature of the problem. Quantification of dizziness using a validated patient reported outcome measure should be the preferred method of investigation of dizziness symptoms. The DHI(sf) and the VVAS were found to be the best PROMs available due to the content of the items and low respondent burden and as such were used to assess dizziness in chapters 4 and 5.

The investigations in this thesis were intended to investigate the hypothesis that dizziness often has a visual component and that this element can be modified by the manipulation of refractive correction. The association between dizziness and vision was shown to be an under-researched area, however the literature pointed to oblique astigmatic changes (Supuk et al. 2016) and anisometropia (Atchison et al. 2001) as areas where additional research might yield further evidence to support the hypothesis.

Chapter 2.

Is there a link between dizziness and vision? A systematic review

The contents of this chapter are based upon the work published as Armstrong D, Charlesworth E, Alderson AJ and Elliott DB (2016). Is there a link between dizziness and vision? A systematic review. *Ophthalmic and Physiological Optics.* 36(4), 477- 486 (Appendix B1) and presented as a poster *at Optometry Tomorrow*, Birmingham, UK on 13th and 14 April 2016 (Appendix B2).

2.1 Introduction

A systematic review of the literature relating to this subject was performed to determine if there was an association between vision and dizziness.

- In this systematic review we aimed to: Investigate the link (if any) between vision and refractive correction and dizziness.
- Determine the methods of measurement of dizziness and vision in research settings and how the link between dizziness and vision may be affected by these methods.
- Determine whether further investigations are needed in this field.

Traditionally, dizziness has been sub-divided into the four categories suggested by Drachman and Hart (1972). These are: Vertigo (the feeling that surroundings or self are spinning). Pre-syncope (the feeling that one is about to lose consciousness). Disequilibrium (the feeling of losing one's balance.

This is often made to feel worse when the patient or the environment moves; Clark et al. 1994), and light-headedness, which is often used to describe the feeling associated with postural hypotension (see chapter 1 for a more detailed explanation of different types of dizziness). Disequilibrium and vertigo are of interest to this study as they both involve movement, the detection of movement which relies, at least in part, on the visual system. It seems much less likely that dizziness associated with light headedness and pre-syncope would be linked to vision and/or refractive correction.

There are several possible links between vision, refractive correction and dizziness. First, balance control (or postural stability) is achieved when the visual, vestibular and proprioceptive systems are effectively coordinated (Yardley 1994). If there is an impairment of one of these systems, the individual relies more heavily on the other two to maintain postural control and minimise disequilibrium and dizziness (Redfern et al. 2001). The visual element of balance control is influenced by central and peripheral vision as well as eye movements (Elliott 2014b) and postural stability has been shown to be reduced in patients with refractive blur, age-related eye disease and eye movement disorders (Anand et al. 2003b; Schwartz et al. 2005; Matheron and Kapoula 2011; Kotecha et al. 2013;).

Second, vision may be associated with dizziness via changes to the vestibulo-ocular reflex (VOR). This reflex ensures the focussed retinal image is stabilized on the retina during head movements by means of equal eye movements in the opposite direction. However, new spectacles change magnification and alter the amount of eye movement gain that is needed to match head movement: myopes tend to have lower VOR gains and hyperopes

higher VOR gains (Cannon et al. 1985). For example, a myopic change in refractive correction in new spectacles minifies the visual world so that a head movement of, say, 20° leads to a much larger eye movement than is now needed (the patient should use a lower VOR gain) and the visual world will move or, as described by patients, it will 'swim' and this could cause dizziness. The adaptation with astigmatic changes is complicated further as different amounts of magnification occur in different meridians. Similarly, adaptation to progressive addition lenses is complicated by variation in magnification across the lens requiring variable VOR gain across the visual field. (Michaelides and Schutt 2014).

Third and finally, some patients are diagnosed with Visual Vertigo. Their dizziness is triggered by an increased sensitivity to rapid changes in their visual surroundings (Redfern and Furman 1994), likely due to altered visual-vestibular integration, leading to greater visual reliance for postural control (Redfern et al. 2001; Zur et al. 2015).

2.2 Methods

This review considered all studies involving adults over the age of 18 years where vision was deemed to be among the factors contributing towards dizziness. Studies which linked or measured any aspect of vision and/or refractive correction in relation to dizziness were considered. The primary outcome of interest was the link between dizziness and vision. Secondary outcomes were the measurement methods used to quantify both dizziness and vision. There were no restrictions on the publication year or status of papers. Case reports were excluded from the review as the evidence offered

by them is of the lowest quality (Greenhalgh, 2014). Only papers published in English were included in the review as no translation facilities were available.

2.2.1 Search strategy

Databases searched were Medline (1944-2015), CINAHL (1932-2015), AMED (1980-2015), Web of Science (1950-2015) and the Cochrane Library. Reference lists from papers included in the review were hand searched and citation chains of all included papers were also searched by hand for further papers using Google Scholar (Rudnicka and Owen 2012). Unpublished sources were searched for using www.opengrey.eu, to reduce publication bias (Rudnicka and Owen 2012).

Subject librarians at the University of Bradford library were consulted about methods for deciding upon the search terms to be used. The search terms were (dizz* or vertigo or ”postural imbalance” or “postural balance” or “postural stability” or disequilibrium or oscillopsia or “light-headed” or disorient*) AND (vision or visual or sight or “dynamic visual acuity” or ocular or “depth perception” or stereopsis or “contrast sensitivity” or spectacles or “refractive error” or multifocal or bifocal or magnification or optometrist or optometry or “field of vision” or “stereo acuity” or AMD or glaucoma or diabet* or cataract or macular or “eye disease”) The combination of search terms is presented in table 2.1.

Table 2.1 Table showing how the search terms were combined during the initial database searching for the systematic review.

SEARCH TERMS

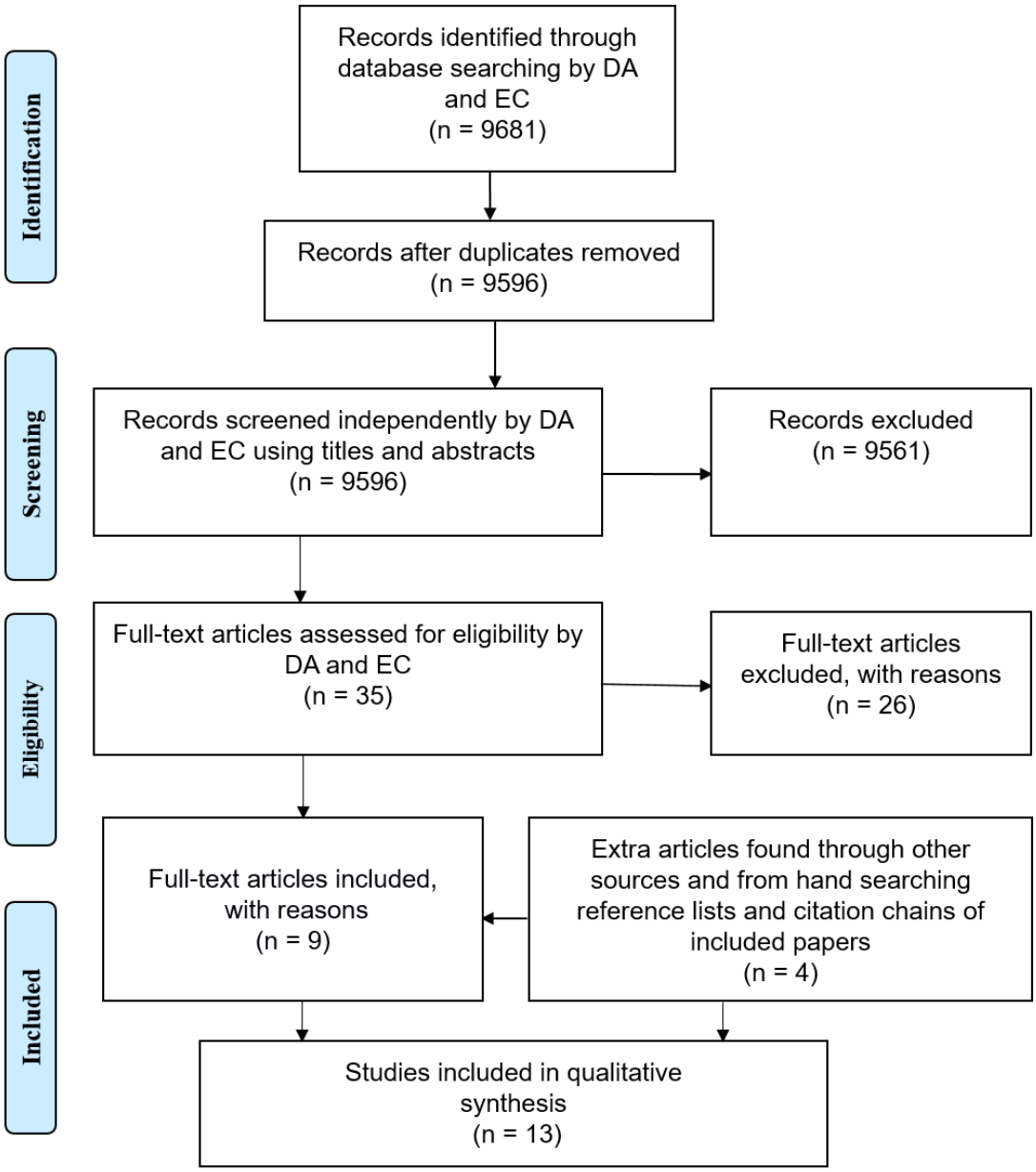
OR	AND	OR		
Dizz*		Vision	"Refractive Error"	Glaucoma
Vertigo		Visual	Multifocal	Diabet*
"Postural Imbalance"		Sight	Bifocal	Cataract
"Postural Balance"		"Dynamic Visual Acuity"	Magnification	Macular
"Postural Stability"		Ocular	Optometrist	"Eye Disease"
Disequilibrium		"Depth Perception"	Optometry	Spectacles
Ocillopsia		Stereopsis	"Field of Vision"	AMD
"Light Headed"		"Contrast Sensitivity"	"Stereo Acuity"	
Disorient*				

2.2.2 Search protocol

Two reviewers, DA and EC, independently searched the databases using the defined strategy. Titles and abstracts of papers identified by the search were reviewed by each reviewer to determine eligibility for inclusion. The two lists of relevant abstracts were then compared, and any abstract identified by only one reviewer was read by a third researcher (AA) who made the final decision on inclusion.

Both DA and EC independently read the full documents of the remaining papers and made decisions on eligibility. The final list of papers from each

reviewer was then compared, and again, any papers identified by only one reviewer were read by AA to determine eligibility. DA and EC manually screened the reference lists and citation chains of each included paper to identify any further studies which should be included. All included papers were stored on an Endnote library and a PRISMA (Moher et al. 2009) flow diagram was used to document study selection (Figure 2.1).



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

Figure 2.1 PRISMA flowchart showing the number of papers at each stage of the systematic review process.

2.2.3 Quality assessment and data extraction

Review-specific data extraction forms (Appendix C1) were created using the Critical Appraisal Skills Programme (CASP) quality assessment tool guidelines (http://media.wix.com/ugd/dded87_e37a4ab637fe46a0869f9f977dacf134.pdf).

The data extraction forms were piloted before the full data search by DA and EC who independently completed data extraction forms for two studies and discussed the results with AA to produce the optimum document.

Four screening questions were included in the data extraction sheet, and studies that failed these questions were excluded from the review. Data extraction sheets had four sections: participant details, measurement of symptoms, outcome measures and miscellaneous. Each section had questions relating to how the study was performed. Data extraction forms were completed by both DA and EC for each study included in the review. Disagreements between reviewers were discussed and resolved with the assistance of AA.

The Strengthening of the Reporting of Observational Studies in Epidemiology (STROBE) (von Elm et al. 2008) guidelines were used to indicate the quality of included studies. Four researchers independently assessed each paper using these guidelines. Their findings were then discussed, and an agreement was reached about the STROBE score to be given to each paper. The included papers were initially grouped according to the methods used to measure visual function and dizziness. Studies were then assessed to determine what association (if any) was found between vision and dizziness.

2.3 Results

Initial database searching identified 9681 papers, with 85 of these being removed as duplicates. Title and abstract screening determined that 35 should be read in full. After the screening process was complete, 13 papers were found which attempted to determine whether there was an association between dizziness and vision. These are detailed in tables 2.3, 2.4 and 2.5. Reasons for rejection are presented in table 2.2. Eight of the included studies were cross-sectional, four were cohort studies, and one was a case control study. Six papers studied a population of 65 years and above, five investigated people of 60 years and above and one study's population was 72 years and above, with the remaining study examining a population of 73 to 92 years. Of the included studies, five were conducted in the USA, three in the Netherlands, two in the UK, and one in each of Colombia, Sweden and Australia. Both genders were included in all studies.

The 13 papers that attempted to determine whether there is a link between dizziness and vision are presented in tables 2.3, 2.4 and 2.5. All thirteen papers were reviewed independently by the four authors and the strength of the association between vision and dizziness was estimated. If vision was found to be an independent risk factor we classed it as a strong association and if an association was found in univariate analysis but not in multivariate this was classed as weak association. Any disagreements were discussed subsequently, and a final decision agreed upon. Each table includes information about dizziness and vision assessment along with study design, quality assessment and population. Table 2.3 presents information from three

studies that found no association, table 2.4 presents information from five studies that found a weak association and table 2.5 presents information from five studies that found a strong association.

Table 2.2 Reasons for rejection of papers which were read in full**.**

Reason for rejection of paper	**Number of papers**
Doesn't attempt to link dizziness with vision	7
Discussion article – information based on clinical experience rather than evidence	6
Balance, not dizziness investigated	6
Case report	3
Weak statistics (vision grouped with spectacles or sensory impairment; percentages of patients with risk factors given with no significance values)	3
Same data used as other included study	1

Table 2.3 Methods of vision and dizziness assessment for studies that found no association between dizziness and vision**.** **(**MV=Multivariate, NS=Not Significant, CS=Contrast sensitivity, VA=Visual Acuity)

Paper	Design and population	Dizziness assessment	Vision assessment	Association OR (95% CI) or Prevalence (%)	Participant number (N)	STROBE quality /22	Comments
1. Aggarwal J Gerentol, 2000	Cross-sectional 65+ USA	"Have you ever been dizzy or light-headed?"	Snellen VA with specs(type not specified, assumed distance)	No association in MV analyses (no data shown)	672	18	No independent link between VA and dizziness. Odd categorisation of VA (6/12 or better; 3/30-6/60 or 6/120+)
2. Menant JAGS 2013	Cohort, prospective, secondary analysis 73-92 Australia	"Since the age of 60yrs, have you suffered from dizziness or vertigo and light-headedness when standing"	Edge contrast sensitivity	Vision impairment 35% dizzy vs 30% non-dizzy; NS CS 21.2dB ±1.9 dizzy vs 21.3 ± 2.0; NS	Dizzy 217 Non-dizzy 299	17	No link with vision. Broader definition of dizziness, includes light-headedness
3.Tinetti Ann Int Med 2000	Cross-sectional 72+ USA	"During past 2 months have you had episodes of feeling dizzy, unsteady or like you were spinning or moving, light-headed or faint?"	50% visual impairment calculated from near VA with Rosenbaum card	Visual impairment >50% 36% dizzy vs. 36% not dizzy; p>0.2	1,087	20	No link with near visual acuity. Broad definition of dizziness as includes light-headedness & feeling faint

Table 2.4 Methods of vision and dizziness assessment for studies that found vision had a weak association with dizziness**.** (UV=Univariate, MV=Multivariate, VA=Visual Acuity, Y/N= Yes or No answer)

Paper	Design and population	Dizziness assessment	Vision assessment	Association OR (95% CI) or Prevalence (%)	Participant number (N)	STROBE quality /22	Comments
4. Colledge BMJ, 1996	Case control 65+ USA	"Suffered from dizziness every 3/12 or more?" Y/N	Eye disease: from medical records VA (Snellen)	Subjects with eye disease 35% dizzy vs 12% control; p <0.001 VA < 6/9, both eyes 15% dizzy vs 4% control; p=0.015	246 (Dizzy 149 Control 97)	18	VA and "eye disease" from medical records more prevalent in dizzy patients
5. Dros Health & Qual Life Outcomes 2011	Cross-sectional 65+ Netherlands	Dizziness Handicap Inventory questionnaire	VA –method not specified	UV: OR 1.7 (1.1-2.7) Not in MV model	417	16	Weak link between visual acuity and impact of dizziness. Limited information available.
6. Kao JAGS 2001	Cross-sectional 60+ USA	Physician asking direct questions, not specified	Snellen VA Cataract from medical records	VA of worse than 6/18 8% dizzy vs 13% non-dizzy, p=0.37 Cataract UV: 28% dizzy vs 12% non-dizzy, p=0.03 MV: OR 5.3 (2.2-12.9)	292 (Dizzy 84, non-dizzy, 208)	17	No link with VA: Cut off of 6/18 lead to low prevalence in both groups Strong independent link between cataract in GP notes and dizziness.
7. Maarsingh BMC 2010	Cross-sectional, prospective 65+ Netherlands	Those who consulted GP due to dizziness	Data from GP notes, impaired vision and cataracts	UV: Cataract 3.7% dizzy vs 2% non-dizzy, p<0.001 Impaired vision 1% dizzy vs 0.6% non-dizzy, p=0.006	3,990	16	Weak link between cataract / impaired vision and dizziness. Low prevalence of impaired vision from GP notes limiting usefulness in MV analysis.
8. Olsson Moller Arch Geronto & Geriatr, 2013	Cohort, longitudinal 60-96 Sweden	"Have you experienced dizziness in last 3/12" Y/N	"Do you have problems with your vision?" Y/N	<80 years: 31% dizzy vs. 21% control; p+0.028 80+ years: 48% dizzy vs. 42% control, p=0.46	<80 6yr: 531 80+ 6yr: 146	17	Self-reported visual problems a weak predictor of 6 year dizziness. Numbers small for 80+ year group.

Table 2.5 Methods of vision and dizziness assessment for studies that found vision had a strong association with dizziness**. (**UV=Univariate, MV=Multivariate, Y/N=Yes or No answer, VA=Visual Acuity, OR=Odds Ratio)

Paper	Design and population	Dizziness assessment	Vision assessment	Association OR (95% CI) or Prevalence (%)	Participant number (N)	STROBE quality /22	Comments
9. Gomez et al. J Nutr, Health & Ageing, 2011	Cross-sectional 60+ Colombia	"Have you ever been bothered by dizziness in the past month"	"Trouble with vision?" Y/N	UV: 1.83 (1.33-2.52); p<0.001 MV: 1.48 (1.05-2.08); p<0.02	1,692	17	Dizziness independently linked with self-reported "trouble with vision"
10. Maarsingh et al. BMC Geriat,, 2014	Cohort, prospective 60+ Netherlands	"Are you dizzy regularly?" Y/N	"Can you see well enough?" Y/N	7yr UV:2.3 (1.5-3.6); p<0.001 7yr MV: 1.8 (1.1-3.0); p=0.016	1,379	18	Visual impairment an independent predictor of future dizziness at 7 years
11. Sloane et al. JAGS, 1989	Cross-sectional 60+ USA	"Have you ever been bothered by dizziness?"	"Blurry vision" or "poor eyesight" or " blindness" Y/N	UV: Risk ratio 2.58, p<0.001 MV: OR 3.7 (2.7-4.9); p<0.001 for 'neurosensory impairment' (10 variables including 'blurry vision', 'poor eyesight & 'blindness' Y/N)	1,622	15	Strong association between dizziness and various aspects of poor vision
12. Stevens et al. Age & Ageing, 2008	Cross-sectional 65+ England	"How often do you have problems with dizziness when you are walking on a level surface?"	Rate sight (very good, good, fair, poor)	MV; 1.7 (1.2-2.4)	2,925	11.5	Self-reported poor vision an independent predictor of dizziness
13. Supuk et al. OPO, 2016	Cohort, prospective & retrospective 65+ England	Dizziness Handicap Inventory (short form) questionnaire	Distance VA (logMAR) pre & post operation	Change in best eye VA MV: OR 17.71, p=0.003	287	19	Dizziness improved by cataract surgery and linked with best eye VA change. Oblique astigmatism may increase dizziness

2.4 Discussion

2.4.1 Studies that found no association between vision and dizziness.

These three studies, (all with good quality reporting levels) included the term ‘light-headedness’ in their dizziness definition. This term has links with postural hypotension and feeling faint, which may cause dizziness but has little or no logical association with vision. Participants (who were largely made up of the older, elderly population - 72+ years) were asked to self-report their dizziness over a long period of time:- 12+ years (Menant et al., 2013) and a lifetime (Aggarwal et al. 2000). This has implications for recall bias and means that a vision measurement made at the time of the examination was compared to a report of dizziness over a long, time span. It is impossible to know the participants’ vision status at the time that they were dizzy and many of them are likely to have had cataract surgery (Klein and Klein 2013; Panchapakesan et al. 2003) and/or new spectacles within this time frame, both of which would have likely improved vision. These studies used differing methods of vision assessment with none of them providing details of visual acuity measurement such as the distance at which the measurement was taken, luminance levels, whether the measurements were taken monocularly or binocularly or with or without spectacle correction, the type of chart used (assumed to be Snellen), the number of clinicians used to take the measurements (inter-clinician measurements have been shown to have a low levels of repeatability: Gibson and Sanderson (1980)) or whether a termination rule of visual acuity measurement was followed (Carkeet 2001). Tinetti et al. (2000) used the Rosenbaum near vision card which

has been shown to be unreliable (Horton and Jones 1997). Only Aggarwal et al. (2000) specified that spectacles were worn at the time of the test.

2.4.2 Studies that found a weak association between vision and dizziness.

Five studies found a weak association between vision and dizziness. These studies generally had small populations (hundreds rather than thousands of participants) and the association was found using univariate analyses meaning that vision may not have had an independent association with dizziness. In four of the papers, no attempt was made to quantify dizziness, with its presence being determined by asking the participant a single question about their dizziness status. Snellen (or unspecified) visual acuity was used to describe vision in three of the studies (Kao et al. 2001; Colledge et al. 1996; Dros et al. 2011), this method of measurement has been shown to be a poorly reliable method of assessment (Ferris and Bailey 1996; Lovie-Kitchin 2015). Again, no details about visual acuity measurement were offered, as was the case in the studies which did not find a link between vision and dizziness (see the above discussion). The cut off, for what is termed ‘impaired vision’ varied between studies and the categories (where stated) did not divide the data equally. For example, Kao et al.’s (2001) paper has a cut off value of ‘VA worse than 6/18’ which would mean the majority of participants (88%) would be in the ‘good vision’ category, placing the remaining participants in the ‘poor vision’ category. This leaves sample sizes in the poor vision category with much reduced numbers when compared with numbers in the good vision category (31 vs 231).

2.4.3 Studies that found a strong association between vision and dizziness

Five studies (detailed in table 2.5) found an independent association between dizziness and vision. Four of these reports had large study populations of over 1000 participants. Multivariate analyses were used, indicating that an independent association of vision with dizziness was found. Studies asked patients mainly about recent dizziness with Supuk et al. (2016) quantifying the amount of dizziness experienced using the short form of the Dizziness Handicap Inventory, which has been Rasch analysed and shown to have good validity (Tesio et al. 1999). These studies also used differing methods of vision assessment omitting details such as luminance levels etc.

2.4.4 Measurement of visual impairment

Six studies (Aggarwal et al. 2000; Colledge et al. 1996; Dros et al. 2011; Kao et al. 2001; Supuk et al. 2016 and Tinetti et al. 2000) used visual acuity and Menant et al. (2013) used contrast sensitivity function to measure visual function. Maarsingh et al. (2010b) took 'data extracted from the database' to determine visual status and five studies (Sloane et al. 1989; Stevens et al. 2008; Gomez et al. 2011; Maarsingh et al. 2014) did not measure visual acuity, preferring to use self-report of vision as an indicator of visual status. This suggests that dizziness may be more highly linked to an individual's perception of their vision, rather than to their measured vision. Self-perception of vision is dependent upon a variety of visual functions such as contrast sensitivity, glare sensitivity and visual fields as well as visual acuity. Studies

have shown strong associations between visual acuity and contrast sensitivity and self-reported disability (Ross et al., 1984; Elliott et al. 1990; Rubin et al. 1994; Dargent-Molina et al. 1996; Rubin et al. 2001) with several showing that contrast sensitivity has a stronger association with self-reported disability than visual acuity (Ross et al. 1984; Elliott et al. 1990; Dargent-Molina et al. 1996). Where patients are asked to report disabilities, reporting bias may be present (Rubin et al. 2001). This may cause a patient who knows their vision is not as good as it could be to over-report a disability. Elliott et al.'s (1990) findings suggested that patients are poor at providing a global description of their overall visual disability and this could compound the problem of reporting bias. Anxiety can have a negative effect on self-perceived health (Carter and Walker 2014) and several studies have shown anxiety to be a risk factor for dizziness (Yardley et al. 1998; Ödman and Maire 2008; Bisdorff et al. 2013) with patients who suffer from anxiety disorders tending to feel more limited by their dizziness when conducting their daily tasks than those who are not anxious (Eckhardt-Henn et al. 2003). Although Gomez and Stevens did not investigate anxiety, Maarsingh and Sloan included 'anxiety', or 'perception of self as a nervous person' in their multivariate analyses (Maarsingh et al. 2014; Sloane et al. 1989) and yet those analyses suggested that self-reported poor vision was an independent risk factor for dizziness even after adjusting for anxiety measures. This suggests that poor vision may well be an independent risk factor for dizziness. Maarsingh's paper also concluded that visual impairment is an independent predictor for future dizziness at seven years indicating that the association between vision and dizziness may well be strong.

2.5 Limitations

There may have been search terms which were overlooked when deciding upon the search strategy. This would result in papers which should have been included in the study being omitted, however hand searching the reference lists and citation chaining all the included papers would safeguard against missing any significant papers. The exclusion of papers not written in English may have resulted in significant papers being overlooked from this review. The assessment of the extent of the association between dizziness and vision was independently made by several researchers and then agreed upon, but as all were clinical vision scientists (two of which were authors on a recent study included in this review (Supuk et al. 2016)) there may have been a bias towards finding an association rather than the reverse.

2.6 Recommendations

Standardisation of methods of vision and dizziness assessment would aid comparison of findings. The use of a validated questionnaire, such as the Dizziness Handicap Inventory (Jacobson and Newman 1990) or its short form (Tesio et al. 1999) to quantify dizziness would help to determine the severity and character of the problem. The nature of visual impairment is very much dependent upon what has caused the difficulty, thus, a simple measure of visual acuity using Snellen charts may not accurately quantify the visual impairment of someone with visual field or contract sensitivity loss. Snellen visual acuity measurements have been shown to have poor repeatability due to practitioner and observer variability (Gibson and Sanderson 1980) and poor chart design (Ferris and Bailey 1996), highlighting the need for a more

accurate assessment of visual acuity. In addition, a more comprehensive assessment of visual function to include aspects of vision such as visual acuity, contrast sensitivity, visual field and stereoacuity such as the assessments used in the SEE project (Rubin 2001) is required to accurately assess vision status. Future studies should be undertaken using more appropriate measures (and cut off values) of vision and dizziness (which should be measured at the same time) to quantify the association between the two, as to date, studies have not done this reliably. Investigations into links between dizziness and vision in the working age population would help to ascertain whether this is a concern for all patients who suffer from dizziness, or whether the problem is limited to the elderly population.

2.7 Conclusions

This review has identified an area where little research has been published to date. The inconsistency of measurement methods for dizziness and vision made accurate comparison of studies difficult. Studies finding no link between vision and dizziness all included the term ‘light-headedness’ in their definition of dizziness, used participants from the older, elderly population (72+ years) and asked patients to recall dizziness over a long period of time. Those finding a weak association between vision and dizziness had relatively small numbers of participants and did not attempt to quantify dizziness or define what was meant by ‘impaired vision’. The five studies finding an independent association between vision and dizziness were typically cross-sectional with large study populations who were mainly asked about their recent dizziness and self-perceived vision status. The overall evidence therefore suggests that

dizziness (although likely not when light-headedness is included in the definition of dizziness) is linked with poor vision.

Chapter 3.

Case reports: Can manipulation of vision and refractive correction reduce symptoms of dizziness?

This study was intended to test the hypothesis that dizziness can be reduced by manipulating refractive correction in terms of spectacle lens power or form. The systematic review of the literature detailed in Chapter 2 concluded that:

a) The literature linking dizziness and poor vision is sparse and the literature investigating a link between refractive correction and dizziness is limited to one paper (Supuk et al. 2016).
b) Self-reported poor vision can be associated with increased dizziness (Armstrong et al. 2016).

Given the very limited information in the literature, potential ways that optometric interventions might improve dizziness were explored using a case series approach. Although limited in design (Greenhalgh, 2010), it was thought that the information gained might be useful in directing the research towards the most promising areas and suggest how the most efficient progress might be made.

3.1 Ethics approval

A protocol for this study was developed and ethical approval was applied for and was granted by the Chair of the Biomedical, Natural, Physical and Health Studies Research Ethics Panel at the University of Bradford on 21st January 2016.

3.2 Patient recruitment

An email request for adult volunteers who had refractive error and who were currently suffering from dizziness was sent to staff and students at the University of Bradford. Staff at the University Eye Clinic were asked to inform anyone who had dizziness problems with their spectacles about the study with a view to them becoming participants. In addition, volunteer patients (people who sit as patients for undergraduate optometry students on a regular basis) at the University of Bradford Eye Clinic were asked if they met the inclusion criteria (of wearing a spectacle correction and suffering from dizziness they felt was connected to their vision) and if they would be willing to take part in the study. Three participants were recruited from University staff, students and Eye Clinic volunteers and three more by word of mouth communication from people who had initially been approached.

3.3 Protocol

Each participant was given an information sheet with details of the procedure for the study prior to consent being taken. Informed consent was taken from each participant before examination.

Each participant underwent a thorough eye examination by an experienced optometrist (DA) to establish a detailed history and symptoms, accurate visual acuities, refraction, binocular vision and stereo acuity tests and to see if any of the results of these tests were related to dizziness symptoms. The rationale behind the tests chosen is explained in sections 3.31 - 3.37.

A subjective assessment of dizziness status was made using the Visual Vertigo Analogue Scale. (Appendix A2). In addition, focimetry and accurate

measurement of ocular centration of spectacles was performed. In one case an experienced orthoptist was consulted in addition to the optometric input.

3.4 Investigative tests

Investigative tests were carried out using procedures detailed in *Clinical Procedures in Primary Eye Care* (Elliott, 2014a), which is an evidence-based procedures textbook that is widely used. The tests most appropriate for each patient based on their history and symptoms were selected from those described below.

3.4.1 Vision and visual acuity

Since self-reported reduced vision can be associated with increased dizziness (Armstrong et al. 2016), and blur caused by reduction in visual acuity has been linked to postural instability (Anand et al. 2003b), assessment of vision and visual acuity was essential to these case studies. Visual acuity (VA) is the most commonly used measurement of visual function. It is a measure of the ability of the eyes to resolve fine detail and should be taken both monocularly and binocularly. ‘Vision’ refers to unaided VA and is measured without the assistance of any corrective lenses. VA may be habitual (evaluated when the patient is wearing their spectacles) or optimal (the best acuity possible using corrective lenses). Habitual VA may not be the same as optimal VA if the patient has had their spectacles for some time, or if the optimal correction is for some reason not tolerated by the patient. A prescription is said to be ‘not tolerated’ by someone when the patient is unable to wear the spectacles because of feelings of discomfort that are not due to the fit of the frame. It is

clearly essential to determine: (1) when spectacles are worn, so that the relative importance of habitual VA and vision can be appreciated and (2) whether any dizziness occurs with spectacles or without.

Vision and VA measurements were carried out using a computerised logMAR visual acuity chart where appropriate, to maximise the precision and repeatability of the measurements (Westheimer 1979; Bailey et al. 1991; Lovie-Kitchen 2015). The LogMAR chart uses five letters on each line with standardized size and spacing to provide a chart where the letters decrease by 0.1 logMAR units per line. This gives an interval scale to enable parametric analysis of results (Westheimer 1979; Bailey et al. 1991) meaning it is more suitable for research purposes than other methods of VA measurement (Lovie-Kitchen 2015). Where the initial VA was originally measured using a Snellen chart in optometric practice, Snellen acuities were recorded to ensure continuity. The charts used in the research clinic were calibrated for use at 3 metres, had both LogMAR and Snellen acuities marked on each line and participants were tested with room lights on full. A termination rule of encouraging the patient to keep reading down the chart until they made four or more mistakes on a line of five letters was used (Carkeet 2001), although where visual acuity was measured in practice, it was recognized that the test chart used might not have had letters small enough to measure a threshold visual acuity. A Visual Acuity Rating score (Bailey and Lovie-Kitchen, 2013) was calculated for ease of comparing visual acuity scores.

Dynamic visual acuity measures the patient's ability to distinguish details of a moving object (Miller and Ludvigh 1962) and presents a more demanding task to the observer than static VA. Redfern and Furman (1994) demonstrated that

patients with vestibular problems had an increased sensitivity to rapid changes in visual surroundings. If the dynamic VA is reduced when compared to the static VA it might suggest that the vestibular ocular reflex is performing sub-optimally since the vestibular ocular reflex stabilizes the retinal image during head movement (Chapter 1 section 1.4). Dynamic VA was used in one case report to assess if there was a vestibular element to the patient's dizziness. The test was carried out using a logMAR projection chart and the participant's head was passively moved through horizontal ±20˚ from primary position by the examiner at a frequency of approximately 1.5Hz (Dannenbaum et al. 2005).

The degree of movement was determined using a protractor to ensure the correct range and a metronome was used to ensure the frequency was 1.5Hz.

3.4.2 Focimetry

A manual focimeter was used to measure the vertex power, axis positioning, prism and optical centres of each participant's spectacles. Inaccuracies in vertex power and/or axis positioning may cause reduction in VA which might lead to dizziness (Armstrong et al. 2016). Miller et al. (1997) concluded that a significant number of people who wear spectacles would be aware of and dissatisfied with, spectacles that contained errors in refractive correction as small as +0.25 dioptres of spherical or cylindrical power. If the distance between the optical centres of a pair of spectacles are different to the inter-pupillary distance of the wearer, then prism will be induced by the spectacles. Induced vertical prism can cause postural instability (Matheron et al. 2007), which could be reported as dizziness.

3.4.3 Refraction

Although the literature concerning the link between changes to refractive correction and dizziness is limited to only one study (Supuk et al. 2016), that study reported that changes to astigmatic refractive error can lead to increased dizziness. It was, therefore, important that any changes to refractive correction were documented during the investigations for these case reports. Accurate subjective refraction to the nearest 0.25 dioptre was carried out by an experienced optometrist to determine the most accurate refractive correction for that individual. In this way optimal and habitual correction could be compared. A trial frame and lenses were used to determine optimal refraction using the habitual refractive error as a starting point. Monocular refraction starting with the best vision sphere technique was used to determine the spherical component of the refraction with the end-point being checked using the duochrome (bichromatic) test. The Jackson cross-cylinder test using a target of concentric rings was used to determine the cylindrical component of the refraction after which a +1.00D blur test was performed to check the end-point of the refraction. Binocular balancing (a procedure to ensure balanced and fully relaxed accommodation in both eyes) using the Humphriss Immediate Contrast technique was carried out where appropriate. Results were recorded in negative cylinder form.

In one case study an open field autorefractor (a computerized instrument that provides an objective assessment of the patient's refraction; this avoids any bias that might be introduced using techniques involving clinician input) was used to assess refractive error since changes in dizziness and unaided visions were being assessed.

3.4.4 Binocular vision assessment

Matheron and Kapoula (2008) reported that patients with vertical heterophoria have worse postural stability. Rosner et al. (2012) demonstrated that treatment of binocular vision anomalies (specifically vertical heterophoria) can reduce symptoms of dizziness. Jackson and Bedell (2012) established that correction of vertical heterophoria can reduce a patient's susceptibility to motion sickness, a condition in which dizziness is often reported (Redfern et al. 2001). Binocular vision testing was therefore included in patient assessments for these case reports where appropriate.

The cover test was used to assess oculomotor alignment prior to refraction. The cover test was performed at distance (6m) and at the patient's habitual near working distance (usually around 40cm), with and/or without spectacles as appropriate for the individual being examined. The practitioner observed the movement of the patient's eye when binocular vision was interrupted by covering one eye whilst the patient viewed a specified target. First, the cover/uncover test was performed to examine for heterotropia (strabismus). Second, an alternating cover test (where the practitioner performed several cycles of covering one eye for 2-3 seconds then moved the cover to the other eye for the same amount of time while observing the movements of the eyes) was performed to examine for heterophoria (the deviation from primary position of the eyes in the absence of binocular fusion). Third (if the first and second tests were inconclusive), a subjective cover test was performed since very small eye movements are too small to be detected, even by an experienced practitioner (Fogt et al. 2000) and small vertical heterophorias may cause dizziness (Rosner et al. 2012). This involved asking the patient

about the direction of any target movements while performing the alternating cover test. Any movements not seen by the practitioner during the alternating cover test but detected by the patient during the subjective cover test are reported as *phi* movements. Where quantification of ocular movements was indicated, a prism cover test was performed. This comprised a cover test as documented above with the addition of the practitioner presenting increasing quantities of prism to an eye until the deviation was neutralized. The direction of the deviation was indicated by the orientation of the base of the prism used to neutralize the movement. If base in prism neutralised the movement, a divergent deviation was indicated, similarly a convergent deviation was indicated by base out prism neutralising the movement. Hypertropia/phoria (where the eye's alignment was too high) was corrected with base down prism and hypotropia/phoria (where the eye's alignment was too low) was corrected with base up prism.

Post refraction, the modified Thorington test was used to quantify any remaining distance vision oculomotor misalignments since the wearing of a trial frame and lenses often makes detecting eye movement difficult for the practitioner. An example of a Thorington card is presented in figure 3.1. The Thorington card used was calibrated to be used at 4m. The Thorington card consisted of a 65cm x 62cm card with a central fixation light and a diagonal scale of numbers and letters denoting intervals of prism dioptres. A Maddox rod (a small disc which refracts light so that a point of light is seen as a red line perpendicular to the direction of the lines on the disc) was placed in front of the right eye, and the patient was asked to look towards the fixation light and report the number or letter on the scale that was in alignment with the red

line. When the patient reported a vertical red line to be aligned with a number, an esophoria was present, when the red line was aligned with a letter, an exophoria was present with ‘A’ representing one prism dioptre, ‘B’ representing two prism dioptres and so on. When a horizontal red line was aligned with a number, a right hypophoria (or left hyperphoria) was present, if the line is aligned with a letter, a right hyperphoria (or left hypophoria) was indicated. This was performed for both horizontal and vertical orientations. The results were recorded in prism dioptres.

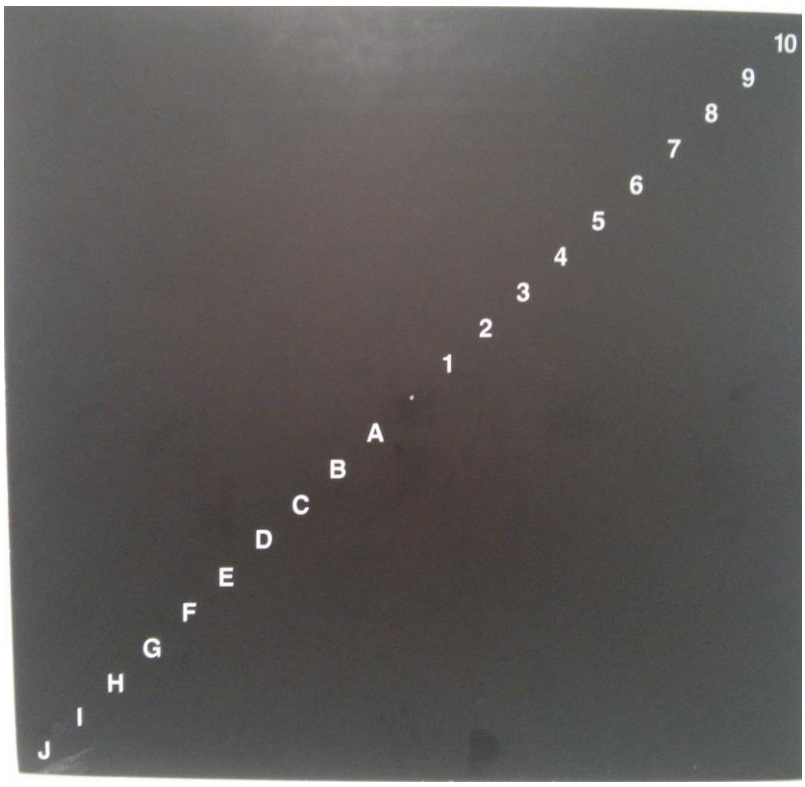


Figure 3.1 A Thorington card *(source: author)*

Ocular motility was carried out when appropriate to assess any restrictions to the eye movements produced by the six extraocular muscles. While performing ocular motility assessment, the practitioner asked the participant

to observe a light from a pen-torch held at 50cm while it was moved along the six cardinal positions of gaze (figure 3.2). The participant was asked to report if any diplopia (doubling of the image) was noticed and the practitioner observed the extent of the eye movements. If diplopia was reported, a cover test was carried out while the eyes were looking in that direction of gaze and the eye that moved to take up fixation when the fellow eye was covered was identified as the eye having the underacting extraocular muscle. The underacting muscle was identified by the direction of gaze where greatest diplopia was reported.

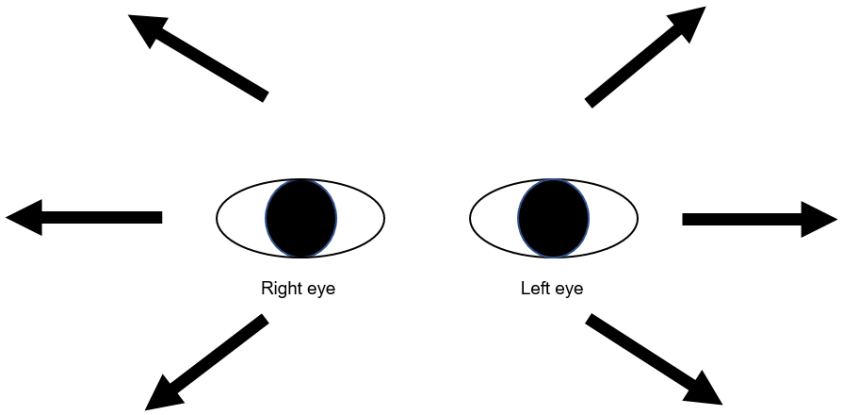


Figure 3.2 The six cardinal positions of gaze used during an ocular motility test *(source: author)*

3.4.5 Ocular dominance

Ocular dominance occurs when the contribution of visual information from one eye is processed in preference to that from the other (Porac and Coren 1976). It is commonly believed that monocular blur is more easily accepted in the non-dominant eye (Seijas et al. 2007) and it has been shown that many

subjects don't show an observable dominance (Seijas et al. 2007). Schwartz and Yatziv (2015) suggested that ocular dominance may be plastic, however their sample size was small and the results far from conclusive. Ocular dominance was tested where appropriate during these case reports to investigate if intolerance to dominant eye blur could have influenced the dizziness status of participants with reduced VA in one eye. Of the tests available that determine ocular dominance, many have been shown to give inconclusive or ambiguous results (Seijas et al. 2007) and the agreement between tests has been shown to be at best only moderate (Rice et al. 2008). The hole-in-card test was used to assess ocular dominance as it is the most commonly used ocular dominance test (Seijas et al. 2007), has been shown to have good test-retest reliability (Rice et al. 2008) and is one of the least likely tests to have uncertain results (Seijas et al. 2007). When performing the test, the subject was asked to hold a card with a 2cm hole in the centre straight ahead and at arms' length. They were then asked to use the hole to enclose a distant object with both eyes open. Ocular dominance was established by closing the eyes in turn and determining which eye was seeing the image closest to the hole. This test was repeated three times per subject. A second (this time, objective) method of determining ocular dominance – the convergence near point test – was used to verify the findings of the hole-in-card test. This test also has been shown to have good test-retest reliability and a moderate agreement with the hole-in-card test (Rice et al. 2008). An accommodative target of a small letter that could just be resolved by the weaker eye was observed by the patient whilst the examiner brought it slowly towards the patient's nose until binocular fixation was no longer possible. At

the point of maximum possible convergence by the patient, the non-dominant eye ‘breaks’ or diverges while the dominant eye maintains fixation, thus the dominant eye can be identified. This test was also repeated three times to confirm the diagnosis. If the two tests disagreed it was taken as an indication that the subject didn’t show clear ocular dominance.

3.4.6 Pupil function

Some neurological disorders can cause dizziness symptoms. Anomalies in pupil reactions may indicate a lesion in the neurological pathway responsible for pupil function, therefore it is important to carry out this test during a routine eye examination.

There were five parts to the test of pupillary function. First, an assessment of the size of the pupils is carried out in both bright and dim room illumination. Pupils are usually round and equal in size (approximately 20% of people have a small physiological difference in pupil size, and their pupil responses are normal (Lam et al. 1987)). Any difference in size (termed anisocoria) that is more apparent in bright light can indicate a problem in the third cranial nerve. Second, the pupils were observed as an accommodative target was brought towards the eyes. Normal pupils constrict due to the accommodation exerted to keep the target in focus. Third the patient was asked to fixate on a distant target that both eyes could see easily. The light from a pen torch was shone for 2-3 seconds into the eye from a distance of 5 -10cm and the reaction of the pupil was observed to assess the direct response to light. Fourth, the pen torch was directed at the eye again and the fellow eye observed to assess the consensual response. Finally, the ‘swinging flashlight’ test was performed

where the light was directed towards each eye in turn for 2-3 seconds and the reactions observed. Abnormal responses to light indicated a defect in the afferent pathway to the visual cortex in the brain.

3.4.7 Dizziness status assessment

Dizziness was assessed using the Visual Vertigo Analogue Scale (VVAS) (Dannenbaum et al. 2011). This subjective test was used because it is quick and easy to administer (Dannenbaum et al. 2011). It allows both the presence and severity of dizziness to be established on a continuous scale and all the scenarios presented to the participant are situations where dizziness could have a visual element in its aetiology. The VVAS classifies the observer as positive for visual vertigo if two or more of the items are valued above zero on the analogue scale, with a value for the severity of the visual vertigo being calculated by summing the ratings of each item and dividing this number by the number of items that have been rated. A score of 90-100 indicates severe visual vertigo. A full description of the VVAS is given in chapter 6, section 6.2.4. and the instrument can be found in Appendix A2.

3.5 Case reports

3.5.1 Case report 1

A 72-year-old female patient (SP) complained of extreme dizziness, disorientation and blurry vision when trying on her new reading spectacles on collection from her optometrist. She was unable to use the spectacles even for a few minutes. She reported that her new distance spectacles (prescribed

at the same eye examination) were comfortable with good vision. A VVAS score of zero indicating no dizziness was found when SP was wearing her distance vision spectacles (VVAS is not suitable for assessing dizziness with near vision spectacles as it does not ask the patient to evaluate dizziness during any near vision tasks).

SP had worn spectacles for as long as she could remember and had had occlusion therapy and strabismus surgery as a child. Her right eye was amblyopic and she had a small esotropia (10^{Δ}) on distance cover test. She was in good health, not taking any medication, and had no previous history of dizziness or vestibular problems and motility and pupil reactions were normal. Her spectacle prescription from her practice optometrist's records is presented below:

Prescription	**Optical centre**	**Visual acuity (Snellen)**	**LogMAR equivalent**	**VAR score**
Distance vision spectacles R +5.50/-1.00x85 L+5.25/-0.50x105	62	6/12 6/6-1	0.30 0.02	85 99
Near vision spectacles R +8.00/-1.00x85 L +7.75/-0.50x105	59	N8@40cm N5@40cm	0.40 0.20	N/A

The test chart used by her optometrist was a projection chart calibrated to be used at 3m that had four letters on each line with the smallest line being 6/4 (~-0.2 logMAR, 110 VAR).

Focimetry of the new near vision spectacles revealed that an error in either ordering or manufacture had been made and they had been made up as

follows:

Prescription	Optical centre	Visual acuity at 40cm	LogMAR equivalent
Near vision spectacles R +5.50/-1.00x85 L +7.75/-0.50x105	59	N32 N5	1.00 0.20

The spectacles were re-made to the correct prescription and the blurred vision, dizziness and discomfort were absent when the new spectacles were worn.

In this case, the patient's dizziness was induced by an extreme situation of refractive correction change and would therefore not be akin to any dizziness that may be induced by a gradual or minor change in lens power that may be more typical of vision-related dizziness. Further investigations of SPs refractive and binocular vision status were not carried out in practice since focimetry of the spectacles pointed to the source of the problem. This case demonstrates how dizziness can be induced in a patient by an inaccurate spectacle prescription (and that it is readily rectified by modification of that inaccurate prescription), suggesting that dizziness and refractive correction may be linked. It also highlights a potential link between induced anisometropia and dizziness. Atchison et al. (2001) reported that two of his 15 subjects reported dizziness with induced anisometropia of just 0.50DS. It supports the hypothesis that manipulation of spectacle correction may be able to induce or reduce dizziness, and that dizziness associated with refractive correction is likely linked to changes in the vestibulo-ocular reflex caused by spectacle magnification (Chapter 1, section 1.4)

3.5.2 Case report 2

A 71-year-old female retired optometrist (LA) contacted the research team after reading an *Optometry Today* article that dizziness and vision research was taking place at the University. She agreed to travel to Bradford to have her dizziness assessed and signed an informed consent document. She brought details of her past spectacle corrections dating from 2008. She reported visual discomfort and dizziness when driving and when experiencing wide open spaces which made her suspect that her dizziness was linked to her vision and refractive correction.

Her general health was good, and she reported no history of vestibular problems. She wasn't taking any prescription medication.

LA had used spectacles for myopia since the age of 11. She remembered having bifocals when at college (during her early 20s) due to problems with reading but recalled not using them very often. Her single vision spectacle correction was then stable for many years until around 1990 (aged 45).

Her first experience of significant visual discomfort, vertical diplopia and dizziness was when undertaking a long-distance drive. She refracted herself the day after and found that 1.5 $^{\Delta}$UP in the right lens over her usual correction alleviated her problem. This prismatic correction was worn successfully for several years with the prismatic correction changing gradually in 0.25$^{\Delta}$ steps until in 2006, LA was wearing 2.5$^{\Delta}$UP in the right lens.

In April 2008 she had an episode of sudden, constant vertical diplopia and associated dizziness which lasted ten days and resolved when new varifocal lenses with increased vertical prism (3$^{\Delta}$UP) in the right lens were obtained.

Another incidence of vertical diplopia (this time, intermittent) and dizziness

occurred in April 2010. This lasted for ‘a few days’ before resolving spontaneously. A new refraction was not attempted as the LA was on holiday at the time.

When LA came to be assessed, she was wearing a refractive correction prescribed in December 2014. These spectacle changes are documented in table 3.3. Unfortunately, there were no binocular status measurements recorded on her case history cards from optometric practice. After having a thorough history and symptoms taken, LA’s spectacle correction was checked and was found to be the same as that prescribed in June 2016 – table 3.1. Her VVAS score on the day was 19 indicating mild dizziness. She reported experiencing mild asthenopia and dizziness, but no diplopia on the day of the assessment. An experienced orthoptist was asked to assess the binocular vision status of LA. This was considered appropriate due to diplopia being one of her symptoms. The cover tests carried out by the orthoptist are summarized in table 3.2 for ease of reading. Further orthoptic tests are summarized in table 3.3. Snellen visual acuity had been recorded on all her past optical record cards, therefore this was maintained in the interests of continuity.

Table 3.1 Changes in spectacle prescription with visual acuities for patient LA**.**

Date	Spectacle prescription	Visual acuity	VAR	comments
2006	R-3.75/-1.50x122 2.5$^{\Delta}$UP L-4.00/-1.50x48 add+2.50	R 6/5 L 6/5 B N4	104 104	Varifocal lenses. No BV tests recorded
April 2008	R-4.00/-1.50x112 3$^{\Delta}$UP L-4.00/-1.25x48 Add+2.50	R 6/5 L 6/5 B N4	104 104	Varifocal lenses. No BV tests recorded
January 2009	R-3.75/-1.25x112 3$^{\Delta}$UP L-3.75/-1.75x45 Add +2.50 N4	R 6/6+ L 6/6 B N4	102 100	Varifocal lenses. No BV tests recorded
November 2010	R-3.50/-1.25x112 3$^{\Delta}$UP L-3.75/-1.25x50 Add+2.50	R 6/6+ L 6/6+ B N4	102 102	Varifocal lenses. No BV tests recorded
October 2012	R-3.50/-1.25x112 3$^{\Delta}$UP L-3.50/1.50x50 Add+2.50	R 6/6+ L 6/6+ B N4	102 102	Varifocal lenses. No BV tests recorded
December 2014	R-3.25/-1.75x112 3.5$^{\Delta}$UP L-3.50/-1.50x50 Add+2.50	R 6/6 L 6/6 B N4	100 100	Varifocal lenses. No BV tests recorded
June 2016	R-2.50/-1.75x107 3$^{\Delta}$UP L-3.25/-1.25x55 0.5$^{\Delta}$DOWN Add+2.50	R 6/7.5^{+2} L 6/6^{-2} (July 2016)	97 98	Varifocal lenses See table 3.2 and table 3.3 for BV tests performed in July 2016

BV= binocular vision
VAR = Visual acuity rating

Table 3.2 Results of tests carried out by an experienced orthoptist on participant LA in July 2016**.**

Test	**Test distance**	**Result**
Convergence with spectacles		Binocular to nose
Prism cover test with spectacles	30cm depressed gaze	2^{Δ} XOP. 2^{Δ} left hypertropia with good recovery
Prism cover test with spectacles	30cm primary position	6^{Δ} XOP. 2^{Δ} left hypertropia with good recovery
Prism cover test with spectacles	6m	1^{Δ} SOP. 1-2^{Δ} left hypertropia with good recovery
Prism cover test without spectacles	30cm depressed gaze	8-9^{Δ} left hypertropia. 7^{Δ}XOP
Prism cover test without spectacles	30cm primary position	6^{Δ} left hypertropia. 12^{Δ}XOP
Prism cover test without spectacles	6m	5^{Δ} left hypertropia with diplopia and 4^{Δ} XOP

XOP = exophoria, **SOP** = esophoria

Table 3.3 The results of further tests carried out by the orthoptist on participant LA**.**

Test	**Results**
Pupil reactions	Anisocoria – right pupil slightly larger than left. No relative afferent pupil defect
Motility	Underaction of right and left superior recti, left superior oblique and left inferior rectus. Overaction of right and left inferior obliques, right inferior rectus and left superior oblique
Palpebral aperture	Right 9mm, left 11mm
Palpebral aperture after 2 minutes of upgaze	Right 7mm, left 10mm

After examining LA, the orthoptist diagnosed:

1. Left hypertropia which was controlled by the prism incorporated into LA's spectacles
2. Anisocoria – right pupil larger than the left
3. Right ptosis

From the evidence of LA's ocular history and her own investigations, the orthoptist suggested that LA's problems may be due to myasthenia gravis, thyroid eye disease or a paresis of the superior division of the third cranial nerve, the latter two being less likely.

Myasthenia gravis is an autoimmune condition that causes weakness in skeletal muscles. Thyroid eye disease is an autoimmune condition that is mainly associated with an over-active thyroid gland. This causes inflammation of the extraocular muscles and the fatty tissue behind the eyes. The third cranial nerve innervates the extra-ocular muscles, the levator muscles of the eyelids and the sphincter muscle of the iris. Paresis of this nerve can be congenital or acquired with the latter having possible causes of vascular disease, space occupying lesions, infection or inflammation, trauma, multiple sclerosis, autoimmune disease (such as myasthenia gravis) and cavernous sinus thrombosis.

LA wished to proceed with the referral at her local hospital, therefore a letter containing the findings and tentative diagnoses was written for her to take to her GP. LA was contacted six months after her visit to the University to ask if she had been given a definitive diagnosis. She responded that she did not have a diagnosis since her symptoms had subsided somewhat and were only present occasionally, therefore she had not contacted her general practitioner

for further investigation.

This case study shows the importance of making full investigations into the possible causes of dizziness and diplopia. LA's dizziness was alleviated with optical correction (in this case in the form of vertical prism), however, the underlying cause may have remained undiagnosed for many years. Matheron and Kapoula (2008) demonstrated that people with vertical heterophoria have reduced postural stability. If the prism in the spectacle lens had been under or over corrected, vertical heterophoria would have been present which may have contributed to LA's feeling of dizziness. The data in table 3.1 indicate that LA had an oblique cylindrical component to her refractive correction and that both the power and/or axes were frequently changed. Changes to oblique cylindrical elements of spectacle refraction have been shown to increase dizziness (Supuk et al. 2016) and postural instability (Kanazawa et al. 2018), therefore this may have been a factor in LA's symptoms.

3.5.3 Case report 3

A 46-year-old female (WS), who felt her dizziness to be vision-related, was assessed by DA. She reported waking up with 'vertigo' and a 'numb left leg' three months previously (14th September 2016). Vertigo was confirmed when further questioning revealed she had symptoms of self and surroundings seeming to spin (Chapter 1, section 1.1). No previous episodes of vertigo were reported. Following her episode of spontaneous vertigo and numb leg, WS had been referred to a neurologist because her General Practitioner had suspected a stroke. She stated that he ordered a visual field test (which was 'normal') and an MRI scan of her head. She reported that the scan had

showed a “possible mark” on her left occipital lobe and had an appointment for a re-scan in two months’ time. The neurologist had prescribed a months’ treatment with betahistine dihydrochloride (an anti-vertigo medication) to be taken three times a day (WS didn’t know the dose) but this had proven to be ineffective and the dizziness symptoms remained. WS had a past medical history of breast cancer, but she had been in remission for the past 3 years and was not taking any medication.

She reported her dizziness to be less apparent on the day of examination by the research optometrist than it had been on initial presentation. She described her dizziness as increasing when she was in left-hand gaze situations such as crossing the road or when at a road junction when driving. She reported the dizziness to be the same with and without the distance vision spectacles. She wore distance vision spectacles for driving only and near vision spectacles for close tasks.

Written consent to view WS’s optometrist’s records was obtained and the results compared to those of the research optometrist (table 3.4)

Table 3.4 Refraction results of examinations carried out on WS by a practice optometrist (22/10/16) and the research optometrist (21/12/16)**.**

Date prescribed	Prescription	Visual acuity	~ VAR	Binocular visual acuity	Binocular ~ VAR
22/10/16	R -0.75/-0.25x70 L -0.50DS Add +1.75	R 6/5 L 6/5 B N5@40 cm	104 104	6/5	104
21/12/16	R -0.50/-0.25x70 L-0.25DS Add +1.75 (likes a close WD)	R $6/6^{+1}$ L 6/6 B N5@? 40cm	101 100	6/6+2	102

VAR = Visual acuity rating
WD = working distance
~ = approximate

DA used Snellen acuities to ensure continuity of measurement. The test chart used was a LogMAR chart at 6m with five letters on each line. The practice optometrist used a projection test chart calibrated to be used at 3m that had four letters on each line with the smallest line being 6/4. The distance from the observer to the test chart was a little too short at 2.80m. This explains the difference in VA between the practice and research optometrist's VA findings. Distance vision spectacles were worn for driving and near vision spectacles were used for close tasks. The ocular centration of these pairs of spectacles were examined and found to be accurate at 64cm for distance and 61cm for near.

Other relevant test results are presented in table 3.5.

Table 3.5 Test results from the examination carried out on WS by DA on 21/12/16**.**

Test	**Result**
Convergence ability	8cm
Ocular Motility	Full and smooth. No diplopia or discomfort reported
Cover test at distance with distance vision spectacles	Orthophoria - no *phi* movements detected
Cover test at distance unaided	Orthophoria - no *phi* movements detected
Cover test at near with near vision spectacles	Orthophoria - no *phi* movements detected
Thorington test	1^{Δ} esophoria, no vertical deviation
Pupil reactions	Pupil equal and round and respond to light and accommodation
Ophthalmoscopy	Both eyes healthy
VVAS Score	34

Of the tests listed in table 3.5, only ophthalmoscopy was recorded on the practice optometrist's records, both eyes were reported to be healthy. WS reported that visual fields and intraocular pressures were carried out at the practice and she was told they were 'fine', but they were not documented on the record card. DA established that WS's spectacles were accurate and there were no other visual factors that needed correction. It was decided that while WS felt that her dizziness was linked to a visual stimulus, no further testing seemed likely to find an optometric link to her dizziness problems. Her dizziness score of 34 on the VVAS suggested that her dizziness had a strong visual element. It seems likely that the dizziness in this case was due to visual vertigo (Chapter 1, section 1.7.1) since it was exacerbated by optic flow during such situations as crossing the road and driving (Bronstein 1995). It is possible that an inner ear problem was responsible for the sudden onset of visual vertigo that subsided with time given that visual vertigo patients are

likely to have a past history of vestibular disorder (Bronstein 1995; Guerraz et al. 2001). WS's dizziness may have been partially attributable to anxiety initiated by the serious nature of her health problems. Anxiety has been found to be a factor in around half of visual vertigo patients (Guerraz et al. 2001). When anxious individuals are subjected to an increase in optical flow, their ability to maintain balance decreases and their likelihood of dizziness increases (Jacob et al. 1995).

This case study demonstrates that optometric interventions for visually-related dizziness may be limited and that residual dizziness may be present even with accurate spectacles and fully functional binocular vision.

3.5.4 Case report 4

A 28-year-old female patient (CF), with no history of vestibular problems or general health problems, who had been suffering from intermittent dizziness since undergoing orthokeratology correction, agreed to have her dizziness monitored. Orthokeratology is a procedure where a specially designed rigid gas permeable contact lens is worn overnight to modify the shape of the cornea to reduce low to moderate amounts of ametropia. The effects are temporary, and the cornea gradually returns to its natural shape when the lenses cease to be worn overnight.

Written consent to examine CFs optometrist's record card was obtained and details regarding prescription before orthokeratology and treatment schedule were obtained. Prior to undergoing orthokeratology, CF was wearing spectacles or soft contact lenses to correct her myopia. The contact lenses were on a two-weekly replacement schedule. Her spectacle lens power (also

the latest refraction result) and contact lens specification before orthokeratology are presented in table 3.6.

Table 3.6 CFs spectacle and contact lens specifications before she commenced orthokeratology**.**

Correction	**Date**	**Type of correction**	**Specification of correction**	**Visual acuity when wearing correction at time of sight test.**
Spectacles	01/05/14	Single vision distance spectacles	R-0.75/-0.75 x 72.5 L -2.25/-0.50x170	6/5 (near N5) 6/5
Soft contact lenses	01/5/14	Acuvue Oasys contact lenses	R 8.6/14.5 -0.75/-0.75x60 L 8.80/14.00 -2.50	6/3.8 (Near 6/3.8

The optical centres of the spectacles were accurate at 58mm and corresponded with CF's interpupillary distance. Her binocular status was 1-3$^{\Delta}$ esophoria detected using the subjective cover test whilst wearing spectacle correction at distance. It was noted that this is unusual in a myopic patient as esophoria is typically associated with hyperopia and exophoria with myopia (Leone et al.2010).

CF started orthokeratology treatment in February 2015. The optometrist's records show that after the first night of sleeping with the lenses in, the right lens had full pupil coverage with no movement on blinking and the left lens was slightly displaced superiorly with no movement on blinking. Her unaided vision on removal of the lenses was R 6/6 and L 6/4.5. A LogMAR chart with five letters on each line, with the lowest available line being -0.02 (6/3.8) was used to assess VA. The displacement was minimal and acceptable so CF was

permitted to continue with the lenses.

An aftercare appointment on 13/04/15 showed that the lenses were well centred and had 0.5mm of movement on blinking. CF was happy with the comfort and the vision attained on removal of the lenses.

On 03/07/15, CF attended for another aftercare and reported that over the past two to three weeks she had noticed that her right vision had become slightly blurry during the day. Again, the lenses looked to be centred well but the edge curve of the right lens was considered too steep and there was an over-refraction of:

R 6/4.8	+0.75/-0.50x55	6/4.8
L 6/3.8	+0.50DS	6/3.8

This indicated a small over-correction by the contact lenses. A new right orthokeratology contact lens was ordered to correct this problem.

Since collecting and using this new right contact lens, she had noticed intermittent dizziness which CF felt was linked to her level of vision. She felt that her right eye was overcorrected by the orthokeratology lens.

CF agreed to have her vision monitored along with her binocular vision status and dizziness status. Measurements were taken every day for the first week and then on days when CF felt dizzy and was able to attend for assessment. An autorefractor was used to determine refractive error status to reduce participant burden since frequent assessments were necessary and a manual refraction would have been time consuming. Readings were repeated for each eye until three identical readings were obtained. ‘Scrolling when using a VDU’ was one of CFs dizziness triggers, however this was not one of the conditions assessed by the VVAS therefore an additional question presented

in the same style as the VVAS was used to assess this scenario. The dizziness score (in millimetres along the 100mm line) for this question was reported separately to the VVAS score.

On 28/11/15 CF began to sleep in the right contact lens only every other night, to try and reduce her dizziness (This was a self-prescribed solution to the dizziness, no practitioner was involved in this decision). When she attended for assessment on 01/12/15 she was aware that the right eye was slightly blurry when compared with the left eye. Table 3.7 contains a summary of the refractive correction, binocular status and dizziness scores for this period of assessment. Dizziness scores, and binocular vision status were assessed with or without refractive correction, depending on whether CF was wearing a correction on that day or not. Ocular dominance was tested using the tests outlined in 3.3.1 to investigate if intolerance to dominant eye blur could have influenced the dizziness status. It was established that CF was right eye dominant. With the exception of 4th November 2015, CF's VAR score in her right eye was less than in her left on each occasion when she reported dizziness.

Table 3.7 Refractive correction, binocular status and dizziness scores obtained when assessing patient CF**.**

Date	Autorefraction	logMAR unaided vision	VAR	VVAS score	Phoria (Thorington) Without Rx
02/11/15	R +2.00/-1.00 x 40 L plano/-0.75 x 152.5	R 0.08 L -0.08 B -0.1	R96 L104 B105	33	2 SOP
03/11/15	R +2.25/-1.00 x 42 L-0.25/-0.25 x 154	R -0.04 L -0.14 B -0.12	R102 L107 B106	43	3 SOP
04/11/15	R +2.00/-1.00 x 40 L +0.25/-0.50 x 179	R -0.14 L -0.12 B -0.24	R107 L106 B112	10	1 SOP
05/11/15	R +1.75/-0.75 x 39 L plano/-0.75 x 134	R -0.16 L -0.16 B -0.14	R108 L108 B107	0	1.5 SOP
06/11/15	R +2.00/-1.25 x 49 L +0.25/-0.50 x 174	R -0.18 L -0.12 B -0.16	R109 L106 B108	0	1.5 SOP
01/12/15	R +0.50/-0.75 x 35 L +0.75/-0.75x173	R -0.12 L -0.18 B -0.16	R106 L109 B108	12*	7 SOP
08/12/15	R +1.00/-0.75 x 25 L +0.25/-0.75 x 163	R 0.08 L -0.06 B -0.04	R96 L103 B102	40*	10 SOP variable
16/12/15	R +1.25/-0.75 x 32 L +0.25/-0.25 x 166	R -0.08 L -1.12 B -0.16	R104 L44 B108	47*	8-10 SOP variable

VAR = visual acuity rating **B** = binocular **SOP** = esophoria. ***** = CF had been sleeping in right contact lens every other night (left contact lens every night).

At the assessment on 16/12/15 it was suggested that CF cease wearing orthokeratology lenses to allow her corneae to return to their natural topographies. CF agreed to stop wearing the orthokeratology lenses and return to full time spectacle lens wear. Dizziness status along with refractive error and binocular vision measurements were recorded during this time. She was assessed during this period until her eyes had stabilized – indicating that her corneae had returned to their natural shape. Her visual acuity was assessed while wearing her spectacles that had been prescribed on 1st May 2014, before commencing orthokeratology. They were made to the prescription:

R-0.75/-0.75 x 72.5
L -2.25/-0.50x170

These data are presented in table 3.8.

Table 3.8 Refractive correction, binocular status and dizziness scores obtained when assessing patient CF after she ceased wearing orthokeratology contact lenses. The spectacles used when assessing aided vision were prescribed on 1st May 2014 (above)

Date	Autorefraction	logMAR aided vision wearing spectacles	VAR	VVAS score	Phoria (Thorington)
26/02/16	R+0.25/-0.25x22 L-1.25/-0.50x158	R-0.18 L-0.22 B-0.22	R109 L112 B112	24**	>10 SOP (approx 14)
03/03/16	R+0.25/-0.25x59 L-1.25/-0.75x171	R -0.18 L -0.18 B -0.14	R109 L109 B107	0**	6-7 SOP variable
10/03/16	R∞/-0.50x34 L-1.50/-0.50x159	R -0.12 L -0.20 B-0.22	R106 L110 B112	13**	8 SOP
14/04/16	R-0.25/-0.50x65 L-2.25/-0.75x150	R -0.18 L-0.18 B -0.16	R109 L109 B108	0**	12+ SOP 7SOP with Rx
03/05/16	R-0.25/-0.50x65 L-2.00/-0.75x160	R -0.18 L -0.18 B -0.20	R109 L109 B110	0**	7 drifting to 14 SOP (variable)
11/05/16	R-0.25/-0.50x55 L-2.25/-0.75x170	R-0.10 L -0.10 B -0.16	R105 L105 B107	0**	7SOP Stable

VAR = visual acuity rating **B** = binocular **SOP** = esophoria. ****** = spectacles were worn on the day this dizziness score was assessed.

The data from tables 3.7 and 3.8 indicated that CF had a significant correlation between dizziness symptoms and the difference between the levels of vision between the eyes (Spearman's rho = 0.95, ρ=<0.001). These data are presented in figure 3.3a. The outlier corresponds to the data collected on 16/12/15 where the difference in VA between the eyes was the greatest. CF's autorefractor result for the left eye was not significantly different to previous results, however her VA was greatly reduced on this occasion. CF reported symptoms of tiredness, dry eye and variable vision on this day and these may have been responsible for the reduction in VA since other factors such as corneal oedema were excluded by a slit lamp biomicroscope examination.

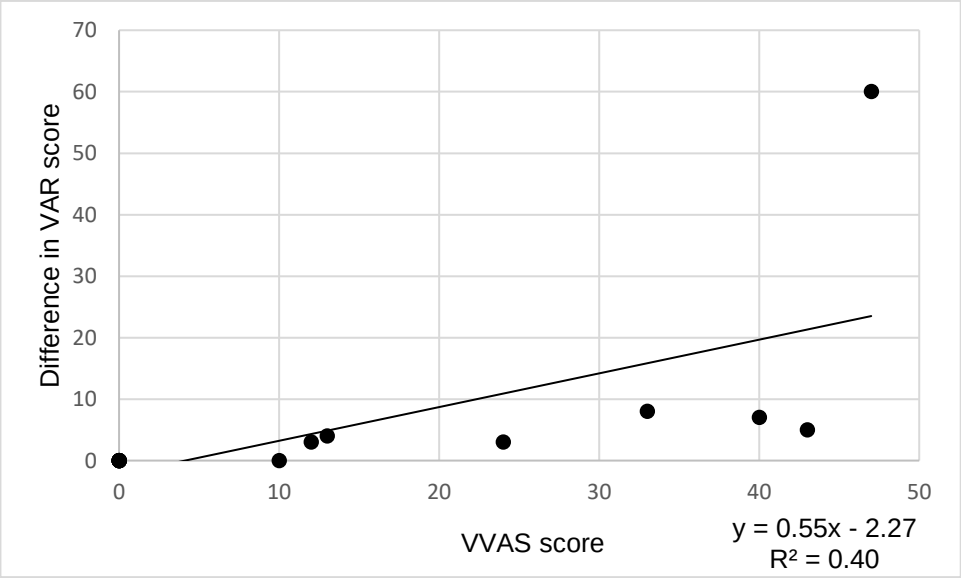


Figure 3.3a The relationship between CF's difference in VAR score and dizziness status**.**

After removal of the outlier, the correlation was more apparent (figure 3.3b) with Spearman's rho = 0.93, ρ<0.001.

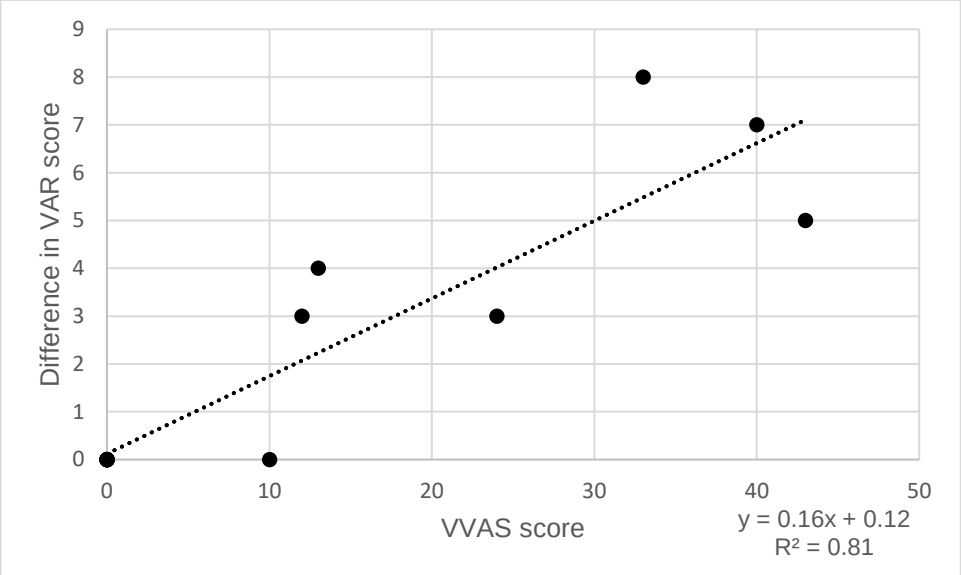


Figure 3.3b The relationship between difference in VAR score and dizziness status after the outlier had been removed

The situation on the VVAS that consistently caused most dizziness were 'walking through a shopping mall', 'walking through a supermarket aisle', 'walking over a patterned floor' and 'being under fluorescent lights' in addition, she reported that scrolling when using a VDU triggered dizziness. All these situations involved movement, either of the subject or the environment (or flicker with fluorescent lights) supporting the suggestion that the cause of CF's dizziness had a strong visual element.

A review of the results indicated that CF's dizziness scores may have been linked to the blur and difference in visual acuity between the two eyes (Atchison et al. 2001) and possibly changed ocular dominance, since it is easier to suppress blur in a non-dominant eye (Jain et al. 1996) In addition to

these two factors, CF's vision status and heterophoria were constantly changing, which might have contributed to her feeling of dizziness.

3.5.5 Case report 5

A 46-year-old female patient (DP) who used spectacles only when driving in reduced lighting conditions complained of dizziness when wearing her new single vision distance spectacles. Written consent was given for DA to examine her optometrist's records. They showed that her vision was good without spectacles at R $6/6^{-3}$ L$6/6^{+2}$ and 6/4.8 binocularly with near vision of N5 binocularly and monocularly (VA was measured on a LogMAR projection chart with five letters on each line). Her general health was good, she was not taking any medication and there was no past history of dizziness or vestibular complaints. She was happy with the vision and comfort when wearing her prescription from 2014 (table 3.9).

Table 3.9 Summary of spectacle and binocular vision status of patient DP during the case record investigation**.**

Date	Spectacle prescription	Visual acuity	VAR	Binocular status at distance	VVAS score
09/04/14	R -0.25/-0.50x20 L plano/-0.50x180	Not available. Test done elsewhere		Not available. Tested elsewhere	N/A
29/09/15	Unaided	R -0.04 L -0.06 B -0.10	97 102 105	1-3 XOP - phi	N/A
29/09/15	R -0.50/-0.50x20 L plano/-0.50x180	R -0.10 L -0.10 B -0.14	105 105 107	1-3 XOP – phi No fixation disparity	N/A
06/11/15	R -0.50/-0.50x20 L plano/-0.25x10 (incorrectly ordered)	R -0.10 L -0.06 B -0.08	105 102 103	1-3 XOP – phi No fixation disparity	18
06/11/15	R -0.50/-0.50x20 L plano/-0.50x180	R -0.10 L-0.10 B -0.14	105 105 107	1-3 XOP – phi No fixation disparity	0

B = binocular visual acuity
XOP = exophoria
phi = movements seen on subjective cover test only, not seen objectively
VAR = Visual acuity rating

DP had a full routine eye examination on 29/09/15 and was told that there was minimal change to her spectacle prescription (table 3.9). She wished to have new frames, so the updated prescription was dispensed. On collection of the new spectacles on 26/10/15, she reported dizziness immediately on trying the new spectacles in the optometrist's practice. Her vision was good, therefore the dispensing optician advised her to try the new spectacles for a week to 'get used' to them. Her visual vertigo analogue scale dizziness score (See chapter 6) was 18. After eleven days she had worn the spectacles on ten days for driving (8 of those days were for hour-long drives to and from her place of work), DP returned to the practice as she was still experiencing dizziness which occurred as soon as she wore the new spectacles. She reported that the dizziness reduced in intensity after wearing the spectacles for around 20

minutes, but it was still noticeable for the duration of wearing. She reported that the right vision was a little better than the left with the new spectacles, which felt uncomfortable.

The spectacle refraction was rechecked and found to be the same as that of the sight test on 29/09/15, further investigation revealed that the left lens had been ordered incorrectly (table 3.9). The left lens was changed to reflect the correct prescription power and the patient reported there was no dizziness at all on collection of this new pair.

The ocular dominance of DP was ascertained using the tests detailed in 3.3.1 and it was confirmed that DP was left eye dominant.

This case supports the hypothesis that dizziness can be caused by small changes to a spectacle correction and that small changes may also reduce or eliminate the problem. In this case it is possible that dizziness could have occurred because the spectacles caused blur in the dominant eye (Jain et al. 1996). If the error had been made with the non-dominant eye the dizziness may not have occurred and the error may not have been noticed. This hypothesis has yet to be tested.

3.5.6 Case report 6

A 51-year-old male, who had been diagnosed with bilateral acute labrynthitis two years previously in October 2014 agreed to have his eyes examined by DA. He was myopic and habitually used varifocal spectacle lenses full time. At the time of diagnosis, he reported needing a stick to walk as he was unable to sustain postural stability unaided. He reported being heavily reliant on his

visual system to maintain balance at that time. He gave an example of this being when he was asked to march on the spot with his eyes closed as part of the diagnostic process, he fell over as soon as the visual cues for balance maintenance were removed. When asked about his ability to perform tasks during this period using the VVAS scenarios as examples, he reported that he was unable to perform five of the nine tasks because of his dizziness. He was asked to complete a retrospective VVAS, answering the questions for the time when he was acutely dizzy. When considering the tasks that he was able to do (being a passenger in a car, being under fluorescent lights, watching traffic at a busy intersection and watching action television) his VVAS score was 29. When the scores of the situations that were impossible were added as maximum dizziness, the VVAS score jumped to 68. The labrynthitis began to slowly resolve after approximately two months of acute symptoms and he had since recovered to what he described as '95% OK'. He now felt that he was more reliant on the contribution his vision made towards maintaining his balance than he was before the episode of labrynthitis. He described feeling 'unsteady' when the visual environment was poor or confusing for example in a dark laboratory or in a crowded shopping mall. He explained that sitting down and/or holding onto a solid object was a useful coping strategy for him.

In December 2014 WM decided to try using single vision distance spectacles (removing the spectacles to read) rather than his varifocal lenses. This was intended to try and reduce his residual dizziness (no practitioner was involved in his decision). To this end, he had a single vision distance pair of spectacles made up from the same prescription as his varifocal lenses were made to. He reported that his dizziness - especially when moving around - was reduced by

this substitution. When he felt that his dizziness had improved sufficiently (after approximately one year), he successfully resumed varifocal spectacle wear. In 2017, WM visited his optometrist for a sight test as he had noticed a reduction in both distance and reading VA with his varifocals. A new prescription was obtained (table 3.10). He chose to return to single vision distance spectacles on that occasion because he decided he was happy to remove his spectacles for near vision work. (He wasn't having any dizziness problems at that time).

The research optometrist reviewed WM's visual status with the single vision distance spectacles made to the same prescription as the varifocals and with his current pair of single vision spectacles to establish if the spectacle prescription differences could have made any difference to WMs dizziness status. Unfortunately, the varifocal spectacles had been discarded, so assessment of them was impossible. Binocular vision tests were carried out at distance since WMs problems were primarily balance and locomotion. Results from these investigations are presented in table 3.10.

Table 3.10 Optometric investigations carried out for WM showing results for both varifocal spectacles and single vision distance spectacles. All measurements were taken at an assessment on 4th November 2016.

	Single vision distance spectacles (2014, made to 2012 prescription)	Single vision distance spectacles (Prescribed September, 2016)
Spectacle prescription	R -2.00DS L -1.25/-0.25x178	R -1.00/-0.50x90 L -0.75/-0.50x10
Visual acuity (taken at examination in 2016)	R 0.28 L 0.14 Near binocularly N6	R -0.14 L -0.02 Near unaided N4
Visual acuity rating score	R 84 L 93	R 103 L 101
Distance cover test with spectacles	Approx. 2^{Δ}XOP (phi movements)	Approx. 2^{Δ}XOP
Thorington test	2^{Δ}XOP, stable No vertical phoria	2^{Δ}XOP, stable No vertical phoria
Dynamic visual acuity	No reduction in acuity for right, left or binocular viewing	No reduction in acuity for right, left or binocular viewing

The results shown in table 3.10 indicate that WMs myopia was mild to moderate when he experienced his acute dizziness symptoms. He described his visual acuity immediately prior to that time to be ‘good’ when wearing his varifocals. Dynamic visual acuity showed no reduction compared with static visual acuity indicating that WM’s vestibular disease may well have completely recovered at the time of measurement. VVAS assessment of dizziness status was carried out retrospectively with WM answering the questions for the specified periods from memory. These data are shown in table 3.11

Table 3.11 VVAS scores for the stages in WMs labrynthitis and recovery. All situations except for 'current' were assessed retrospectively.

	Acute labrynthitis (with varifocals) (October 2014)	With varifocals and residual dizziness (December 2014)	With single vision distance spectacles and residual dizziness (December 2014)	Current. With new single vision distance (assessed 4th November 2016)
VVAS score	29 (68 when impossible activities are scored at maximum)	23	15	0

This suggests that the improvement in dizziness status reported by WM when he changed from varifocal spectacles to single vision distance spectacles was due to the design of the spectacle lens (Michaelides and Schutt, 2014). Blur, magnification and peripheral distortions are experienced when looking through the lower portion of a varifocal lens at an object beyond the near vision range. This can reduce certainty of stepping accuracy and height judgement (Johnson et al. 2007; Timmis et al. 2010) Furthermore, viewing through different parts of the lens require many changes in vestibulo-ocular reflex gain which can induce dizziness (Michaelides and Schutt 2014). It would appear that WMs labrynthitis led to much greater reliance on vision for his postural control and that this led to the difficulties in using his varifocal spectacles. When the labrynthitis improved and vision was involved less in postural control, he seemed able to revert back to varifocal spectacle use. This case study suggests that spectacle design may be a contributory factor to dizziness and suggests that all vision and spectacle issues may be particularly relevant when patients become more reliant on vision for postural control as occurs after vestibular disease (Guerraz et al. 2001; Bronstein 2005).

3.6 Limitations

Where information was taken from previous optometric practice examinations, the information gathered was not subject to a protocol comparable to that used by the researcher. Visual acuities established from past optometric practice records may have been measured on truncated charts and the researcher was not able to establish whether a termination rule (3.3.1) was applied to the procedure. In case report 4, examination was only possible on days when CF could attend the research site. There may have been days when she was very dizzy where examination was not possible. Dizziness status was examined retrospectively in case number 6, These measurements may have been subject to recall bias.

Case reports by nature have limited use as evidence (Greenhalgh 2010) however these case reports were undertaken as an exploratory study to determine if further investigations into the area of vision and dizziness would be useful and to potentially highlight fruitful areas of study.

3.7 Conclusions

Evidence from these case reports suggests that dizziness is linked to vision and refractive correction when large differences in visual acuity between the eyes are induced, when refractive correction and ocular dominance are changed and when vision status is fluctuating. In addition, different spectacle designs may contribute to the experience of dizziness and patients may be more susceptible to dizziness caused by visual and refractive problems when they become more reliant on vision for postural control during and shortly after vestibular disease.

3.8 Further research

Further investigations of the effects of refractive correction on dizziness are indicated to confirm a link and to examine the types of refractive correction changes and spectacle design most likely to cause problems due to dizziness. Research to investigate this would ideally be designed to assess patients who have been dissatisfied with their spectacles and returned to practice for further investigation.

Case study 1 suggested that large refractive correction changes may contribute towards dizziness. This finding led to an investigation into refractive changes and dizziness of cataract patients (Chapter 4) with the hypothesis being that large refractive changes can cause dizziness. Case studies 2, 5 and 6 suggested that small refractive correction errors, uncorrected prism or varifocals (in susceptible individuals) may cause dizziness. This led to a study that examined the dizziness status, refractive change and spectacle design of patients who had returned to optometric practice because they were dissatisfied with the spectacles supplied after routine eye examinations (Chapter 5). The hypothesis for this study was that small refractive correction changes can cause dizziness.

Case studies 4 and 5 suggested that ocular dominance may have a role in dizziness. This could be investigated using a similar protocol to that of Atchison et al. (2001), where participants would be asked to wear a series of spectacles with differing small focal errors before reporting their dizziness and visual comfort status. Ocular dominance would be established after the wearing period to reduce bias and the hypothesis would be that small focal errors in the dominant eye would be less likely to be tolerated than similar

errors in the non-dominant eye.

Chapter 4.

Do Large Refractive Correction Changes Increase Dizziness?

4.1 Introduction

The information gathered in chapter three suggested that changes in spectacle prescription and vision can be associated with dizziness symptoms indicating that further investigation of refractive correction changes and dizziness was needed. The intention of this study was to test the hypothesis that dizziness is associated with large changes in refractive correction.

Vision could play a role in the aetiology of dizziness symptoms via its input to the vestibulo-ocular reflex (VOR) and postural stability (Chapter 1, section 1.4). The vestibular system provides information about the position of the head in space, and the VOR links the vestibular system with the eye muscles. Rapid, compensatory eye movements are needed to stabilize the image on the retina during head movements. If there is a change to spectacle magnification, the VOR gain is also changed (Demer et al. 1989, Cannon et al. 1985). Dizziness symptoms may be experienced by susceptible individuals (until adaptation is complete) when eye movements are no longer at the correct speed to match the movement of the object of interest.

The most common cause of changes in refractive correction in older people is cataract, with patients experiencing myopic and astigmatic shift (section 4.4) as the cataract progresses. This study intended to monitor the dizziness and refractive status of cataract patients to investigate the link (if any) between magnitude of refractive correction change and dizziness. A consultant ophthalmologist and consultant optometrist at Bradford Royal Infirmary were

approached to ask for their help with monitoring the dizziness and refractive status of their cataract patients and they readily agreed to participate. The research question was investigated by asking patients who were on the waiting list for cataract surgery to complete the short form of the Dizziness Handicap Inventory referring to the time period immediately after they received their latest pair of spectacles. The refractive correction change between this pair of spectacles and the previous pair of spectacles was established and vector analysis was used to break down the refractive correction change into its components so that analysis of the type of change that was associated with increased dizziness could be ascertained.

This research study met with many difficulties. Indeed, the project was eventually (and reluctantly) cancelled without a satisfactory answer to the research question being obtained. This chapter documents how obstacles were overcome and makes suggestions as to how this research question could have been investigated differently.

4.2 Ethics approval

The processes of ethics approval both for the University of Bradford (UoB) and the National Health Service (NHS) were undergoing changes in procedures and rules during the period of application. The Integrated Research Application System (IRAS) was used for obtaining NHS ethics approval for research studies and their rules and requirements were undergoing changes intended to reduce the time taken between application and recruitment of the first patient, which in 2015-16 had a median time of 231 days (NHS Health Research Authority 2017). The requirement for IRAS approval was replaced by Health Research Authority (HRA) approval on 1st

April 2016. At this time IRAS was still reviewing the application for this study. IRAS completed their review before advising the research team that their approval was no longer valid with local research and development (R&D) departments. These changes in rules and procedures proved to be a major factor in the delays experienced when applying for ethics approval for this study.

For ease of comprehension, the process has been divided into three parts - UoB ethics approval, NHS ethics approval, and HRA and local ethics approval. Each series of events is presented in tabular form.

4.2.1 UoB ethics approval

An internal review of the proposed research protocol was needed before NHS ethics approval could be applied for. After the internal application had been submitted, the rules changed to include a review of the IRAS submission, therefore the IRAS application had to be completed and passed on to UoB ethics before it was submitted to IRAS. This change in procedure was designed to reduce the number of amendments requested by IRAS since the application and supporting documents would have already been reviewed by ethics advice specialists. The proceedings for this application are presented in table 4.1.

Table 4.1 Timetable of events leading to UoB internal ethics approval for the research project 'Do Large Refractive Correction Changes Increase Dizziness?'**.**

Date	Event
27-10-15	Ethics checklist submitted to UoB ethics.
27-10-15	Informed by UoB ethics that IRAS applications must now be reviewed by UoB ethics before submission
27-11-15	IRAS application and supporting documents submitted to UoB ethics.
02-12-15	Acknowledgement of application received from UoB ethics.
10-12-05	UoB ethics advised some amendments to IRAS application
05-01-16	Amended application and documents submitted to UoB ethics
13-01-16	IRAS application and supporting documents approved by UoB ethics.

4.2.2 NHS ethics approval

After gaining internal UoB approval for the study, an application to conduct the research project was submitted to NHS ethics via IRAS (project reference number: 187995). The application was reviewed by the East Midlands – Leicester South Research Ethics Committee (REC). Minor amendments to some of the documents and procedures were advised by IRAS and the application was resubmitted on completion of these recommendations. Each time an amendment was made to any part of the IRAS application or to any of the supporting documents – (even if - as in one case - the amendment was as minor as the addition of a logo to that document) electronic signatures from the Chief Investigator, academic supervisors, sponsor and local collaborator had to be provided to ensure that all key personnel were aware of any modifications being made to the protocol or documents. The amendments and

acquiring of signatures took some time as documented in table 4.2.

Table 4.2 Timetable of events from initial application to IRAS approval being granted for the research project 'Do Large Refractive Correction Changes Increase Dizziness?'

Date	Event
10-02-16	Application for NHS ethics approval submitted to IRAS
18-02-16	IRAS application scheduled for review by REC
23-02-16	REC requested minor amendments to the application
16-03-16	IRAS application resubmitted with recommended amendments
05-04-16	REC issued 'favourable opinion' for IRAS application

4.2.3 HRA and local ethics approval

Local ethics approval was necessary to establish that the research site had adequate staff to carry out the data gathering and to ensure that patient care would not be adversely affected by the implementation of a research project within the department concerned.

After obtaining the necessary signatures, an application was sent to Research and Development (R&D) at Bradford Royal Infirmary for permission to conduct the research in the hospital. A week later, the research team were informed that R&D now needed HRA approval before processing any research applications. The research ethics approval system had changed its processes during the time it had taken to gain IRAS approval.

HRA approval was applied for and since the study had already gained approval under the previous system, R&D at Bradford Royal infirmary

activated their document approval process whilst waiting for HRA approval to reduce any further delays to starting the research.

The steps taken to gain R&D approval are documented in table 4.3

Table 4.3 Steps taken to gain R&D approval after IRAS approval had been obtained**.**

Date	**Event**
05-02-16	Feasibility of study discussed in a meeting with Bradford Royal Infirmary R&D
21-04-16	Application to Bradford Royal Infirmary R&D submitted
28-04-16	Notification of R&D requirement to have HRA approval
28-04-16	R&D requested a minor amendment to the patient information sheet
29-04-16	HRA approval request submitted
16-05-16	HRA 'escalation' email sent (this is a process where the HRA are informed that the researcher has not had a response within two weeks)
18-05-16	Received HRA reply that they were very busy, and they would review the application as soon as possible
13-06-16	Phone call made to HRA to ask when application would be reviewed. Was told they would "try and expedite" the process
04-07-16	Email sent to HRA to ask when application would be reviewed
10-07-16	Phone call made to HRA to ask when application would be reviewed. Was told it would be reviewed "soon"
27-07-16	Email sent to HRA to ask when application would be reviewed
28-07-16	HRA requested a copy of UoB insurance certificate as the one submitted with the original application had since expired
28-07-16	UoB insurance certificate emailed to HRA
03-08-16	HRA approval received

After ten months of waiting and applying to various bodies, the research team finally obtained approval to start gathering data for the study.

4.3 Research passport application.

During the feasibility meeting of 5th February 2016, R&D advised the research student to apply to Bradford Royal Infirmary for a ‘research passport’ that would allow her to carry out research within the Trust. After securing the appropriate signatures and documents, an application was made, and she was informed that a ‘letter of access’ would be sufficient to be allowed to process the data gathered from the participants’ medical records. This was granted and was valid for twelve months. An extension to the letter of access became necessary because the ethics approval process took much longer than expected.

4.4 Methods

The most common causes of refractive correction changes in older adults is cataract. In many cases, patients experience a gradual shift in refractive error as the cataract progresses. Pesudovs and Elliott (2003) found that refractive error shifts in a myopic direction in around 50% of patients with nuclear cataract and those with cortical cataract experience an astigmatic refractive error change in approximately 25% of cases. Taking these figures into account, it was anticipated that approximately a third of patients seen in Hospital Eye Service cataract clinics would show a significant change in their refractive error in those years prior to being referred.

A ‘significant change’ was defined as a refractive correction change that met the criteria set out by Cumming et al. (2007) for a ‘major change’. These criteria are as follows:

- A spherical change of ≥ ±0.75DS
- A cylindrical power change of >0.75DC
- A 10°axis change on a cylindrical power of up to 0.75DC
- A 5° axis change on a cylindrical power >0.75DC
- Any change to prism
- Introduced anisometropia (difference in mean sphere between the two eyes) of 0.75D

Bradford Royal Infirmary performed cataract surgery on around 200 patients per month. We intended to enrol 150 participants over nine months (recruitment of 180 to allow for a drop-out rate of 20%). Previous studies suggested that this would be easily achievable (Supuk et al. 2016).

Sample size estimation was calculated using the formula N=10k/p, from (Peduzzi et al. 1996) where k is the number of covariates (in this case age and gender) and p is the likely proportion of positive cases (in this case, a positive case was a participant with a significant shift in refractive correction as defined by Cumming et al. (2007)) in the study population. Thus, the estimated sample size (using the prevalence figured found by (Pesudovs and Elliott 2003) for those with nuclear cataracts would be N=20/0.5 (= 40) and the estimated sample size for those with cortical cataracts would be N=20/0.25 (= 80) giving a total of 120 cataracts. About 40% of cataracts include some nuclear and 40% some cortical (Klein et al. 1992; Mitchell et al. 1997) so 80% of cataracts would be of interest to the study giving a recruitment target of 120/0.8 = 150 participants.

Dizziness status was measured using the short form of the Dizziness Handicap Inventory (DHI(sf)). The DHI(sf) was chosen because the Dizziness Handicap Inventory (DHI) is the most widely used dizziness questionnaire (Fong et al. 2015) and its short form has been Rasch analysed (Tesio et al. 1999) and found to compare well with the original DHI whilst having the advantage of reduced participant burden. The DHI(sf) provides ordinal data based upon dizziness symptoms and its effect on function and quality of life by asking the patient if symptoms or activity limitation are present for thirteen situations. An answer of 'yes' does not score any points and an answer of 'no' scores one point, thus, a score of 13 indicates the absence of dizziness and a score of zero indicates significant symptoms and activity limitation.

It was anticipated that the majority of potential participants would be elderly, therefore the DHI(sf) was favoured over the VVAS because of the potential difficulties for an older person to accurately convert the subjective experience of dizziness into a visuospatial image (Carlsson 1983). In addition, the VVAS was not developed using modern psychometric techniques and it does not contain any item relating to how dizziness affects quality of life (section 1.12.3).

4.4.1 Methods - Participants

Patients who had been referred to the Ophthalmology Department to be considered for cataract surgery and who were over the age of 18 years, were approached by a member of the direct care team to ask for their participation in the study. The care team member explained what the research was about and what it would entail and answered any questions the patient may have had. A participant pack containing an information sheet, a questionnaire, a

consent form, an optometrist details form and a prepaid envelope was provided for each potential participant. Patients were permitted to take the information packs away so that they had enough time to consider whether to take part. All participants were asked to complete a consent form, an optometrist details form, and the short form of the Dizziness Handicap Inventory (DHI(sf)). The DHI(sf) questionnaire asked them to answer the questions when considering how they felt in the two months following the acquisition of their latest pair of spectacles.

Participants were asked to return the consent form, optometrist's details form and completed questionnaire to the research team in the prepaid envelope.

4.4.2 Methods - procedures

Current refractive correction data were obtained from optometric referral reports and recorded in negative cylinder form. Previous refractive error data were obtained from hospital records, copies of previous prescriptions or by asking the participants' optometrists to provide a copy of the prescriptions (a copy of the consent form was presented to the optometrist in question when asking for this information).

It was assumed that all participants were at the same level of adaptation to their spectacles before the refractive correction change took place since it was impossible to accurately determine otherwise. A retrospective value for dizziness in two different situations would have led to confusion and introduced more recall bias. Refractive correction data up to and including two years prior to referral for cataract surgery were used in the study. If latest refractive correction data were more than two years old, the participant was excluded from the study to reduce recall bias. These refractive corrections

were recorded to the nearest 0.25DS, 0.25DC and 2.5 degrees and were recorded in negative sphero-cylindrical form. Visual acuity (where available) was recorded using Snellen as this was used almost exclusively in high street practice at that time.

All data were collected, stored and reported anonymously. Names and contact details were stored on paper separately to questionnaire data in a locked cabinet. Questionnaire and refractive correction data were stored on a password protected University of Bradford computer (with only the research student having the password which was not written down anywhere) using an identification number only for each set of data. It was intended that where a participant asked to be kept informed of the outcome of the research, names and contact details would be stored electronically, however, no participants indicated that they wished to be informed of the outcome of the research, therefore no names and contact details of participants were stored in this way.

In accordance with NHS procedure, all participant recruitment was documented in detail on the EDGE patient management system by the person on the care team who had undergone appropriate training and then by the research student (who had also undertaken appropriate training) when data had been collected. The EDGE patient management system is used by the NHS to record the progression (in real time) of all research studies being undertaken within the NHS. Researchers are required to record when a patient moves from one stage to another during the study by recording the dates that the patient was pre-screened, approached, consented, recruited, on follow-up and completed. These dates must be recorded on the day that the event took place. If for any reason the patient was taken off study, this

would also be recorded by date and reason for removal from the investigation.

4.4.3 Methods – analysis

Demographic data and dizziness scores were collated to indicate the level of dizziness reported in the population being studied.

Vector analysis of the participants' refractive correction changes was performed on past and present refractive corrections to allow change in spectacle prescriptions to be accurately compared. A sphero-cylindrical spectacle lens may be represented as the sum of three vectors - a mean spherical equivalent (M), a cylinder at 0° (J_0) and a cylinder at 45° (J_{45}) (Thibos et al. 1997). Since we were interested in the magnitude of the change of the different components rather than the direction of change, absolute values of M, J_0 and J_{45} were used in the analyses in addition to the change in anisometropia. Correlations between DHI(sf) scores and refractive correction components were analysed to determine any association between the two.

4.5 Study progress

The study protocol was implemented in the local collaborator's cataract clinic immediately on receipt of R&D approval. Two hundred participant packs were delivered to the clinic and each person who met the recruitment criteria was approached to ask for participation in the project. After only eight weeks, it became clear that recruitment targets were not going to be met using only Bradford Royal Infirmary cataract patients as just one clinic per week had staff who were able to spend time recruiting potential participants. Only eight participants had returned consent forms and questionnaires to the research team and one of those had an incomplete consent form, therefore could not

be used.

The research team agreed that other potential sites should be approached to ask for their involvement in the project. To this end, The Yorkshire Eye Hospital was contacted three times via past and present members of staff to ask for access to their patients for the study, however, we were unable to interest them in the research.

An ophthalmologist and optometrist from the Ophthalmology department at St. James' University Hospital agreed to help with recruitment for the study with the result that the project was extended to include their routine cataract patients. Local ethics approval procedures were initiated (on 20th September 2016) and once approval was in place (received on 10th October 2016), the research student attended the next scheduled staff training at Ophthalmology Outpatients at St James' University Hospital to explain procedures and to ask the direct care team to actively promote recruitment to the study.

4.6 Procedural changes

After five months of recruitment 29 sets of questionnaires had been returned and full datasets were in place for only 13 patients, therefore, the research team decided to change the recruitment process to follow that of a previous study (Supuk et al. 2016) to improve participant numbers. Supuk et al.'s study had a response rate of 29% with 79% of responses yielding useable data from cataract patients at Bradford Royal Infirmary. HRA approval was sought (22nd March 2017) to allow a member of the direct care team to mail an invitation letter and participant pack directly to the home address of all patients who were on the cataract extraction waiting list, with a personalised letter inviting

patients to participate in the study (NHS ethics rules prevented members of the research team being allowed access to patients' personal data until consent had been given). A member of staff at Bradford Royal Infirmary indicated that she would be happy to perform this task, so as soon as HRA and local ethics approval was granted (9th May 2017), procedure at Bradford Royal infirmary was changed to follow the new protocol. By this time, 112 participant packs had been supplied to potential participants in clinic at Bradford.

The team at St. James' University Hospital were unable to implement this amendment, so the original recruitment method was continued at this site. On recommendation of the ophthalmology consultant, the research student obtained a research passport letter of access from Leeds Research and Innovation department that gave permission to attend cataract clinics and talk to patients in the waiting area about the study with the aim of improving the recruitment rate.

Over the next four months, 289 participant packs were mailed directly from Bradford Royal Infirmary cataract clinic to potential participants and St. James' University Hospital cataract clinic continued to approach patients when they attended for consultation. Over the seven-month period of recruitment at Leeds, 450 participant packs were issued to potential participants at St. James' Hospital, Leeds. Despite all these efforts, only 51 patients returned questionnaires during nine months of recruitment.

The research team decided to analyse the data that had been collected thus far to determine whether the study had the potential to provide useful information if further data were to be collected.

4.7 Results and data analysis

51 patients returned questionnaires using the prepaid envelopes. 6 people returned the blank participant pack paperwork in the prepaid envelope, 4 of them with a note saying they did not wish to take part. 1 participant returned their questionnaires without fully completing the consent form and 2 participants returned the forms with insufficient details to be able to contact them or their optometrist so were excluded from the study. This resulted in 25 full datasets and 17 partial datasets. Of the partial datasets, 4 did not have any optometrist contact details, 10 had only one refractive correction available and 3 optometrists refused to provide refractive correction details. Where complete refractive correction data were available, all values were prescribed within the past two years, therefore all data were useful for the study.

Completed participant packs were obtained from 23 Bradford Royal Infirmary patients and 22 St. James' University Hospital patients. The response data is summarised in figure 4.1.

4.7.1 Demographic data

Of the 25 full datasets, 15 (60%) were from females. Participants had an age range of 54-91years, mean 73 years (SD = 9.2), median 72 years. 7 (28%) respondents were from St. James' University Hospital, Leeds and 18 (72%) from Bradford Royal Infirmary.

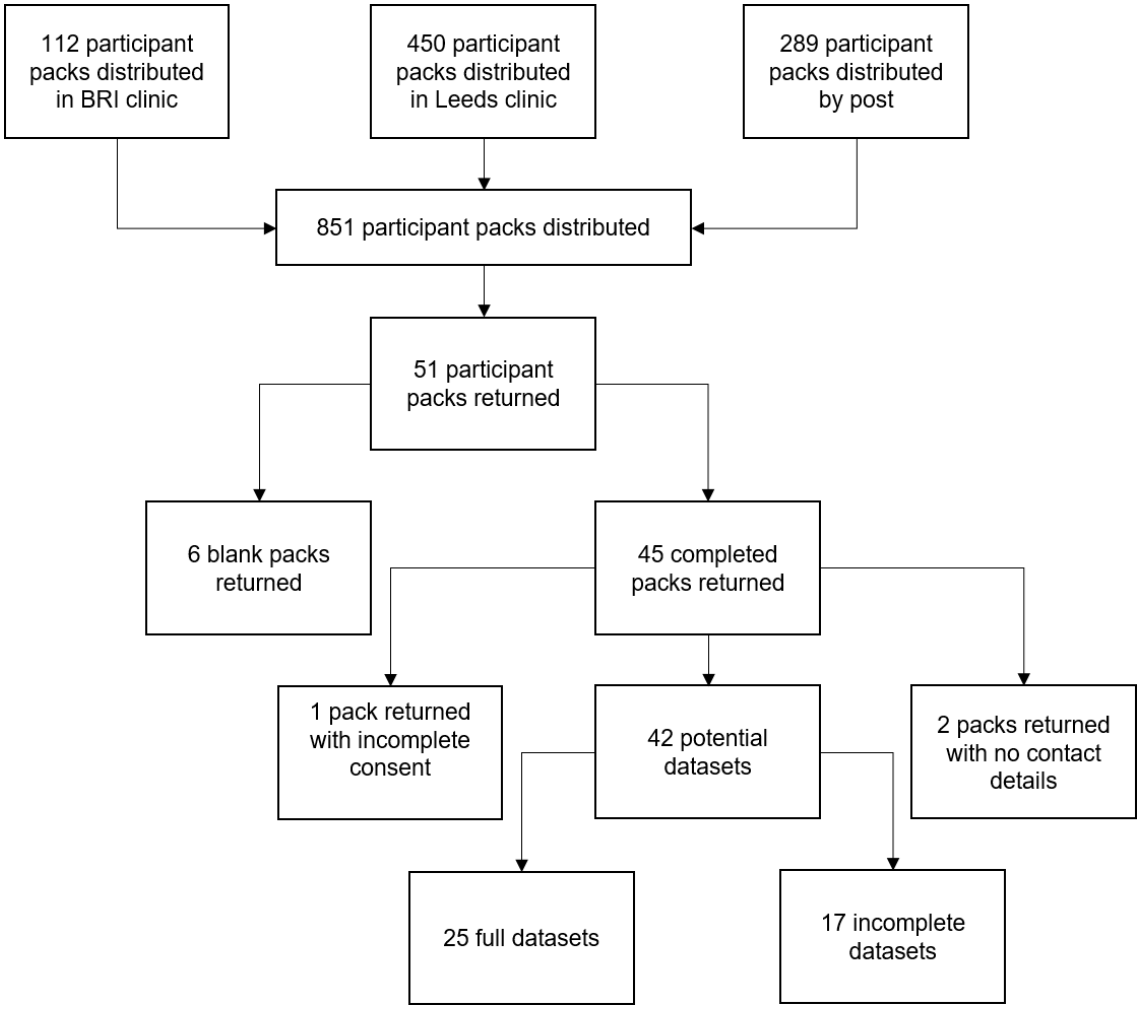


Figure 4.1 Flow chart detailing the stages of data collection for the study 'Do Large Refractive Correction Changes Increase Dizziness?'

4.7.2 Dizziness scores

The participants reported varying degrees of dizziness which is summarised in the histogram in figure 4.2. The distribution of DHI(sf) scores indicated that participants had varying degrees of dizziness, ranging from a score of 13 (no dizziness) to 3 (dizziness symptoms in ten of the thirteen situations) with a median score of 11 (dizziness symptoms in two of the thirteen situations). Six (24%) patients had a score of 13 indicating that they did not have any dizziness symptoms.

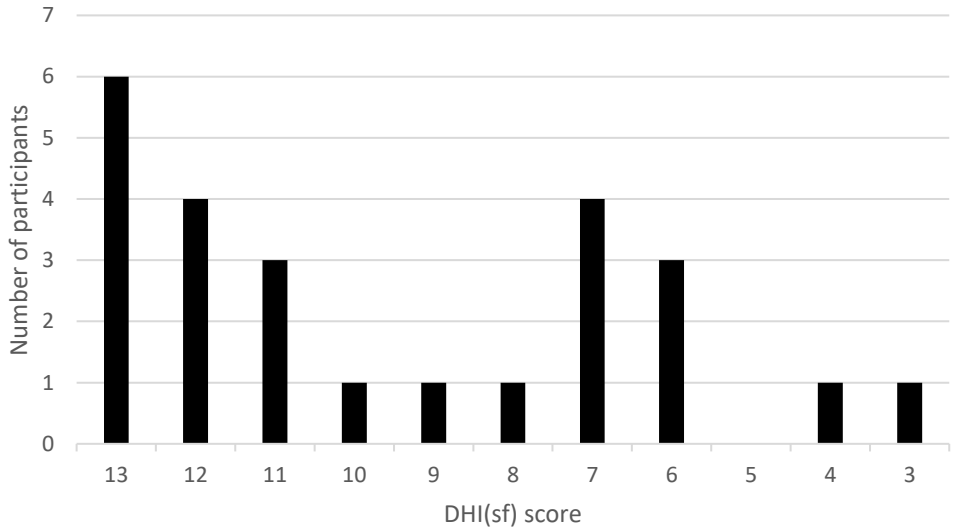


Figure 4.2 Histogram showing the number of participants for each category of dizziness determined by the DHI(sf).

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4.7.3 Refractive correction changes and dizziness scores

Each participant's refractive error change was examined and a prediction made as to whether that person might have experienced dizziness due to their refractive error change using Cumming et al. (2007) criteria (section 4.4) to decide what represented a 'major change' in refractive correction.

Each participant was categorised as 'likely', 'unlikely' or 'uncertain' depending

on their likelihood of having dizziness linked to their change in refractive error. Where Cumming's criteria for major change were met, that participant was categorised as 'likely', where the refractive correction change was borderline, the participant was categorised as 'uncertain' and where the criteria were not met, a category of 'unlikely' was applied. This resulted in 12 (48%) likely, 6 (24%) unlikely and 7 (28%) uncertain.

The DHI(sf) score for each patient was placed in a scatterplot where the marker was coloured to represent one of the three predicted dizziness likelihood categories. This is presented in figure 4.3. On examination of figure 4.3 it was evident that there was no relationship between dizziness prediction based on refractive correction change and DHI(sf) scores.

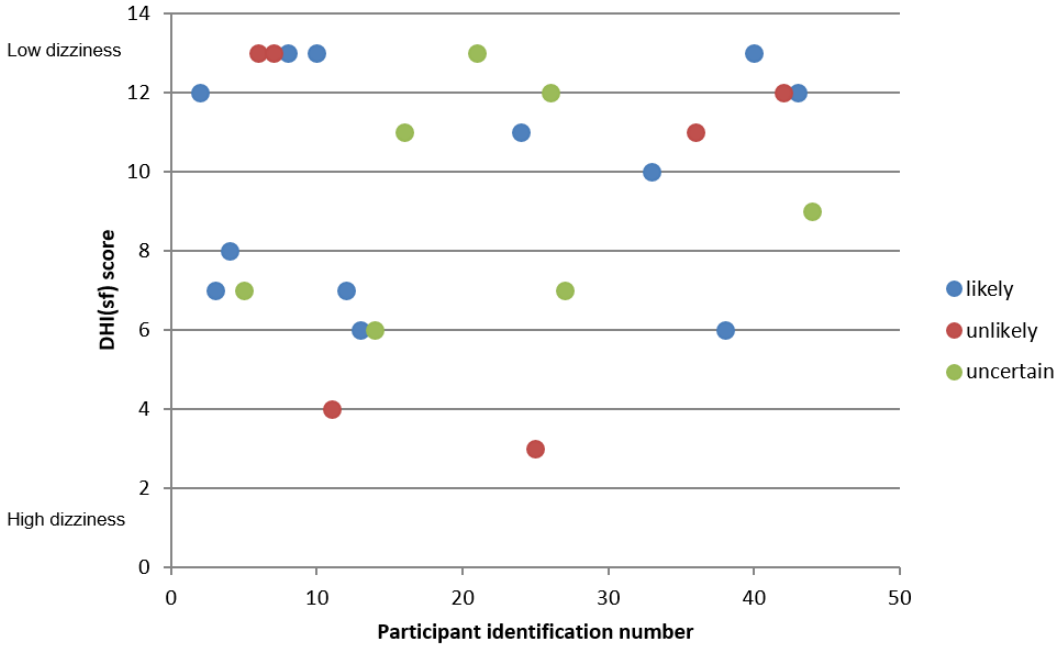


Figure 4.3 Scatterplot showing the DHI(sf) scores of each participant. The colour of the marker indicates their dizziness prediction based upon their refractive correction change**.**

The participants were then categorised based upon their DHI(sf) responses. A DHI(sf) score of 13 indicated no dizziness at all. A score of 12 or less indicated the presence of some dizziness symptoms with increasing dizziness as the score decreased. A score of 0 indicated the patient was dizzy in all the situations presented by the instrument.

SPSS statistics (version 23.0; Armonk, NY:IBM Corp) was used to perform normality and correlation tests. Since the sample size was small, the Shapiro-Wilk test was performed to assess normality of the data. When considering all participants, data for DHI(sf) scores, J_{45} change and anisometropia change were not normally distributed ($p<0.05$). M change and J_0 change had only weak evidence for normality ($p>0.05$ but <0.50). When considering only those participants who were categorized as dizzy (DHI(sf) score ≤12), J_{45} change and anisometropia change were not normally distributed ($p<0.05$). DHI(sf) score and M change had weak evidence for normality ($p>0.05$ but <0.50) and J_0 change could be reasonably assumed to be normally distributed ($p>0.50$). Scatterplots were generated (using Microsoft Excel 2016) to show correlations between each component of refractive correction change and DHI(sf) score. These are shown in figure 4.4 a-d for all participants and in figure 4.5 a-d for participants who showed dizziness symptoms.

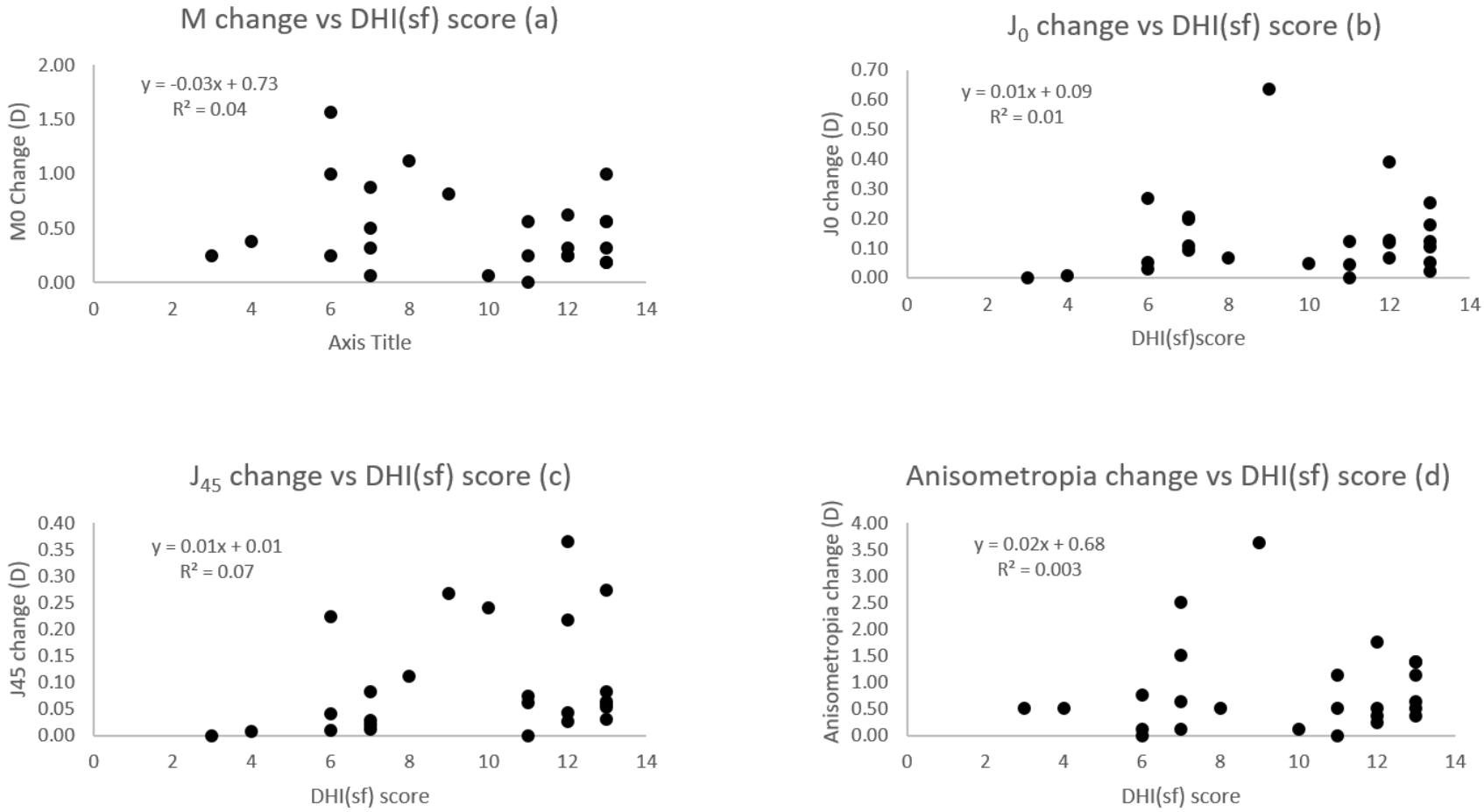


Figure 4.4 a-d Scatterplots for M change (a), Jo change (b), J45 change (c) and anisometropia change (d) vs DHI(sf) score for all participants**.**

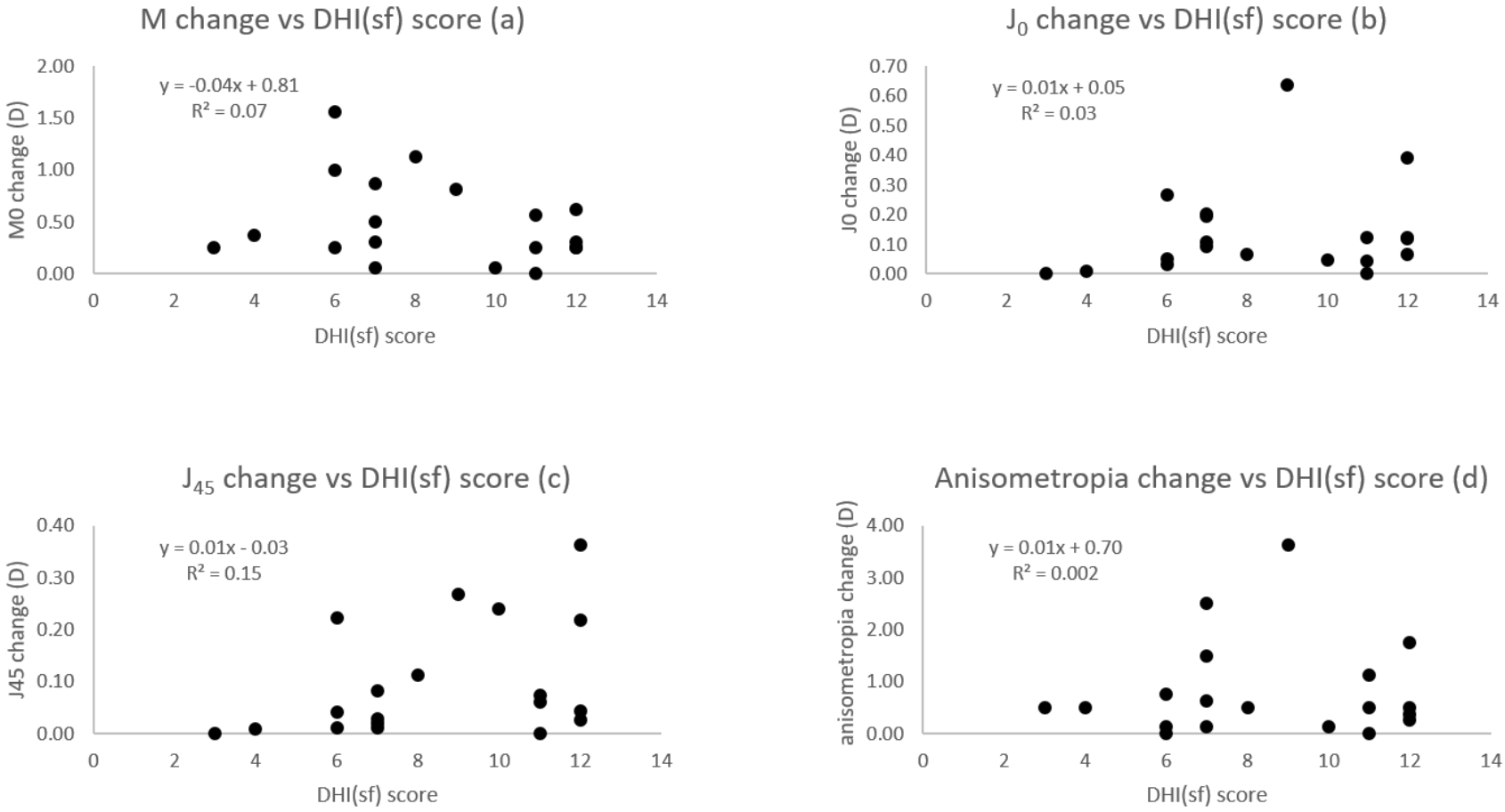


Figure 4.5 a-d Scatterplots for M change (a), Jo change (b), J45 change (c) and anisometropia change (d) vs DHI(sf) score for dizzy participants**.**

Since normality tests showed that none of the data for all participants and only one of the sets of data for dizzy participants could reasonably be categorised as normal, non-parametric tests were performed to assess correlations between refractive correction change and dizziness scores. Kendall's tau was used to assess correlation since the dataset was small and there were many scores of the DHI(sf) that had the same rank, in these circumstances, Kendall's tau has been suggested to be a more accurate estimate of the correlation. (Field 2013). Spearman's rank correlation coefficient (rho) was also applied to the data because it is the more popular of the non-parametric coefficients, therefore, may be more easily interpreted by many individuals. Kendall's tau values and Spearman's rho values are presented in tables 4.4a and 4.4b. The results of these tests combined with the scatterplots in figures 4.4 a-d and 4.5 a-d show that the correlation coefficients showed negligible to weak association (Hinkle et al. 2003; Walker and Almond 2010) with the conditions categorised as having weak correlations being for J_{45} change in both cases. In all cases except J_{45} change, the correlations were not statistically significant since $p>0.10$, however for J_{45} change the correlations showed a trend that was approaching significance since $p>0.05$ and <0.10.

Table 4.4a Kendall's tau correlation coefficients for each refractive change category vs DHI(sf) score for all patients (N=25) and for patients who reported dizziness symptoms (n=19).

		M change	J_0 change	J_{45} change	Anisometropia change
All participants DHI(sf) scores (N=25)	Correlation coefficient	-0.10	0.16	0.28	0.14
	Significance	0.52	0.30	0.06	0.38
Dizzy participants DHI(sf) scores (n=19)	Correlation coefficient	-0.17	0.23	0.34	0.03
	Significance	0.36	0.20	0.06	0.86

Table 4.4b Spearman's rank correlation coefficients for each refractive change category vs DHI(sf) score for all patients (N=25) and for patients who reported dizziness symptoms (n=19).

		M change	**J_0 change**	**J_{45} change**	**Anisometropia change**
All participants DHI(sf) scores (N=25)	Correlation coefficient	-0.13	0.21	0.37	0.18
	Significance	0.53	0.31	0.07	0.40
Dizzy participants DHI(sf) scores (n=19)	Correlation coefficient	-0.23	0.30	0.43	0.03
	Significance	0.36	0.21	0.07	0.89

4.8 Decision to abandon the study

In nine months of data collection, only 25 full sets of data were obtained. Since the target recruitment was 150 (section 4.4), it was predicted that (if recruitment continued at the same rate) a further four and a half years of recruitment would be necessary to achieve the optimum quantity of data. Furthermore, analysis of the data collected thus far indicated negligible to weak correlations between refractive correction changes and dizziness, with only the J_{45} condition showing a trend that was approaching significance. Had any of these data been significant, there would have been potential value in continuing to recruit participants to test the hypothesis.

Reluctantly, the research team decided that collection of data should end since both time and financial resources would expire before enough data could be assembled.

4.9 Discussion

The course of this study was far from smooth - from application for ethics approval to implementation of the protocol and data collection, problems were encountered at almost every step. Nevertheless, this research provided valuable training for future studies involving NHS ethics and afforded a useful insight into deciding upon alternative courses of action when a project doesn't follow its planned schedule.

The data hinted at support for the findings of Supuk et al. (2016) (astigmatic refractive error changes – especially oblique changes – are associated with increased dizziness). Correlation coefficients for J_{45} had significance values of $p>0.05$ and <0.10 indicating that the results found were approaching

significance. A larger sample size might have shown a significance of $p<0.05$, however, resources and time did not allow for the continued collection of data.

The first problem encountered by this research project was the amount of time taken to obtain NHS ethical approval. This was primarily caused by the change to NHS ethics approval rules and the considerable backlog of applications that these new rules generated. This was an unavoidable setback that was unique to the timeframe and hopefully would not occur in future ethics approval applications. When changes to procedure became necessary, delays were experienced due to the necessity of applying to an already overstretched NHS ethics system for approval of the changes.

Secondly, the response rate was very poor at 6% (51/851), with full data sets being obtained for only 3% (25/851) of potential participants. This was despite alternative methods of recruitment being undertaken.

Patients referred for cataract surgery in the Bradford area are given a choice of where they would like to be treated. Bradford Royal Infirmary is the only hospital in the area that can offer general anaesthetic and deal with complex cases, therefore the patient base of Bradford Royal Infirmary tends to be skewed to include more complex cases than other service providers. The patients considered to be complex, are often older, and have additional eye disease and health problems. Some of these factors may have caused them to be less likely to respond to the questionnaires than those people who were younger and healthier (Kaldenberg et al. 1994). Patients at both hospitals were given participant packs and were given the option to take them home to consider if they wished to participate. This might have meant that some potential participants overlooked the study when they arrived at home due to

preoccupation about their hospital visit, or they may have misplaced the pack during their time in clinic.

Some patients responded to the study but had failed to complete all sections of their consent form, optometrist details form and/or questionnaire. Incomplete consent or contact details meant that the patient could not be included in the study. Where an incomplete questionnaire was returned, the patient was contacted by post to ask if they would complete the missing information. This request added more delays to the data collection process and was not always responded to. Optometrists were contacted to ask for previous spectacle prescription details in every case, however, 3 optometrists did not respond to the request despite being contacted initially by post and then by telephone and email. In ten cases, the participant had only visited the referring optometrist on one occasion, and details of previous prescriptions were not available.

4.10 Limitations

The use of the DHI(sf) was one of the limitations of this study. It was developed to assess patients with vestibular problems, and some of the questions (for example those asking about dizziness when turning over in bed) ask about situations with little or no input from the visual system. However, the DHI(sf) was the most suitable and most commonly used instrument (Fong et al. 2015) available at the time of planning this study. In addition, the question ‘Because of your problem, do you have difficulty reading?’ could have easily been misinterpreted by a population of patients who had cataracts which is also a problem that may cause difficulty with reading. Indeed, 14 of 19 patients who

reported dizziness symptoms said that they had difficulty reading, with 3 of the 4 of those who only reported one dizziness symptom stating that their problem was with reading – suggesting that the question had perhaps been misinterpreted.

The precision of the DHI(sf) data relied on the participants being able to accurately recall their dizziness symptoms when they first had their spectacles. Some of these patients had bought their spectacles up to two years previously, therefore it may be reasonable to predict that some of the DHI(sf) data may not be wholly accurate.

As with all studies that require self-report of symptoms, those with cognitive disabilities were effectively excluded since the participant was required to consent to participation and to understand the questions being asked. These subjects are suspected to be most likely to have multiple risk factors for dizziness due to their frailty (Tinetti et al. 2000).

There was no way of knowing the level of adaptation of each participant at baseline, in other words, whether they were well adapted to the spectacles worn before the change of refractive correction being investigated. It seems reasonable that a person who was only just coping with a refractive correction might be more sensitive to changes in spectacle lens power than someone who was well adapted to their spectacles.

Finally, there was no way of knowing if the participants' dizziness was linked to the refractive error change or whether any individual had dizziness before they began to wear their new spectacles.

4.11 Alternative ways to research this question

This research question would perhaps be better investigated in optometric practice rather than in the Hospital Eye Service. It would require optometrists to become involved in distributing participant packs and explaining the research to patients who had cataracts, but who did not yet need referral to the Hospital Eye Service because refractive correction changes provided acceptable visual acuities. These patients could be asked to answer the questionnaire before their new spectacles were issued and then again, a week after they had collected their new spectacles. This way, recall bias would be reduced and a record of the patients' dizziness status before the new spectacles were worn would be obtained for a more accurate assessment of any dizziness that the spectacles may have induced. Information about medical conditions and medication should be asked to determine if a participant was likely to have experienced dizziness due to either of these factors. An alternative questionnaire should be used as the DHI(sf) has been shown to be less than ideal for this project (section 4.9). When this study was being designed, it was recognised that an instrument to assess visually-related dizziness was not available and this led to the development of a new questionnaire – the VRD-25 (Chapter 6). The development of this instrument was not complete when this research was carried out. The VRD-25 would be a more suitable instrument to use for this study.

Chapter 5.

Can the changes in spectacle lens power prescribed during routine eye examination cause dizziness?

The contents of this chapter are based on the work presented as a poster at *Optometry Tomorrow*, The College of Optometrists' annual conference and trade exhibition. Birmingham, UK on 13th and 14th March 2016 (Appendix B3).

5.1 Introduction

Case reports (Chapter 3) suggested that an evaluation of the effect of spectacle lens design and spectacle correction changes would be valuable in the study of vision-related dizziness. Dizziness may be induced by a refractive correction change (despite an improved visual acuity) because of spectacle magnification changing the compensatory eye movements needed to maintain a stable retinal image during movement (chapter 1, section 1.4).

If certain refractive correction changes are more likely to induce dizziness (Supuk et al. 2016), the population who are most likely to have these changes are those who returned their spectacles to their optometrist because they were unable to adapt to them.

There have been numerous studies investigating why some patients return to optometric practice after being unhappy with their new spectacles, however, none have investigated symptoms that prompted the patients' return, rather they have explored the cause of the problem from the practitioners' point of view by reporting whether the error was in the spectacle prescription, the manufacture or fit of the spectacles etc. (Wood et al.1983; Mwanza and Kabasele 1998; Hrynchak 2006; Steele et al. 2006; Freeman and Evans 2010;

Howell-Duffy et al. 2012). It has been documented that even small, binocular focal errors of 0.25D of spherical or cylindrical power cannot be tolerated by some patients (Miller et al. 1997). However, participants were asked about the 'comfort' of the vision rather than any specific symptoms such as dizziness. Atchison et al. (2001) also assessed patients' tolerance to errors in refractive correction and found that small (±0.50DS), spherical anisometropic errors caused symptoms of dizziness in two of the fifteen subjects who participated in the study, but not to the same spherical errors in both eyes. Cylindrical changes have been found to be a common cause of spectacle dissatisfaction (Hrynchak 2006) and Guyton (1977), Werner and Press (2002) and Elliott and Howell-Duffy (2015) warned against large changes in astigmatic correction, particularly for oblique axes, in their prescribing advice. Supuk et al. (2016) found that oblique cylindrical changes following cataract surgery were associated with increased dizziness. The aim of this study was to determine whether dizziness is a cause of patient dissatisfaction when spectacle prescriptions are changed and what type of prescription changes (if any) were most likely to cause dizziness problems and dissatisfaction. We hypothesized that astigmatic changes at oblique axes would be a significant cause of spectacle dissatisfaction and dizziness in this study. In addition, the study sought to determine if patients and/or practitioners considered the possibility of dizziness being a potential consequence of poor adaptation to new refractive correction.

5.2 Preliminary investigation

The term ‘spectacle remake’ is commonly used by optometric staff to describe an episode where a patient returns to the practice because they are in some way unhappy with their new spectacles, and the investigation into what may be causing the dissatisfaction results in the spectacles being made again (possibly with a different prescription, a different type of spectacle lens, a different frame or different measurements of the lens position in the frame).

The term ‘recheck’ is used in optometric practice to describe the consultation with an optometric practitioner following a patient being dissatisfied with their new spectacles.

Spectacle ‘non-tolerance’ is used by some practitioners to describe any episode where a patient returns to the practice because they feel they cannot tolerate wearing the new spectacles for any reason (Freeman and Evans 2010). Other practitioners use the term to describe a situation where the patient is dissatisfied with their spectacles, but the prescription and lenses are accurate. This suggests that the problem is due to the patient’s inability to adapt to the new spectacles (Howell-Duffy et al. 2010). In this study, ‘spectacle non-tolerance’ refers to the latter of these two situations.

Access to the database at a branch of Specsavers Opticians in Northern England was possible because a research team member was an employee at the time of this preliminary study. An initial search of 155 ‘spectacle remakes’ revealed 97 orders that were remade due to inaccurate ordering or measurements, transposition and transcription errors, lab errors or patients taking advantage of the ‘no quibble, no fuss guarantee’ (which permits a remake of the spectacles if the patient changes their mind about the frame or

lens type within three months of purchase). These remake episodes were disregarded since the reason for remake was not due to refractive correction change. Six patients out of the remaining 58 (10%) reported symptoms of dizziness and/or imbalance with their new spectacles according to the optometrist's record card. 12 (21%) of patients had presented with vague symptoms such as that their vision was 'not quite right' or that they 'preferred their old spectacles' without mentioning the word dizziness. It may be that these patients didn't have symptoms of dizziness, or that the practitioners involved did not question the patients with regards to this possibility. The vague nature of many complaints suggests that dizziness may have been involved in some of these cases since people often find it difficult to describe dizziness symptoms (Grill et al. 2013).

These preliminary findings suggested that a more comprehensive investigation into the symptoms leading to spectacle remakes was needed, to attempt to answer the following questions:

- How many patients (if any) return to their optometrist and have their spectacle prescription changed because they are unhappy with their spectacles due to induced dizziness?
- What are the terms used by patients to describe the symptoms that prompted them to return to their optometrist following the acquisition of a new pair of spectacles?
- Do changes made to spectacles at the recheck reduce any symptoms of dizziness?
- What type of refractive correction changes are most likely to induce dizziness?

- Do patients and/or practitioners consider the possibility of dizziness being a potential consequence of poor adaptation to a new refractive correction.
- Are oblique cylindrical changes more likely to cause dizziness than other refractive correction changes?

5.3 Ethics approval

Ethical approval was granted by the Chair of the Biomedical, Natural, Physical and Health Sciences Research Ethics Panel at the University of Bradford on 6th June 2016.

5.4 Methods

The directors of three Specsavers stores in Northern England were contacted to request permission to inspect their remake records. Access was granted to gather information for 'approximately six months' by the practices. All spectacle remake records, between the dates of 01/04/16 and 31/10/16 were retrospectively examined to identify any patients who had their spectacle prescription or spectacle lens type changed because of a recheck were contacted by post by the practice, to ask if they would agree to participate in the study. Invitation letters and participant packs were sent to patients on a month by month basis and were addressed to the patient with a hand-written, personal salutation (Larson and Poist 2004). This communication took place four to six weeks after the remade spectacles had been collected to ensure that the patient could answer the question that asked if their problem had been resolved by the new refractive correction. Patients were sent a participant

pack with their invitation letter. This pack contained:

- A participant information sheet
- A consent form
- A questionnaire about spectacle adaptation problems
- A prepaid envelope

The spectacle adaptation problems questionnaire is presented on pages 139-141

Spectacle Adaptation Problems Questionnaire

Ref no……..

All information is provided anonymously – *Please do not give your name*

1. Please enter your age

2. Please select your gender *(please circle)*

   Male
   Female

3. What is your current occupation?

4. What medicines or tablets do you take? *(leave blank if no medicines, or you do not wish us to know)*

Spectacle Adaptation Problems Questionnaire continued

5. When you were wearing the spectacles that you were unhappy with, did
   you have any of the following symptoms? *(Please tick all that apply)*

□ A feeling of dizziness

□ A "swimmy" sensation or general feeling of motion sickness *e.g. like car or sea-sickness*

□ A "motion-sickness" feeling when moving around but you felt okay when seated

□ Concern about being unsteady on your feet when standing

□ Distorted vision *e.g. the floor appearing to be sloped, door frames appearing curved, things appearing to be the wrong shape*

□ Blurry distance vision *e.g. subtitles on TV*

□ Blurry close vision *e.g. reading a newspaper*

□ Your new spectacles were just not feeling 'right' but it was difficult to say why

□ Other – *please write any other symptoms here*

Spectacle Adaptation Problems Questionnaire continued

6. Has the problem that you had with your new spectacles now been resolved? *(please circle)*

Yes No Partially

Thank you for completing this questionnaire. Your help is greatly appreciated.

This project is funded by the College of Optometrists

Participants were asked to return the consent form and completed questionnaire in the prepaid envelope. The questionnaire was designed to obtain data relevant to the research question and was in the style of the Spectacle Adaptation Questionnaire (SAQ) (Howell-Duffy 2013). The full version of the SAQ was not used since the presence or absence of symptoms was being investigated in this study - not the frequency or consequences of symptoms, as investigated by the SAQ, therefore the full version of the SAQ would have placed unnecessary burden on the respondents. The questionnaire was intended to identify people who had dizziness problems, those who had blurred or distorted vision and those with symptoms that they felt difficult to describe and included a section where participants could add any other symptoms they experienced that were not on the list provided. Finally, the questionnaire included an item asking whether the dizziness had been fully, partially or not resolved by the change in spectacles.

No personal identifying data were stored electronically. Information regarding each spectacle remake episode was stored with reference number on a password protected computer with only the researcher having the password.

The following data were collected (where available) for analysis from the optometric record card:

- Age and gender.
- Habitual distance refractive correction (with visual acuities where available) and type of spectacles – this was the spectacle correction that the patient was wearing when they attended for their sight test.

- Distance refractive correction and visual acuities found at the sight test that resulted in a remake along with type of spectacles dispensed.
- Distance refractive correction and visual acuities found at the recheck sight test along with type of spectacles dispensed.
- Presenting symptoms at recheck.

Patient records were assessed to determine if patients voluntarily provided information that they were suffering from dizziness symptoms and whether this was recorded by the practitioner.

5.4.1 Exclusion criteria

All patients who had had their spectacles remade were considered for inclusion in the study. Those excluded were:

- Patients under the age of 18 years.
- Patients whose spectacles were changed under the ‘no quibble, no fuss’ guarantee which states: “We want you to be completely happy with your purchase at Specsavers. If you have any concerns within three months of the date of purchase, we will put it right. No quibble, no fuss” this allows patients to have their spectacles remade if they change their mind about the frame or type of lenses within three months of purchase.
- Patients who didn’t take their new spectacles from the practice before they were remade, for example, where the error (such as the wrong tint colour) was noticed by staff and corrected before they were collected.
- Patients who wore single vision spectacles for near vision only.

5.5 Data analysis

Information regarding the terms used to describe adaptation problems and dizziness symptoms was recorded and analysed along with the methods used to resolve the problem.

Spectacle prescription changes were analysed by three optometrists who each had over 20 years post-registration experience. Each patient's habitual spectacle prescription was compared with the prescription that had caused the patient to return to practice. The three optometrists used Cumming et al.'s (2007) criteria and their years of experience to determine the most likely cause of the spectacle dissatisfaction. The Cumming et al.'s (2007) criteria for a 'major change' in refractive correction were as follows:

- A spherical change of ≥ ±0.75DS
- A cylindrical power change of >0.75DC
- A 10°axis change on a cylindrical power of up to 0.75DC
- A 5° axis change on a cylindrical power >0.75DC
- Any change to prism
- Introduced anisometropia (difference in mean sphere between the two eyes) of 0.75D

Refractive correction changes were categorised into seven groups. These were:

1. Over-plussed (The spectacle correction had more mean sphere equivalent positive power than necessary)
2. Over-minussed (The spectacle correction had more mean sphere equivalent negative power than necessary)
3. Cylindrical changes (The power, axis or both components had been changed)
4. Prismatic changes (A prism had been added, removed or changed)
5. Anisometropia (A major change in the difference in mean sphere between the two eyes)
6. Varifocal non-tolerance (Inability of the patient to wear varifocals despite the prescription and spectacle manufacture being accurate)
7. Bifocal non-tolerance (Inability of the patient to wear bifocals despite the prescription and spectacle manufacture being accurate)

Dizziness status was assessed via the responses to the questionnaire. A respondent was considered to have dizziness symptoms if they answered the questionnaire by indicating that they had any of the following symptoms:

- A feeling of dizziness
- A ‘swimmy’ sensation or general feeling of motion sickness *e.g. like car or sea sickness*
- A ‘motion sickness’ feeling when moving around but you felt okay when seated
- Concern about being unsteady on your feet when standing

A respondent was considered to have possible feelings of dizziness if they did not indicate any of the above symptoms, but indicated the response:

- Your new spectacles were just not feeling ‘right’ but it was difficult to say why

An alternative way of analysing the data would have been to use vector analysis (Thibos et al. 1997). This would have involved breaking each prescription down into its component vectors (see chapter 4, section 4.6.3), and using these values to compare changes for each element of refractive correction. This approach has been used previously to show that oblique cylindrical changes lead to increased dizziness (Supuk et al. 2016), but this was with a large sample size of 287 and the results lacked clinical context. The spectacle prescription that was prescribed at the retest was compared with the habitual refractive correction (where the patient reported that the problem had been fully or partially resolved) to investigate if the former was closer to the latter than the rejected prescription.

5.6 Results

A total of 1075 patient records were examined to determine whether the inclusion criteria were met. 587 records were rejected as not meeting the inclusion criteria. These records were mainly rejected because the spectacles had been remade to the same prescription, but the patient was unhappy with some aspect, for example, the frame, the coating or the tint. The rate of spectacle dissatisfaction (after removal of patients who took advantage of the ‘no quibble, no fuss’ guarantee and those who had their spectacles replaced under statutory guarantee) was 2.4%, however, only those who had their

spectacles re-made were investigated, therefore patients who had a re-test that resulted in no change to the spectacle lenses (where, for example, a frame adjustment might have solved the problem) were not included in the spectacle dissatisfaction numbers.

488 invitation letters and participant packs were sent by post to patients (age range 19-93 years, mean 59 (SD 14)) who met the inclusion criteria. Only eight (1.6%) of 488 recheck records included the words ‘dizzy’ or ‘vertigo’ to describe the patient’s symptoms and seven others (1.4%, giving a total of 15) used similar terms such as “off balance” and “feels drunk”. There were other descriptions of symptoms that were vague and could have indicated dizziness. (Grill et al. 2013). These are presented in table 5.1. There was a sizeable number of retest records (86 or 18%) that simply noted that the patient was not able or willing to wear their varifocals with no indication of why. Twenty-six retest records (5%) did not document any reason for the retest.

Table 5.1 A summary of the vague symptoms recorded in the recheck records that could have indicated dizziness for the patients who were sent invitation letters for the study**.**

Symptom noted by optometrist at retest	**Number of patients (out of 488)**
‘prefers old prescription’	25
Spectacles ‘too strong’	24
Spectacles ‘not right’, ‘strange’, ‘odd’ or ‘feels like looking through a goldfish bowl’	17
‘eyes not working together’	2
‘multiple things wrong with new specs’	2
‘nausea’	1

5.6.1 Respondent data results

120 (25%) participants returned completed questionnaires and consent forms. 63% of respondents were female. The age range of respondents was 20-88 years and the mean age was 62 years (SD = 13). The numbers of respondents in each age category are shown in figure 5.1. One respondent's data were removed from the analysis because they didn't have a change to their refractive correction (the invitation letter had been sent in error) leaving N=119. Non-respondents were 57% female, with a mean age of 57 years (SD=14) and an age range of 18-93 years.

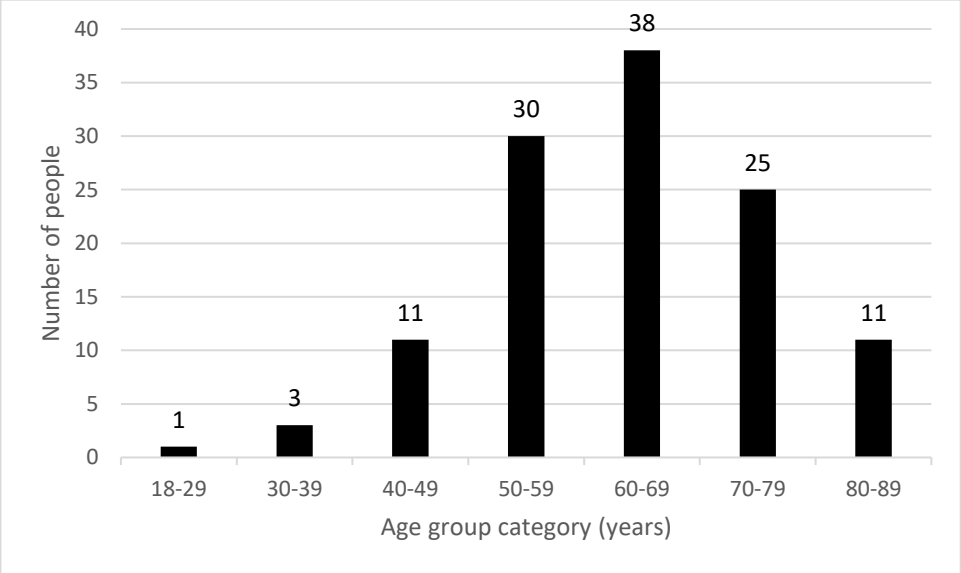


Figure 5.1 Histogram showing the number of respondents in each age category**.**

None of the record cards of the respondents included a report of feeling dizzy at the retest, although four felt "off balance" or "off balance and sick" and one felt "drunk" with the new spectacles. Twenty-one people were recorded as having vague symptoms that may have indicated dizziness. These symptoms are documented in table 5.2.

Table 5.2 A summary of the vague symptoms recorded in the recheck records that could have indicated dizziness for the patients who responded to the invitation to participate in the study**.**

Symptom noted by optometrist at retest	**Number of patients (out of 119)**
'prefers old prescription'	9
Spectacles 'too strong'	6
Spectacles 'not right', 'strange', 'odd' or 'feels like looking through a goldfish bowl'	4
'multiple things wrong with new specs'	1
'nausea'	1

29 records (24%) indicated that the patient was unable or unwilling to wear varifocal lenses with no indication of why.

Forty-five respondents (38%) reported that they had suffered from dizziness symptoms according to the criteria set out in section 5.5 via the questionnaire. Seventy-four respondents (62%) did not report any dizziness symptoms; of those 24 responded positively to the question 'your new spectacles were just not feeling 'right' but it was difficult to say why'.

75 respondents (63%) reported that their problem had been fully resolved by the remade spectacles, 33 (28%) reported that the problem had been partially resolved and 11 (9%) stated that the problem had not been resolved. Of those who reported dizziness symptoms, these figures were 15 (47%), 11 (34%) and 6 (19%) respectively.

The data from the habitual refractive correction and the sight test of respondents were examined and discussed by the three experienced optometrists mentioned in section 5.5 to determine the likely principal cause of spectacle dissatisfaction. These data are presented in figure 5.2.

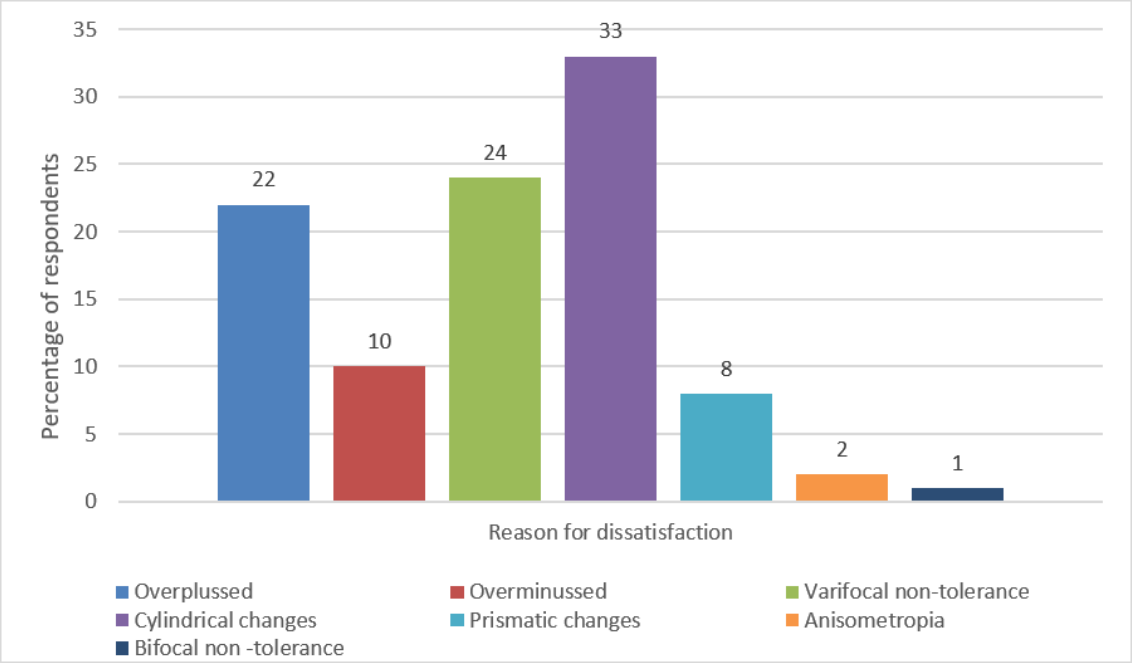


Figure 5.2 The reasons for spectacle dissatisfaction for the people who responded to the invitation letter and questionnaire.

The cases where varifocal and bifocal lenses were involved could not be accurately assessed for this study since it was impossible to determine whether the refractive correction change, or the lens design was responsible for the patients' dissatisfaction with their spectacles. Therefore, the patients who were classified as 'varifocal non-tolerance' and 'bifocal non-tolerance' were removed from further analyses. Twenty-nine respondents' data were removed leaving 90 sets of data in the final analyses. The most likely causes for dissatisfaction for these participants were changes to the cylindrical component of the refractive correction (43%), over-plussed corrections (29%) and over-minussed corrections (14%) (figure 5.3).

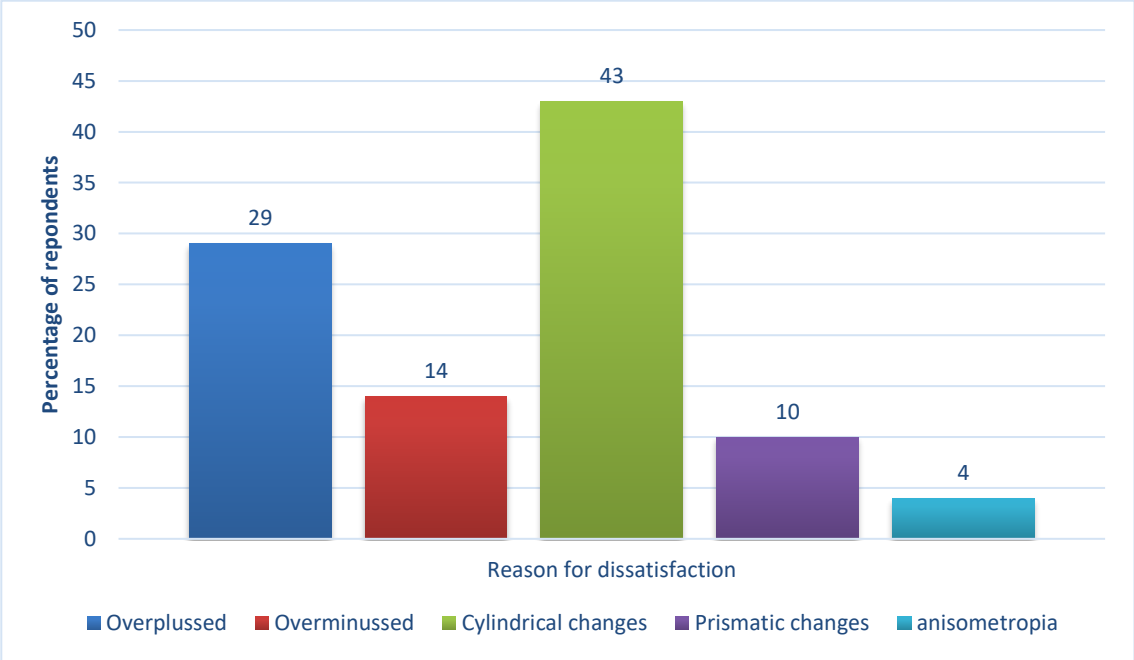


Figure 5.3 The reasons for spectacle dissatisfaction for the people who responded to the invitation letter and questionnaire after varifocal and bifocal non-tolerance cases were removed from the data (N=90).

Next, the likely causes of spectacle dissatisfaction in conjunction with the responses to the questionnaire about dizziness symptoms were investigated. These data are presented in figure 5.4. The people who responded positively to the question ‘your new spectacles were just not feeling ‘right’ but it was difficult to say why’ were classified as ‘not dizzy’ since it was impossible to ascertain if they were, in fact dizzy despite this answer pointing to the possibility of dizziness.

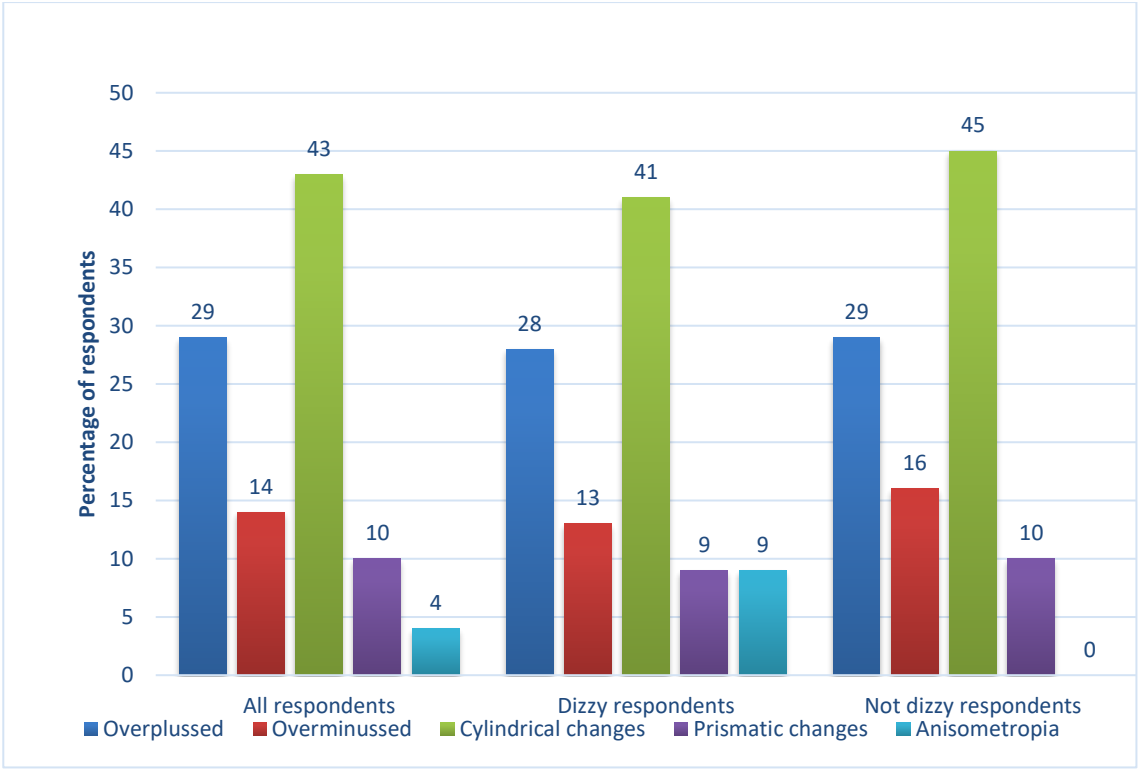


Figure 5.4 The most likely causes of spectacle dissatisfaction in dizzy and not dizzy patients for respondents who had a change in refractive correction.

Each patient who had the most likely cause of their spectacle dissatisfaction classified as cylindrical changes, was categorised as having with-the-rule astigmatism, against-the-rule astigmatism, oblique astigmatism or 'one eye with, other against'. The findings of this investigation are shown in figure 5.5. Cylindrical power may be classified as being 'with the rule' against the rule', oblique' or 'mixed'. 'With the rule' astigmatism occurs when the vertical meridian of the cornea is steeper than the horizontal meridian. This is corrected using a negative cylindrical lens with its axis in the horizontal meridian and negative power in the vertical meridian. Against the rule astigmatism occurs when the horizontal meridian of the cornea is steeper than the vertical meridian and is corrected using a negative lens with its axis in the vertical meridian. With the rule astigmatism is more common in younger

patients while against the rule astigmatism is more common in older patients (Leung et al. 2012). Oblique astigmatism occurs when the steeper axis of the cornea is obliquely orientated. In this study, with the rule astigmatism was defined as a negative cylindrical lens placed at an axis of between 180°and 30° or 150°- 180°, against the rule astigmatism was where a negative cylindrical lens was placed at 60°- 120°and oblique astigmatism was defined as a negative cylindrical lens placed at 31°- 59° or 121°- 149°.

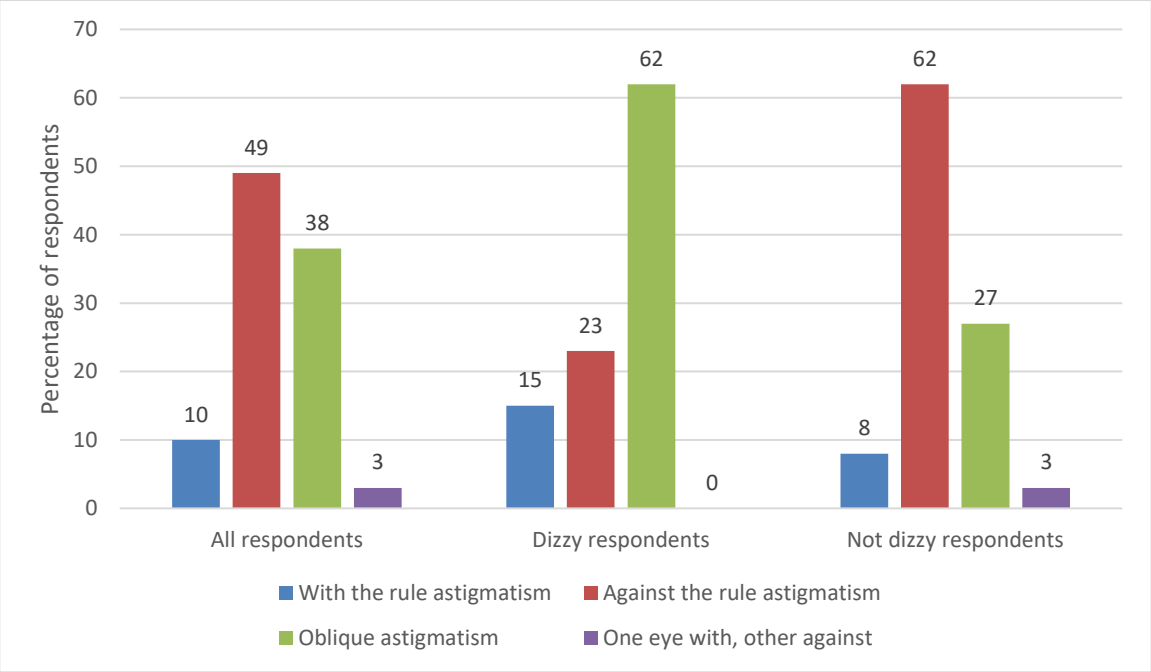


Figure 5.5 Types of astigmatism in dizzy and not dizzy patients who were classified as having cylindrical changes as the most likely cause of their spectacle dissatisfaction.

5.7 Analysis and discussion

Problems with adaptation to change in refractive correction can be due to a change of retinal image size and the resulting vestibulo-ocular reflex (VOR) adaptation (Elliott 2014b). Magnification (or minification) provided by

spectacle correction changes means that a mismatch of head and eye movements can lead to dizziness until adaptation is achieved (Cannon et al. 1985). Optometrists seem unaware of this link since only 3% of the 488 records of patients who were sent questionnaires included a report of ‘dizziness’ or similar at the time of their re-test, and five (4%) of the 119 records of respondents. Thirty eight percent of the 119, however, indicated that they had symptoms of dizziness in their questionnaire responses. Another possible explanation for this is that patients often find it hard to precisely describe their dizziness feelings (Grill et al. 2013). The 26 record cards (from the 488 people who were sent invitation letters) that didn’t document a reason for spectacle dissatisfaction could be explained by poor record keeping (the optometrist asked the correct questions, but failed to record the answers), or possibly by the optometrist not asking the patient to describe their problem.

Positive responses to the description ‘your spectacles were just not feeling ‘right’ but it was difficult to say why’ (where there were no positive responses to the questions that indicated dizziness) could be explained by either the patient not suffering from any dizziness symptoms, or there being some mild dizziness symptoms that the respondent found hard to describe (Grill et al. 2013).

The vague symptoms reported at the recheck examination of some the 119 respondents (table 5.2) may have indicated dizziness. If optometrists were more aware of these vague symptoms they may be inclined to ask further questions - particularly about dizziness - should their patient report them. Similarly, when a patient indicates that they are unable or unwilling to wear their varifocal lenses, an indication of the problems they have experienced

would assist the practitioner in their decision making and reduce the chances of the same situation arising at the patient's next eye examination.

The majority of respondents (91%) reported that their spectacle dissatisfaction problem had been fully or partially resolved by the revised refractive correction, indicating that optometrists are skilled at solving problems caused by refractive correction changes. This may be due to practitioner experience of dissatisfaction problems or their implementation of the clinical maxim 'if it ain't broke, don't fix it' since 75% of people had their problem fully resolved by their spectacle prescription being changed back to or to within a minor change (as defined in section 5.5). It is likely that practitioner experience played a role in both the prescribing and retest examinations (Howell-Duffy 2013).

The data from figure 5.2 indicate that the refractive correction change that was most likely to result in spectacle dissatisfaction (33% of cases) was modification of the cylindrical component of the spectacle lens power. Astigmatic spectacle power changes cause differences in magnification along two different meridians. This may cause the patient to experience distortions to their vision until adaptation is achieved, for example the sides on a rectangular object may appear curved. This degradation of image has implications in judging objects and distances (such as when negotiating steps (Johnson et al. 2013) and the maintenance of postural stability may be affected leading to a report of dizziness.

The next most common principal cause of spectacle dissatisfaction was varifocal non-tolerance (24%). There are multiple reasons why varifocal lenses may induce or increase dizziness and these are associated with the design of the lens:

Unwanted oblique astigmatism. A traditional varifocal lens consists of a distance vision area and a near vision area which are connected by a progressive area, or corridor (figure 5.6). To ensure smooth transition of these areas of differing spectacle power, an oblique cylindrical lens is incorporated in the peripheral blending area (Meister and Fisher 2008a). The oblique cylindrical power is almost zero in the progressive areas but increases in the blending areas according to the Minkwitz theorem which states that the rate of change of astigmatism perpendicular to the umbilic (the line that joins the spherical points on the lens surface) changes at twice the rate of the power change along the line (Sheedy et al. 2005). In other words, the amount of unwanted cylindrical power is proportional to the power of the add. Varifocal lenses with a short corridor of progression from distance lens power to near lens power (popular when smaller spectacle frames were fashionable) therefore had higher levels of unwanted peripheral astigmatism than lenses with a longer progression corridor since the power change along the umbilic was rapid. This peripheral oblique astigmatism is likely to induce blur, distortion and image movement which may lead to dizziness and discomfort for the wearer (Guyton 1977), especially during dynamic vision situations.

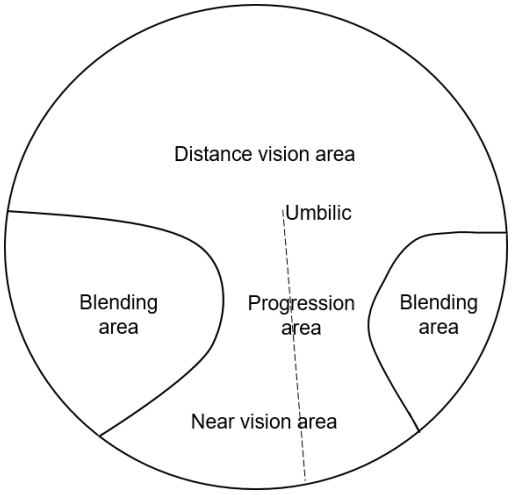


Figure 5.6 Schematic diagram of the refractive areas of a varifocal spectacle lens showing the areas that typically give distorted vision**. *Source: author***

Varifocal lens design has been evolving since the first commercially viable, mass-produced varifocal lenses became available in the 1960s. The aim of reducing unwanted peripheral oblique astigmatism to improve lens acceptance has been central to many new developments.

Originally, varifocal lenses had a symmetrical design about the umbilic, such that the same blank could be used for glazing either eye before the lens was surfaced. The near inset was achieved by rotating the lens nasally by an average of 9° (Meister and Fisher 2008a). However, this rotation increased the extent to which the blending zone was visible in the nasal field of view of the distance vision area, thus reducing the binocular field of view at distance and inducing blur in the right nasal field upon left hand gaze and vice versa. This blur could lead to an increase in dizziness (Armstrong et al. 2016).

Asymmetrical lens design was developed to reduce this interruption to the binocular field of vision. The near inset was therefore achieved without

having to rotate the lens allowing a wider binocular field of view, however as the eyes moved horizontally, the asymmetric design meant that different powers were being viewed by each eye through corresponding points on the lenses, leading to reduced comfort due to binocular fusion being more difficult (Meister and Fisher 2008a). This problem led to lenses being designed with horizontal symmetry to reduce the differences in power, unwanted astigmatism and prism between corresponding points on the two lenses.

Hard and soft lens designs attempted to address the problem of the visual discomfort caused by the unwanted oblique cylindrical power in the peripheral blending areas. A ‘hard lens design’ had more concentrated, smaller areas of oblique astigmatism in the blending areas, providing larger areas of clear vision, but at the same time increasing the amount of unwanted oblique cylindrical power in the periphery. This type of varifocal was consequently better for continuous tasks that needed good visual acuity rather than for dynamic vision situations where the presence of higher amounts of unwanted oblique cylindrical power would likely trigger dizziness and visual discomfort. A ‘soft lens design’ spread the unwanted astigmatism over a larger area of the surface of the lens, decreasing the amount of cylindrical power at any point, and increasing the comfort of and ease of adaptation to the lens in dynamic conditions. This design narrowed the area of clear vision. (Meister and Fisher 2008a). Modern varifocal design techniques attempt to reduce the amount of unwanted oblique cylindrical power in the blending area by orienting the axis of astigmatism more vertically or reducing the cylindrical power by using ‘free form’ technology to create a custom lens for each individual based upon the best form for that wearer’s prescription (Meister & Fisher 2008b). Free form

lens design allows each lens to be surfaced to an individuals' specification, allowing custom design of lenses to suit the wearer and at the same time, removing excess irregularities in power (Meister & Fisher 2008a, 2008b; Charman 2014).

The VOR – since the spectacle magnification varies depending upon where the wearer looks through the lens, a change in VOR gain (chapter 1, section 1.4) is necessary as the patient moves their eyes to view different targets (Michaelides and Schutt 2014). If the patient finds it difficult to adapt to the VOR gain change then they may suffer dizziness when wearing a varifocal lens. The variable nature of magnification across the lens means that movement of an object may be different to that of the image viewed through the varifocal. This may lead to a conflict between the VOR and the image perceived which could lead to vertigo and motion sickness (Meister and Fisher 2008a). This conflict might also lead to uncertainty about the movement and position of objects leading to anxiety, postural instability and dizziness (Charman 2013).

Blur and distortions – rapid changes in cylindrical power over the surface of the lens can lead to blur and geometric distortion being experienced by the varifocal wearer (Meister and Fisher 2008a), especially when viewing through the peripheral blending areas. Blur and distortion cause decreased visual acuity which has been linked to increased dizziness (Armstrong et al. 2016).

The third most common principal cause of spectacle dissatisfaction was over-plussed correction (22%). A spectacle prescription that has too much positive power will give the wearer both magnification and blur. The former means that the VOR would be interfered with as described in section 1.4 and the latter

would lead to reduced vision which has been found to be linked with dizziness (Armstrong et al. 2016). Similarly, it has been shown that refractive blur can adversely affect standing postural control in the elderly (Anand et al. 2003b). A sensation of reduced postural stability would likely be reported as dizziness by an individual.

The removal of the data of patients who were wearing bifocal and varifocal lenses (figure 5.3) left cylindrical changes and over-plussed prescriptions as the most common causes of spectacle dissatisfaction in this study. Hrynchak (2006) also concluded that cylindrical lens changes were the most frequent reason for spectacle dissatisfaction. Werner and Press (2002) and Elliott (2008, 2014b), warned against too large a change to the cylindrical component of a spectacle prescription and Guyton (1977) explained how astigmatic spectacle lenses can cause distortion due to meridional magnification and that some people are unable to tolerate these distortions. He provided detailed guidelines for prescribing such lenses based on this evidence.

The most common cause of dissatisfaction in both dizzy and not dizzy respondents was cylindrical changes (41% and 45% respectively), followed by over-plussed correction (28% and 29%) and over-minussed correction (13% and 16%). The proportion of dizzy and not dizzy responders was similar for each of these types of spectacle lens modification. All three respondents who had their cause of spectacle dissatisfaction classified as ‘anisometropia’ were in the ‘dizzy’ group of respondents. This was the only group of refractive correction types that showed a clear difference between dizzy and not dizzy respondents, although the number is clearly very small. This finding supports

the work of Atchison et al. (2001) who found that two participants reported dizziness when small amounts (±0.50D) anisometropia were added to their spectacle correction. Anisometropia likely contributes towards dizziness due to the uneven VOR adjustments needed for each eye when an image is stabilised on the retina. A change in the amount of anisometropia would require a complex adaptation of the VOR because the difference in magnification between the two lenses changes the way that objects are perceived (Adams et al. 2001). This might take longer to adapt to than a change that is similar in magnitude and direction made to both eyes. (Sehizadeh 2005). Further evaluation is needed.

When participants who had been classified as having cylindrical changes as the most likely cause of their dizziness were analysed further, oblique cylindrical changes were significantly more common among respondents who reported dizziness symptoms. (Fisher's exact 1-sided chi-squared test ρ=0.04). Fisher's exact chi-squared was used due to the low sample size and a one-sided test was used as our hypothesis was that oblique astigmatic changes would cause greater dizziness than astigmatic changes at other axes. This supports the work of Supuk et al. (2016) who found that oblique cylindrical changes to refractive correction following cataract surgery were associated with more dizziness than other spectacle lens changes and Kanazawa et al. (2018) who found oblique cylindrical spectacle lenses cause a greater reduction in postural stability than other introduced astigmatic errors in healthy subjects. In addition, the findings of the study detailed in Chapter 4 hinted at support for these findings despite the sample size being insufficient for the results to be significant. Guyton (1977) stated that cylindrical changes

are less acceptable to spectacle lens wearers when the axes are oblique and Elliott (2014b) identified the VOR adaptation necessary to maintain a stable retinal image as being the cause of these adaptation problems. This has implications for both optometrists when prescribing and for ophthalmologists when performing cataract surgery. The goal of astigmatic reduction during cataract surgery should be to specifically avoid changing oblique astigmatism. Participants were asked whether their dissatisfaction had been fully, partially or not resolved. 75 patients (63%) indicated that their problem had been fully resolved, with 28 (33%) reporting that partial resolution had been achieved. Only 11 people (9%) stated that the problem had not been resolved. Of the patients whose dissatisfaction was fully resolved by the new prescription, 75% of them had their refractive correction changed back to their habitual prescription or to within a minor change (as defined in section 5.6) of their habitual correction. This supports the findings of Howell-Duffy et al. (2012) who concluded that implementation of the clinical maxim ‘if it ain’t broke, don’t fix it’, where appropriate, would reduce spectacle dissatisfaction in optometric practice by approximately 32%.

5.8 Limitations

The study was retrospective, therefore no protocol for retest patient management was followed by the optometrists involved. This approach, however, had the advantage of gaining a true impression of the behaviours of optometrists when conducting a retest examination. Had the study been prospective with a protocol for optometrists to follow, the optometrists involved may have changed the way that they conducted sight tests and the omission

of questions about dizziness and shortfalls in record keeping during retest examinations would not have been highlighted.

The response rate meant that 75% of people who had remakes were not assessed. Measures recommended by Kanuk and Berenson (1975) and Larson and Poist (2004) were applied to maximise response rate (including a stamped addressed envelope, a questionnaire with the lowest respondent burden possible, a personal hand-written salutation, University logo and sponsorship to instil trust and an assurance of anonymity). Follow-up letters or phone calls were not used because the store directors felt that more than one contact might be perceived as a nuisance by their patients. Younger people were less likely to respond to the invitation to participate ($t(476) = -3.54$, $\rho < 0.001$), perhaps because the older population were more likely to be retired and had more time to become involved in the study. There was no significant difference between the likelihood of males or females to respond to the invitation letter ($\chi^2(1) = 1.13$, $\rho = 029$). The response rate was similar to that of Supuk et al. (2016) who had a 29% response rate and who implemented a follow-up procedure to improve participation. Nevertheless, the study is limited by the small sample size in each of the different refractive correction change groups. This was unavoidable due to restrictions on the length of time data collection was permitted by the participating practices.

There was no way of knowing if patients had a pre-existing vestibular condition which a refractive correction change could have exacerbated, however none of the respondents stated that they were taking any medication used to treat a vestibular problem and there were no records of vestibular disorders in the optometrists' notes in either the original sight test or the retest of respondents.

The questionnaire used was not a standard, validated instrument. The most commonly used questionnaire about dizziness is the Dizziness Handicap Inventory (Fong et al. 2015), however this instrument was developed and validated to be used on an older population of people with vestibular disease and there are questions relating specifically to vestibular disease (for example asking about dizziness symptoms when turning over in bed or bending over) that have no visual element. These questions would be irrelevant to this study. The question in the Dizziness Handicap Inventory asking if reading caused 'your problem' might be easily misinterpreted by patients who were having problems with reading in their new spectacles due to blur rather than dizziness. In addition, questions about blurry vision and other sources of spectacle dissatisfaction were needed and these are not available in the Dizziness Handicap Inventory.

Relevant questions from the Spectacle Adaptation Questionnaire were chosen instead (Howell-Duffy, 2013). This is a validated questionnaire, but it is not specific to vision-related dizziness and the use of all the items would have placed unnecessary burden on respondents by gathering information that was not useful to the research question.

5.9 Conclusions

Changes in spectacle power prescribed after routine eye examinations can induce dizziness. These dizziness symptoms may be fully or partially resolved by a change in spectacle power. Oblique cylindrical lens modifications are the most likely spectacle power changes to induce dizziness, which confirms a recent cataract surgery cohort study (Supuk et al. 2016). Anisometropia was

also found to be a likely source of dizziness by this study. This finding has also been suggested by an investigation into spectacle lens acceptance. (Atchison et al. 2001), but the sample size was very low and this needs further investigation.

Optometrists seem unaware of the link between dizziness and vision and do not ask specific questions about dizziness symptoms (and/or do not record them). Patients who return to practice because of dissatisfaction with their new spectacles may not be able to describe what they feel is the cause of their problem, therefore optometrists should, first of all, ask a general question about the visual comfort of the new spectacles such as ‘when you put your new glasses on, does your vision feel comfortable?’. If a patient states that they feel uncomfortable, further questions should follow that ask specifically about dizziness symptoms, for example ‘do your new glasses make you feel dizzy, swimmy or imbalanced. Optometrists should be wary of changing oblique cylindrical powers (and perhaps partially prescribe such changes (Guyton 1977; Werner and Press 2002; Elliott, 2008; Elliott 2014b), particularly when patient have risk factors for dizziness such as increasing age, female gender, hypotension, visual impairment, polypharmacy, vestibular disorders, anxiety, vascular disease and depression.

Conservative changes to spectacle lens power, especially when oblique cylinders are involved, would be less likely to induce dizziness problems than larger changes.

5.10 Further study

A study with a larger sample size of remakes would be valuable, particularly to follow-up the potential link between anisometropic refractive changes and dizziness.

This study highlighted the need for a questionnaire to assess visually caused dizziness. The development and validation of such an instrument was undertaken and is reported in chapters 6 and 7.

Chapter 6.

The development of the Vision-Related Dizziness questionnaire – VRD-25.

The Development of the Vision-Related Dizziness Questionnaire (VRD-25). The contents of this chapter and chapter 7 are based upon the work published as Armstrong D, Alderson AJ, Davey, CJ and Elliott DB (2018), 'The development and validation of the Vision-Related Dizziness (VRD-25) patient-reported outcome measure'. *Frontiers in Neurology* 9, 379.doi:10.3389/fneur.2018.00379 (Appendix B4) It was presented as a poster at Academy 16. The American Academy of Optometry Conference. Anaheim, USA 10th and 11th November 2016 (Appendix B5).

6.1 Introduction

Vision related quality of life is difficult to quantify due to differences in individual patients' expectations, goals and previous experience. When a patient describes their dizziness, they may give a detailed picture, or they may be very vague as symptoms may be subtle and difficult to describe accurately. Objective methods of quantifying dizziness may not be useful in determining whether a patient has a significant problem as, what is intolerable to one individual, may be perfectly acceptable to another. In other words, the activity limitation or inconvenience caused by dizziness is a very subjective experience it is for this reason that vision-related dizziness may be best measured using a self-assessment questionnaire or patient-reported outcome measure (PROM).

A review of the literature concerning questionnaires used to quantify dizziness

revealed that there were no instruments that had been developed to quantify visually caused dizziness (1.12.3 and 1.12.4). Table 6.1 presents an overview of the features of the most commonly used dizziness and vision-related quality of life PROMs. Currently available PROMs had limitations that made them unsuitable to be used in research into visually related dizziness for a number of reasons – listed below:

- They were validated on older, vestibular patients meaning they may not be appropriate for use on a general population of people with vision-related dizziness, some of whom might have no vestibular component to their dizziness. (DHI and DHI(sf).
- They may not have been validated using modern psychometric techniques (VVAS).
- How dizziness impacts on quality of life is not assessed (DHI, DHI(sf), VSS and VVAS).
- Questions may not be wholly appropriate since they were aimed at a vestibular population (DHI and DHI(sf)), refer to daily living tasks with no reference to dizziness (ABC scale) or have questions that could be easily mis-interpreted (DHI and DHI(sf)). The DHI question that asks ‘because of your problem, do you have difficulty reading?’ could be taken to be asking about problems caused by cataracts, if a Hospital Eye Service population was being studied.
- There may be difficulties in interpreting and answering the questions due to the recording method used (VVAS).

The limitations of these PROMs indicated that a new instrument was needed to be used in the investigation of vision-related dizziness.

The aim of this study was to use modern test theory to develop and validate the first PROM which could be used to quantify visually caused dizziness and the associated quality of life and activity limitations, in the general adult population. The final instrument would be a validated PROM with a five-point Likert scale, developed on a general population and intended for use in clinical investigations of vision-related dizziness. It should be possible to use the information gathered by the instrument to assist clinicians in making decisions about refractive correction in patients who present with this problem.

Table 6.1 Summary of the use and development of the questionnaires found to be most useful in the development of the VRD-25 questionnaire**.**

Instrument	Intended use	Development population	Number of items	Response categories & scoring
Dizziness Handicap Inventory	To evaluate the self-perceived handicap of vestibular disease	Dizzy patients referred for vestibular testing. Age 21-82 N=63	25	3 – Yes, Sometimes, No 0=no handicap 100=significant handicap
Vertigo Symptom Scale	To quantify number & frequency of vertigo symptoms & examine the relative influence of vertigo & anxiety on distress & handicap	Patients attending neuro-otology clinic. Age 18-80 N=127	34	6 point Likert 0=never 5=very often, more than once per week
Activities-specific Balance Confidence Scale	To give a precise description of elderly people's everyday difficulties & fear of falling	Community living, self-classified as low or high mobility Age>65 N=60	16	0=no confidence 10=completely confident to perform task without losing balance
Visual Vertigo Analogue Scale	To assess feelings of dizziness in patients with peripheral or central vestibular impairment	Patients with acute unilateral peripheral vestibular loss or central vestibular dysfunction presenting to neurology or ENT clinic N=50	9	0=no dizziness 100=maximum dizziness
Quality of Vision Questionnaire	To assess quality of vision in patients who wear refractive correction, have had refractive surgery or have a disease which affects quality of vision	Age 21-78 who have refractive surgery, cataract surgery or cataracts N=900	10 symptoms, 3 scales	4 response categories each for severity, frequency & bothersomeness
Spectacle Adaptation Questionnaire	To measure spectacle adaptation problems	Age 18-87 who have had problems adapting to a new power of spectacle correction N=364	18	3 point Likert scale. Never, occasionally, most/all of the time. Scores converted to a weighted interval measure using Rasch. Higher score = more adaptation problems

6.2 Ethics approval

Ethics approval for this study was granted by the Chair of the Biomedical, Natural, Physical and Health Sciences Research Ethics Panel at the University of Bradford on 11th February 2015. NHS ethics approval was granted by NRES Committee South Central – Hampshire A on 7th September 2015, by St. James' University NHS Trust on 18th December 2015 and by Bradford Teaching Hospitals NHS Foundation Trust on 25th April 2016.

6.3 Development

The process identified by Pesudovs et al. (2007) for developing new questionnaires was followed. This is outlined in figure 6.1.

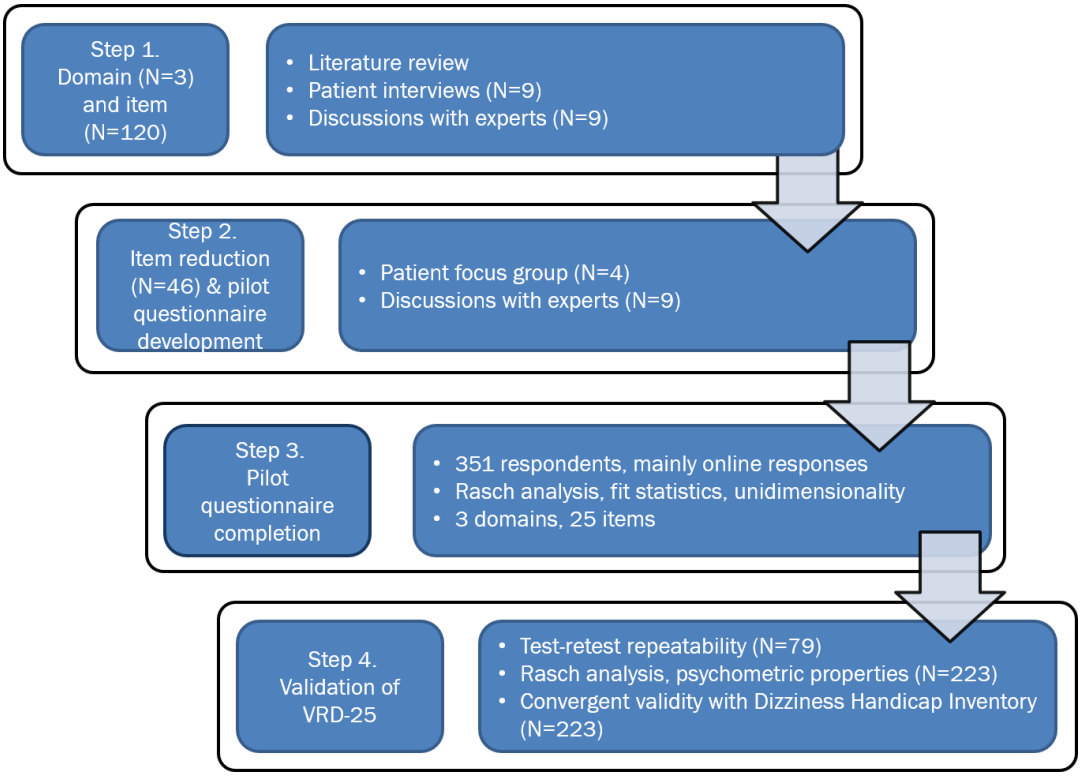


Figure 6.1 Flow chart showing a summary of the process for the development of a new questionnaire**.**

6.3.1 Literature search

The first stage in the process of developing a new instrument was to ascertain the extent to which items contained in currently available instruments were useful with regard to visually caused dizziness.

PROM's relating (separately) to visual disability, vision-related quality of life and dizziness were identified from the abstracts of papers found in the search. The questionnaires identified in the literature review (1.12.3 and 1.12.4) were examined to identify domains and items which possibly related to visually caused dizziness. Possible items were then grouped according to the type of task, for example 'recreational activities' would be grouped with 'playing sports' and 'playing with the children'. The structure of the Rasch-developed visual symptom PROM, Quality of Vision (McAlinden 2010) was incorporated into the item identification process so that each item had three subscales of 'frequency', 'severity' and 'bothersomeness' of symptoms. Response categories of 'so severe/bothersome that I have reduced doing this' and 'so sever/bothersome I have stopped doing this' were included to provide assessment of the activity limitation aspect of dizziness. Questions were worded to maintain the frequency/severity nature of the possible responses.

6.3.2 Expert and patient interviews

Patients who reported that they had problems due to dizziness (recruited from the staff of the University and patients from local falls and vision clinics) were interviewed to determine the main difficulties they experienced because of their dizziness. People were recruited and interviewed face to face until saturation of themes had been reached. Patient were asked to describe situations that induced or exacerbated their dizziness and these

circumstances were noted.

Some situations (such as ‘walking along a supermarket aisle’, ‘walking in busy, crowded areas’ and ‘using an escalator’) were identified by most patients. When no new dizziness inducing or exacerbating situations had been identified following the latest two interviews, it was presumed that saturation of themes had been reached. These patients included three people with self-reported vision-related dizziness linked to age-related cataract, multifocal spectacle lens use, large spectacle power or refractive changes plus three patients with visual vertigo. Three patients had self-reported vestibular disease only and helped differentiate between dizziness problems linked to vestibular disease and those linked to vision-related issues. This provided an overview of the key problems associated with dizziness as well as confirming that the questions found during the literature search were relevant to the experiences of dizzy people.

Nine experienced clinicians in the areas of falls (geriatric medicine and physiotherapy), ophthalmology, optometry and vestibular disease (medicine, audiology and physiotherapy) were consulted to identify any other domains and items that should be considered for inclusion.

6.3.3 Expert focus group

Opinions about the relevance and usefulness of questions were sought first by consultation with nine appropriately experienced clinicians in the areas of falls, ophthalmology, optometry and vestibular disease. Items deemed to be irrelevant, duplicate or unhelpful were discarded. Where a group of questions was asking about tasks with similar visual requirements, the task that would apply to the most number of people was chosen to represent that visual

demand situation. The resulting draft questionnaire had three categories of questions (frequency, severity and bothersomeness) following the example of past research into similar questionnaires (McAlinden et al. 2010). The expert focus group queried whether the 'bothersomeness' category was useful as they believed that if a patient thought their dizziness was bothersome, they would also rate it as severe. It was also noted that the term 'bothersomeness' was felt to be out-dated, and as a result, may not be fully understood by patients. It was decided that this should be one of the questions that the patient focus group would be asked. The definition of dizziness was another area where it was decided that the patient focus group should also be consulted before firm decision was made.

6.3.4 Information from a systematic review of the literature

The results from a systematic review of the literature (Chapter 2) suggested that the use of the description of 'light-headed' was not associated with visually caused dizziness. In view of this information, questions that related to 'light-headedness' (most often used to describe symptoms associated with postural hypotension) were removed from the draft questionnaire as they were deemed irrelevant to visually caused dizziness.

6.3.5 Patient focus group

A focus group of four patients (age range 35-79 years, two females) who reported vision-related dizziness (two with diagnosed visual vertigo and two with dizziness linked to multifocal spectacle wear) met with two researchers in attendance to discuss the draft questionnaire. These people were recruited from staff of the University and patients at the University Eye Clinic (who attended undergraduate primary care clinics regularly as volunteer patients)

and were additional to the nine patients described previously. They were asked their opinion on the points highlighted by the expert focus group, then each item was considered in turn and a decision made as to the relevance and content of that item.

6.3.6 Cognitive interviews

When a question was deemed suitable to be included in the pilot questionnaire, the focus group was asked to comment about the wording and ease of comprehension of that question and any necessary changes were made. The ‘bothersomeness’ section of the questionnaire was deemed to be redundant. The focus group felt that the term was out-dated and agreed with the experts that if a patient found their dizziness to be ‘bothersome’, they would also regard it as severe. The focus group suggested that examples of frequencies (for example ‘Occasionally (e.g. 1-2 times per month)’) should be added to the response scale to clarify exactly what each category was intended to represent. It was considered that questions concerning triggers and coping strategies for dizziness should be included in a separate questionnaire.

The resulting 46 item (consisting of 23, 2-part questions) questionnaire was the basis for the resulting pilot questionnaire. It included three domains of symptoms (17 items), activity limitation (17 items) and psychosocial issues (12 items). A five-point Likert scale for responses was used to minimise respondent burden while maximising measurement of the construct (Khadka et al. 2012) (APPENDIX D1). Question numbers and content of the item in the pilot questionnaire are detailed in table 6.2.

Table 6.2 Question numbers and content of each item in the 46-item pilot questionnaire.

Questionnaire number	Content of the item
1 f&s	Being a driver or passenger in a car
2 f&s	Watching moving traffic/trains and/or crossing roads
3 f&s	Watching moving scenes on TV or scrolling on a VDU
4 f&s	Walking alongside busy roads
5 f&s	Moving around, but OK when seated
6 f&s	Moving around the home
7 f&s	Walking down a supermarket aisle
8 f&s	Walking around obstacles
9 f&s	Walking on uneven or sloping surfaces
10 f&s	Walking up or down stairs
11 f&s	Stepping onto or off an escalator
12 f&s	Using a lift
13 f&s	Standing in a wide open space
14 f&s	Difficulties with heights
15 f&s	Difficulties with reading
16 f&s	Job or household responsibilities
17 f&s	Hand/eye coordination
18 f&s	Concentration
19 f&s	Feeling confused or disorientated
20 f&s	Feeling anxious or upset
21 f&s	Enjoyment or participation in social activities or pastimes
22 f&s	Being afraid people may think you are intoxicated
23 f&s	Being afraid to leave home on your own

6.3.7 Pilot questionnaire

As the diagnosis of dizziness is often multifactorial and difficult and many patients are unaware of whether vision is part of the aetiology of their dizziness (Colledge et al. 1996), the inclusion criteria for completion of the pilot version of the PROM comprised any patient, over the age of 18 years with self-reported dizziness in the past month. As this area of research is currently limited, a specific (and perhaps limiting) definition for ‘visually-related dizziness’ was not included. Paper versions of the questionnaire were made available to potential participants from the Falls Clinic at St. James’ Hospital, Leeds, the Vestibular Diseases and Audiology clinics at Bradford Royal Infirmary and staff and students from the University of Bradford. Informed consent was obtained from patients who completed the paper version of the

questionnaire.

In addition, an electronic version of the PROM was created using Wufoo (http://www.wufoo.com) with a description which explained that a questionnaire was being developed to quantify vision-related dizziness. It was available for completion on the Wufoo site between 4th April, 2016 and 21st June, 2016. Consent was given by the patient submitting the online PROM. The research was publicised via e-newsletters and social media to international dizziness-related support, national and international support centres for older people and a wide range of older peoples' forums and support groups in the UK. Table 6.3 presents detailed information of the sources of publicity.

Table 6.3 The methods of online publicity for the pilot version of VRD-25.

e-newsletters	e-mail invitation	Social Media
University of Bradford	National Pensioners Convention	The Vestibular Disorders Association
Optometry Today	NW regional Pensioners Association	Age UK,
The College of Optometrists	South Ribble Pensioners Association	Parkinson's support groups
The Vestibular Disorders Association	Leeds Older Peoples Forum	Migraine & Vertigo support group
	University of Bradford Staff & Students	Pensioner support services (South Africa)
		Vertigo & Menieres disease support group
		The Women's Institute, UK & Canada
		Supporting Older people - Harrogate
		Dizzy Vertigo Life
		Bradford & Keighley Pensioners Association
		Leeds Older Peoples forum

Minimum sample size was 250 as determined by 'Sample size and item calibration (or person measure) stability - found at https:// www.rasch.org/rmt/rmt74m.htm (Linacre 1994).

Supplementary information gathered included respondent age, gender, cause of dizziness, whether any treatment for dizziness was being received, coexisting medical conditions and whether the respondent had fallen in the last six months.

6.4 Rasch analysis

Rasch analysis is used to avoid the pitfalls and weaknesses of traditional questionnaire scoring methods and is the preferred method when developing new PROMs.(Pesudovs et al. 2007; Vianya-Estopa et al. 2010; Finger et al. 2012; Gothwal et al. 2015; Latham et al. 2015) When a Likert answer scale is used with a numerical value for each response and an overall instrument score is gained from adding individual item scores, it is assumed that all items have the same level of difficulty, and that the response categories are linear. Some of the problems with these assumptions can be identified using examples of items from VRD-25. It would seem logical that the activity of watching traffic at a busy junction might have more dizziness associated with it than walking down a supermarket aisle. Using the response options and scoring below:

Response	Never	Occasionally	Quite often	Very often	All the time
Score	0	1	2	3	4

It seems unlikely that responses of ‘all the time’ would be twice as troublesome as ‘quite often’ for all the various items of VRD-25.

Rasch uses probabilities to create a model of the expected association between items and respondents giving a weighting for every item and the response scale for each item, in this way it can predict the most likely response when a person with *x* amount of dizziness is asked about a task of *y* difficulty. Converting ordinal data from questionnaire responses into continuous interval data in this way allows linear measurement (Mallinson 2007) on a logit (log odds unit) scale. A logit is the logarithm of the odds or $p/(1-p)$. A linear scale

allows a useful comparison of respondent function over time, for example before and after an intervention. The model assumes that some people have more dizziness than others and that people with more dizziness symptoms will report having more dizziness. Responses from each participant to every item are ranked (items in order of difficulty and participants in order of magnitude of difficulty due to the trait being investigated) to generate an overall view of the suitability of the questionnaire to the target population. This is called the person-item map, an example of this is figure 6.2a. If items and people are largely matched in distribution with the mean scores similar, the person-item map indicates that the instrument is of suitable difficulty for that population. If there are more items towards the top of the distribution with people being towards the bottom, the questions are, on average, too difficult to give an even distribution of responses and this is termed a floor effect. A slight floor effect is demonstrated in figure 6.2a. Likewise, if items are towards the bottom and people are towards the top of the distribution, the questions in that instrument are too easy for the population. This is termed a ceiling effect. Where there are missing data or answers, Rasch gives a score for that item based on the expected score created by the model which is derived from that person's scores for other items.

Rasch produces fit statistics which allow the user to detect variations between the Rasch theoretical model and the data collected by the practitioner. If an item does not conform to the model, it is deemed mis-fitting and can be identified using the infit and outfit values generated by Rasch analysis. The difference between the observed score and the theoretical model score is termed the residual. The ideal residual is 0 and values outside ±0.75 are

considered ‘unexpected’. If the residual is low, actual and anticipated scores are similar. When assessing residual scores of an instrument, the differences are squared to remove negative values so that summing of residual scores is possible. Infit values are information (variance) weighted and are sensitive to erratic responses that do not fit the pattern identified by the model when patient ability matches item difficulty. Infit values are the more useful fit statistic because they are not as influenced by an occasional outlier. Outfit values are not information weighted and are sensitive to outliers, (unexpected response patterns) where patient ability and item difficulty differ. A value of less than 0.8 indicates a lack of variance (the responses to the item are too predictable), meaning limited measurement of the construct is given, consequently the item is somewhat redundant. Values greater than 1.20 indicate there is more variance than expected and that item is considered mis-fitting. Values of greater than 1.40 indicate a substantial misfit where responses are considerably different to the majority (Linacre 2009). Fit statistics that lie between the values of 0.6 and 1.4 are commonly used in studies that develop and validate PROMs using Rasch analysis (Vianya-Estopa et al. 2010; Bond and Fox 2013; Latham et al. 2015).

6.4.1 Response category probability curves

The response categories of an instrument can be evaluated using category probability curves, an example is figure 6.3. These identify any response categories that are over- or under-utilised and confirm whether responses are provided in a suitable order.

6.4.2 Principal components analysis (PCA)

If item responses are to be appropriately summed to provide a total score, it is a requirement that the construct must be unidimensional. PCA gives an indication of the dimensionality of a construct by examining the variance. A construct is considered to be unidimensional when the influence of the measure is removed from the data and all that is left is random 'noise'. PCA analyses the factors to investigate which one is responsible for the most variance. This is described as the 'variance explained by measures' and is the variance that is explained by item difficulties, rating scale structure and person abilities. If the variance explained by measures is >60%, the construct is estimated to be unidimensional (Linacre 2009). If variance explained by measures is <60% this is an indication that something other than the construct being measured (in this case, visually-related dizziness) is influencing patient responses (Linacre 2009; Bond and Fox 2013). 'Unexplained variance' is the term used for all other variance that remains after the influence of the measure has been removed from the data. To determine if the unexplained variance is merely random noise or something more substantial, the residuals must be analysed. This is achieved by contrasting positively loaded items with negatively loaded items and these contrasts are used to identify any other dimensions that may be present. The amount of correlated information in the variance not accounted for by the instrument is the eigenvalue. If the unexplained variance explained by the first contrast has an eigenvalue of <3.0 (this has the strength of 3 items), satisfactory unidimensionality is indicated (Linacre, 2009; Franchignoni et al. 2015), although many studies have used the more stringent eigenvalue of <2.0 (Gothwal et al. 2009; Vianya-Estopa et

al. 2010; Smith, 2002; Pseudovs et al. 2010; Latham et al. 2015) or even <1.5 (Lundström and Pesudovs 2009). If a second dimension is found, then a contrast plot (figure 6.6) is used to identify the items that contribute to this dimension and the content of these items can be examined to identify any common components that may be contributing to another dimension. This procedure is repeated to provide second, third etc. contrasts. If items in an instrument are found to have more than one dimension, the items in each dimension should be grouped together and analysed separately (Linacre 2009; Bond and Fox 2013).

6.4.3 Differential item functioning

Differential item functioning (DIF) is a test of whether responses to an item are biased by the person who is responding. It can establish whether one population answers the items of a PROM considerably differently from another, despite having the same ability for the attribute being assessed (Bond and Fox 2013), in other words, it indicates if there are unexpected responses associated with the respondent being a member of a subsample (Dorans and Holland 1992). Using VRD-25 as an example – it might examine if males exhibit different frequency or severity of dizziness for a certain task when compared with females. If all items retain their calibration irrespective of the age or gender of their respondents, then DIF does not exist for the instrument (Bond and Fox 2013). Two methods of reporting DIF are Mantle-Haenszel and Rasch-Welch.

Mantel-Haenszel requires complete data and uses the Pearson χ^2 test to compare the invariance of the responses between the two groups, to give an odds ratio for the reference and comparison groups for each item. If the odds

ratio is equal to 1, DIF is not present as this indicates that the responses to that item are similar for both groups. If the DIF odds ratio >1, this indicates that the reference group in this study experiences more dizziness, or more frequent dizziness than the comparison group. If DIF odds ratio <1, this indicates the reverse. (Lord 1980; Holland and Thayer 1986). If there are missing data, then this method requires those datasets to be deleted before DIF analysis. When Winsteps is applied to calculate DIF using the Maentel-Haenszel method, items with missing data are ranked according to their estimated responses (derived from responses to other items), so missing data is replaced by estimated responses to give a full dataset (Linacre, no date a). The Rasch-Welch method of calculating DIF uses all available data and can be used where there are incomplete data (Linacre 2015). The Rasch-Welch method has been shown to have greater reliability than the Mantel-Haenszel where comparison groups are small (n = 100 - 200) and it retains reliability when groups are large (N>300) (Schultz 1990) and it is for that reason that Rasch-Welch was used in this study.

If the Rasch-Welch DIF contrast is >0.5 logits there is a large difference in response patterns between the two groups being compared. The difference is significant if $t \geq \pm 2$ (Linacre 2009). If the DIF contrast is a positive number, then the item was found to be more difficult for the first group than the second group in the comparison. If the DIF contrast is negative, the converse is true. In the case of this study, a positive value means that the first group suffer from less severe or less frequent dizziness than the second group.

6.5 Results

351 participants completed the pilot questionnaire. The mean age was 57±14, range 20-94; 79% were female, 95% were completed online; 75% were from North America, 21% from Europe, 2% from Africa, 1% Asia and 1% Oceania. The most common self-reported causes on respondents' dizziness were vestibular. A comprehensive list of self-reported causes is presented in table 6.4. 38% had fallen in the last six months. 68% had medical problems in addition to their dizziness, the most common coexisting medical condition was depression and/or anxiety with 9.7% of participants reporting suffering from this complaint.

Table 6.4 The self-reported cause for dizziness for the respondents to the pilot questionnaire of VRD-25**.**

Cause	**Number of patients**	**%**
Vestibular / Ménières / vertigo / labrynthitis	203	58
Unknown	90	26
Visual	16	5
Brain/nerve injury/head trauma	13	4
Didn't want to say, but knew cause	10	3
Migraine/stress	7	2
Virus	5	1
Drug adverse reaction/toxicity	4	1
BP/heart probs	2	0.6
anaemia	1	0.4

6.6 Analysis

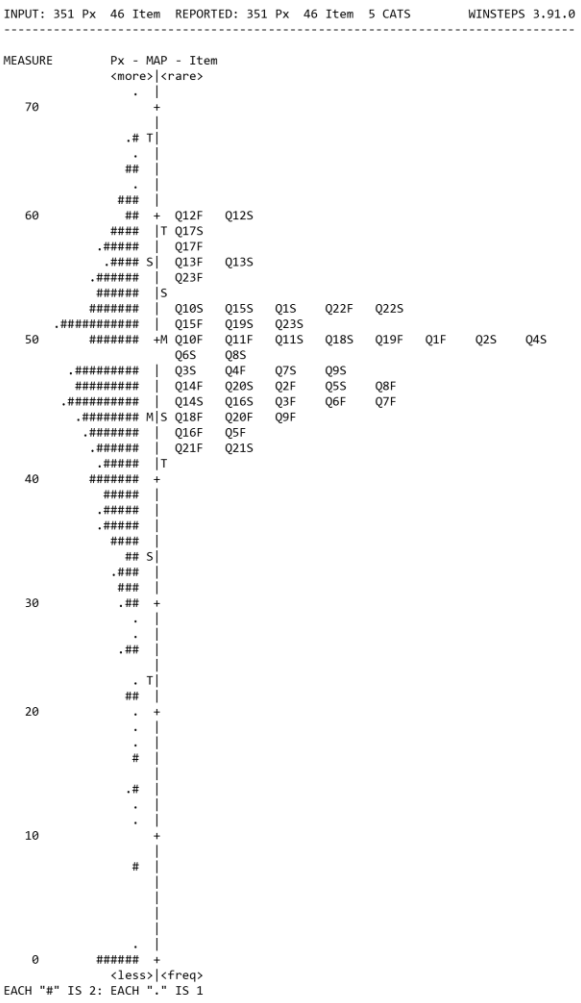
Winsteps version 3.91.0; Chicago, IL was used to analyse the data collected by the pilot study. Initial analysis of the full dataset (351 respondents) showed person separation to be very good at 3.55 (SD 1.43) (questionnaires typically aim for 2.0 and above) (Linacre 2009) with person and item separation

reliabilities of 0.93 and 0.98 respectively and a difference between the item and person means of 0.67 logits.

6.6.1 Person reduction

Each person's responses to the pilot instrument were examined and 16 sets of data were discarded as they had greater than 33% missing data, therefore were deemed incomplete (Pesudovs et al. 2004) or reported not being dizzy in the previous month. Removal of these responses improved the person separation of the instrument to 4.10 (SD 1.25) and reduced the difference between person and item means to 0.55 logits. The person-separation and item-separation reliabilities were 0.94 and 0.98 respectively.

When comparing figure 6.2a (351 patients) to figure 6.2b (335 patients), the small floor effect in figure 6.2a has been reduced by the removal of the 16 sets of inappropriate data.



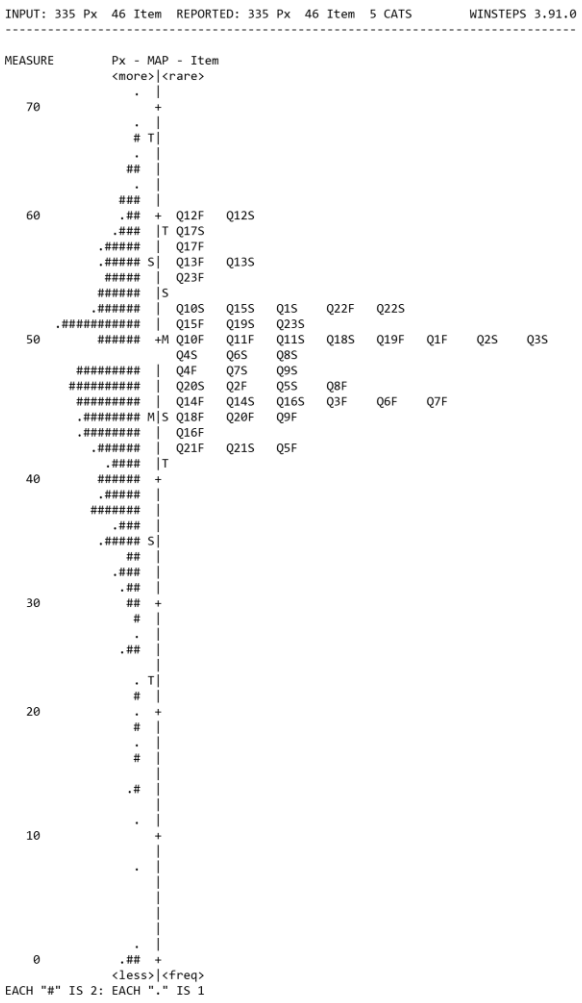


Figure 6.2a **Figure 6.2b**

Figure 6.2a Person-item map generated from the full dataset of the pilot version of VRD-25. The average positions of items are shown on the right of the dashed line as numbers with the items at the top being more rarely endorsed as they are only responded to positively by people who have high levels of dizziness. People are shown on the left of the dashed line with those who suffered from more dizziness located nearer the top of the map.

Figure 6.2b Person-item map generated from the pilot data after misfits had been removed.

6.6.2 Response category analysis

Category probability curves were generated for the response scales (Figure 6.3) from the remaining 335 responses. The x-axis represents the amount of dizziness. The category most likely to be chosen by a patient with that degree of dizziness is shown by the curve with the highest probability.

These indicated that the response categories were provided in an appropriate order, but that category three ('very often (e.g. 2-6 times per week)' or 'so severe I have reduced doing this') was being marginally under-utilised. An investigation into the effect of collapsing (or combining) categories three and four was carried out because of this finding. The category probability curves for the data with categories three and four combined are presented in figure 6.4.

Although the category probability curves for the data with collapsed categories showed a small improvement in regularity of the curves, the research team decided to retain all five categories because removing it would reduce the discriminating power for patient symptom levels and frequencies (Preston and Colman 2000; Lozano et al. 2008) and rating scales with fewer response categories have been shown to be less reliable (Preston and Colman 2000). In addition, instruments with fewer than five response categories tend to be rated unfavourably by respondents (when considering the degree to which they could express their feelings) when compared to those with five or more categories (Lozano et al 2008).

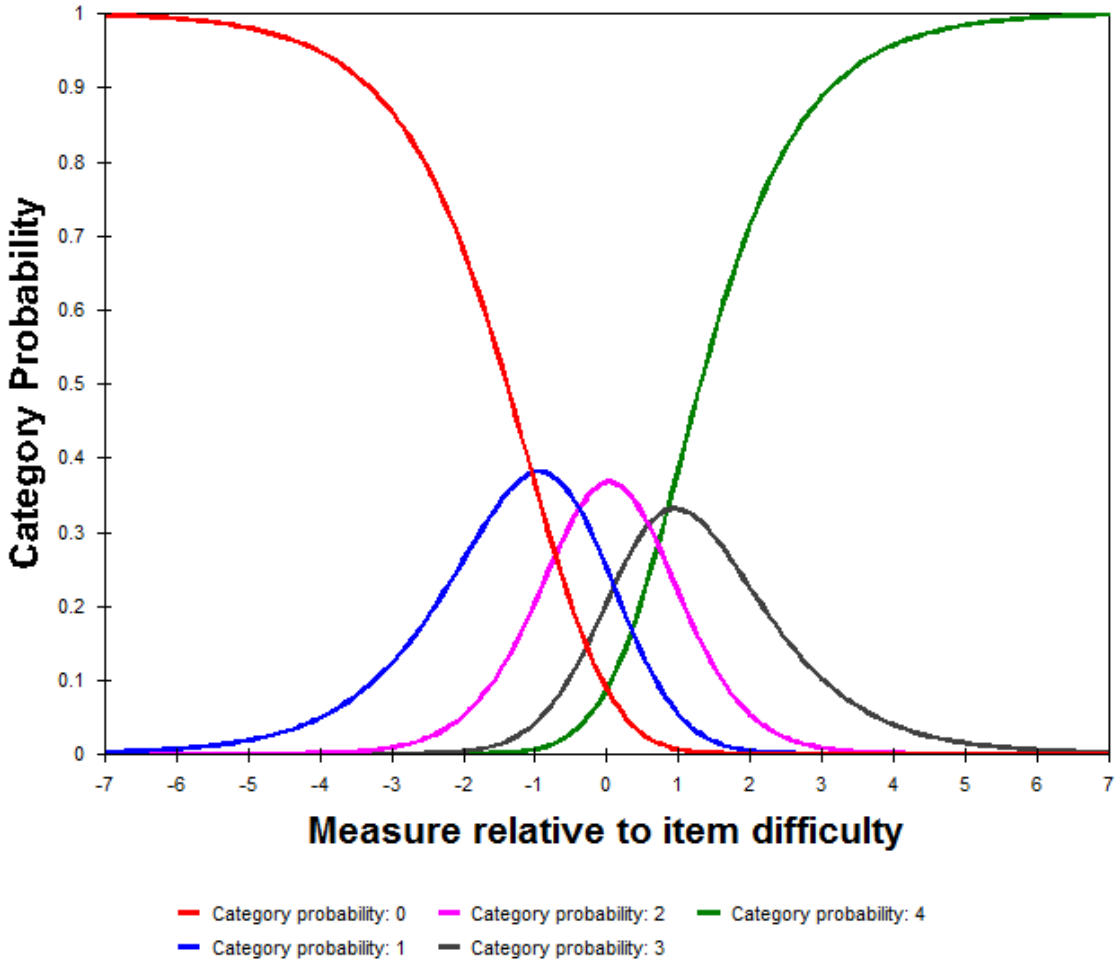


Figure 6.3 Category probability curves for the five response categories from the 335 responses to the pilot questionnaire**.**

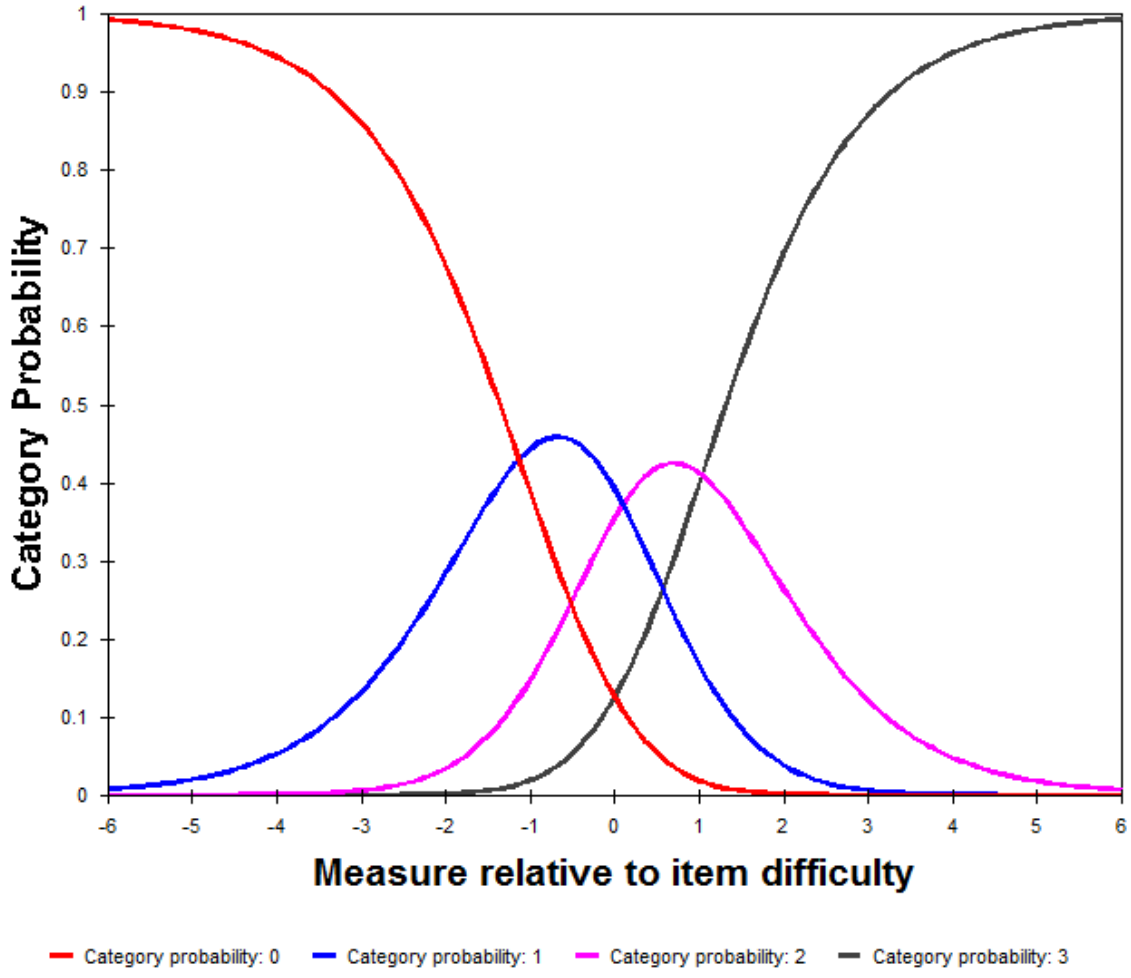


Figure 6.4 Category probability curves for the four response categories from the 335 responses to the pilot questionnaire after collapsing categories three (very often/so severe I have reduced doing this) and four (all the time/ so severe I have stopped doing this)**.**

6.6.3 Item reduction.

Redundant items increase respondent burden whilst contributing nothing to the investigation of vision-related dizziness. Individual items from the pilot data were examined in terms of their fit to the Rasch model using infit and outfit values. Items with values outside the range of 0.6-1.4 (Linacre 2009) were removed iteratively, starting with the most poorly fitting item. After each item

elimination, the model was re-analysed to identify the next mis-fitting item that was to be removed. If removal of an item adversely affected the patient or item separation, that item was reintroduced into the model and the process repeated for the next item on the misfit list. Each question of the pilot consisted of two parts (asking about frequency and severity of the dizziness experienced when undertaking a specific task). Where one of the two associated questions were removed, the other was removed (even if infit and outfit were within inclusion criteria) to investigate if that exclusion would negatively affect the model. If no negative effect resulted, the 'partner' item was also removed. Where the model was adversely affected by the removal of a 'partner' question, that part of the question was retained in the final instrument (Linacre 2016, pers. comm., 8th August).

This procedure is detailed in table 6.5 and table 6.6. The process removed twenty-one (46%) poorly fitting items to produce a final instrument consisting of twenty-five items – VRD-25.

Table 6.5 This table details the first steps taken to reduce mis-fitting items from the pilot version of VRD to produce VRD-25**.**

Step	Item(s) removed	Infit	Item separation after removal	Person separation after removal	Difference in measure (logits)	Action
1	14f	1.72	6.81	4.11	0.56	Remove 14f
2	14s	1.46	6.86	4.12	0.58	Remove 14s
3	3f	1.67	6.72	4.11	0.60	Remove 3f
4	13f	1.61	6.91	4.13	0.59	Remove 13f
5	22f	1.57	7.02	4.13	0.59	Remove 22f
6	12f	1.53	6.71	4.13	0.56	Remove 12f
7	3s	1.18, but next misfit due to other measures	6.82	4.02	0.57	Remove 3s
8	15f	1.49	6.94	4.02	0.57	Remove 15f
9	23s	1.41	7.07	4.03	0.57	Remove 23s
10	23f	1.44	7.08	4.02	0.56	Remove 23f
11	20f	1.42	7.23	3.99	0.58	Remove 20f
12	1f	1.48	7.23	3.99	0.58	Retain 1f for now
12	8s	0.55	7.17	3.94	0.57	Remove 8s
13	1f again	1.45	7.32	3.93	0.57	Remove 1f
14	17f	1.45	7.05	3.93	0.54	Remove 17f

After step 14, all items were within 0.6-1.4, so partner questions were removed (again, iteratively) with the most mis-fitting first. Step 15 resulted in item 5f mis-fitting, however 5f's removal adversely affected the model's fit, so it was retained in the analysis.

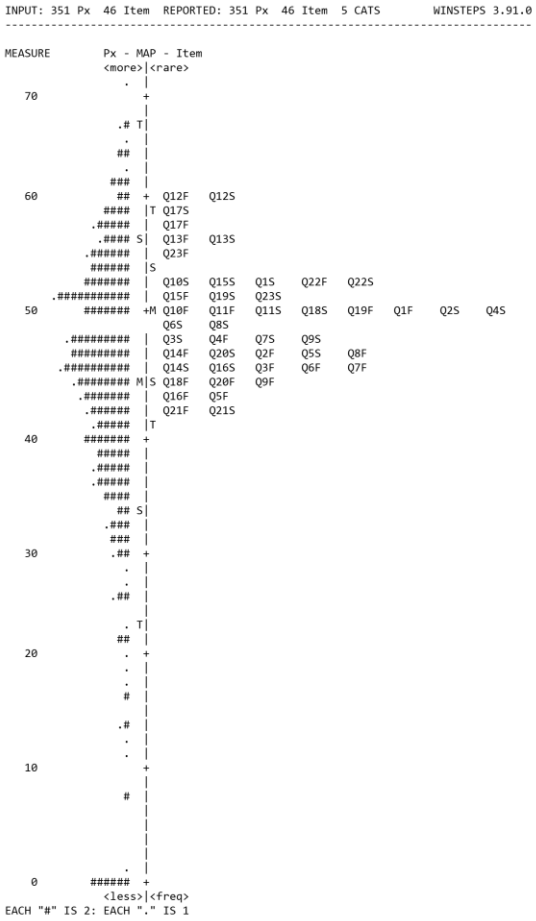
Table 6.6 This table details the continuation of the item reduction process, after all items were within 0.6-1.4 to produce the final VRD-25 instrument**.**

Step	Item(s) removed f=frequency s=severity	Infit	Item separation after removal	Person separation after removal	Difference in measure (logits)	Action
15	13s	1.27	6.88	3.92	0.53	Remove 13s
16	5f	1.42	6.78	3.89	0.55	Retain 5f for now as 5s fits well
17	22s	1.29	6.94	3.92	0.51	Remove 22s
18	12s	1.30	6.11	3.91	0.46	Remove 12s
19	15s	1.25	6.09	3.91	0.44	Remove 15s
20	20s	1.04	6.21	3.90	0.44	Remove 20s
21	8f	0.95	6.31	3.83	0.44	Remove 8f
22	17s	1.07	5.09	3.82	0.39	Retain 17s
23	1s	1.03	6.29	3.81	0.43	Remove 1s
24	17s again	1.10	4.97	3.80	0.43	Retain 17s

After step 22, all items were within 0.6-1.4 infit and outfit and the means were very close at 0.43 logits. The removal of 17s was attempted again, however effect on the item separation was unfavourable, so that item was retained in the final VRD-25 questionnaire.

The final instrument had a person separation of 3.81(SD1.46) with a difference between person and item means of 0.43 logits. The person and item separation reliabilities were 0.94 and 0.96 respectively.

The person-item maps for the pilot instrument and the final instrument are presented in figures 6.5a and b to aid comparison of the data. They show that the person-item means are closer after item reduction and the small floor effect has been reduced.



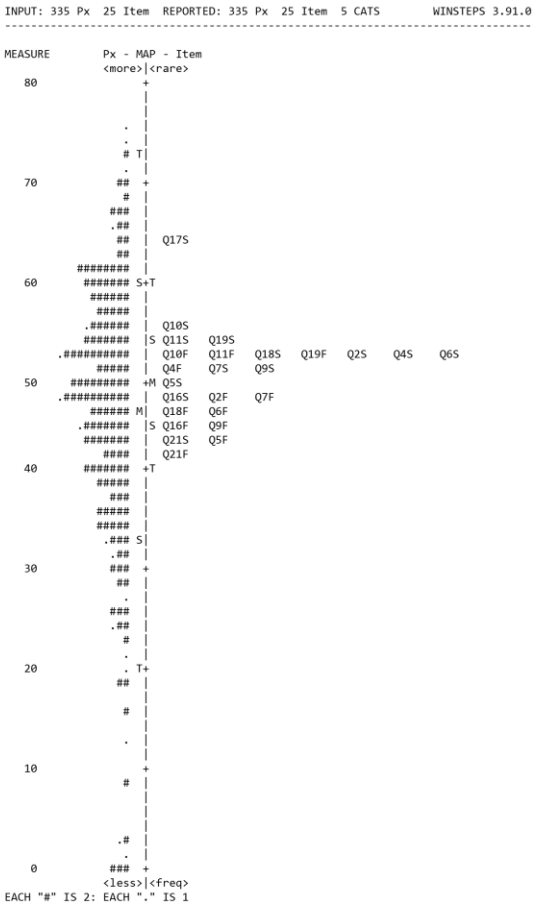


Figure 6.5a **Figure 6.5b**

Figure 6.5 The person-item maps for the pilot instrument (a) and the final VRD-25 instrument (b). Figure 6.5b shows that the person-item means are closer than before item reduction and the small floor effect has been reduced.

When this process was completed, the items were re-numbered so that the version of VRD-25 used in the validation process made sense to participants. The pilot item numbers and VRD-25 (validation study version) are shown in table 6.7

Table 6.7 Pilot item numbers and equivalent VRD-25 (validation study version) item numbers**.**

Pilot item number	**VRD-25 (validation study version) item number and content**
2 f&s	1 f&s watching moving traffic/trains/crossing roads
4 f&s	2 f&s walking alongside a busy road
5 f&s	3 f&s problems moving around but OK when seated
6 f&s	4 f&s moving around the home
7 f&s	5 f&s walking down a supermarket aisle
9 f&s	6 f&s walking on uneven or sloping surfaces
10 f&s	7 f&s walking up or down stairs
11 f&s	8 f&s stepping onto or of an escalator
16 f&s	9 f&s job or household responsibilities
17 s	10 s hand/eye coordination
18 f&s	11 f&s concentration
19 f&s	12 f&s feeling confused/disorientated
21 f&s	13 f&s social activities, sports & pastimes,

6.6.4 Principal components analysis

Principal components analysis indicated that the data were not unidimensional, with 56.6% of raw variance explained by the measure. The eigenvalues are presented below.

Raw unexplained variance	1st contrast eigenvalue	3.21
	2nd contrast eigenvalue	2.77
	3rd contrast eigenvalue	2.38
	4th contrast eigenvalue	1.96
	5th contrast eigenvalue	1.73

The first contrast was above the cut-off value of 3 (Linacre 2009; Franchignoni et al. 2015) indicating that more than one construct was being measured by the instrument. The item map for the analysis is shown in figure 6.6. The item map showed that there was no clear, common factor to explain the split between questions. The contrast plot showed that the questions loading most heavily onto the first contrast (>0.40 eigenunits) were:

- 2f, Do you have problems walking alongside a busy road because of your dizziness?
- 8f, Do you have difficulty stepping onto or off an escalator because of your dizziness?
- 6f, Does your dizziness make it difficult to walk on uneven or sloping surfaces?
- 7f, Is it difficult for you to walk up or down stairs because of your dizziness?
- 8s, How severe is the dizziness that you experience when you are using an escalator?
- 2s, How severe is the dizziness that you experience when you are walking alongside a busy road?

Al these situations involve locomotion, however other items that also involve locomotion, for example 3s – How severe is the dizziness that you experience when you are moving around (but OK when seated)? And 4f – How severe is the dizziness that you experience when you are moving around your home? Show negative loadings of -0.40 and -0.37 respectively, indicating that locomotion may not a rational way to divide the questions. The loading, measure, infit mean square and outfit mean square values shown in table 6.8.

Infit and outfit values for the VRD-25 items were all within 0.6-1.4. The logical way for the data to be split was by questions relating to frequency and severity. The data were split in this way and the two subscales re-analysed.

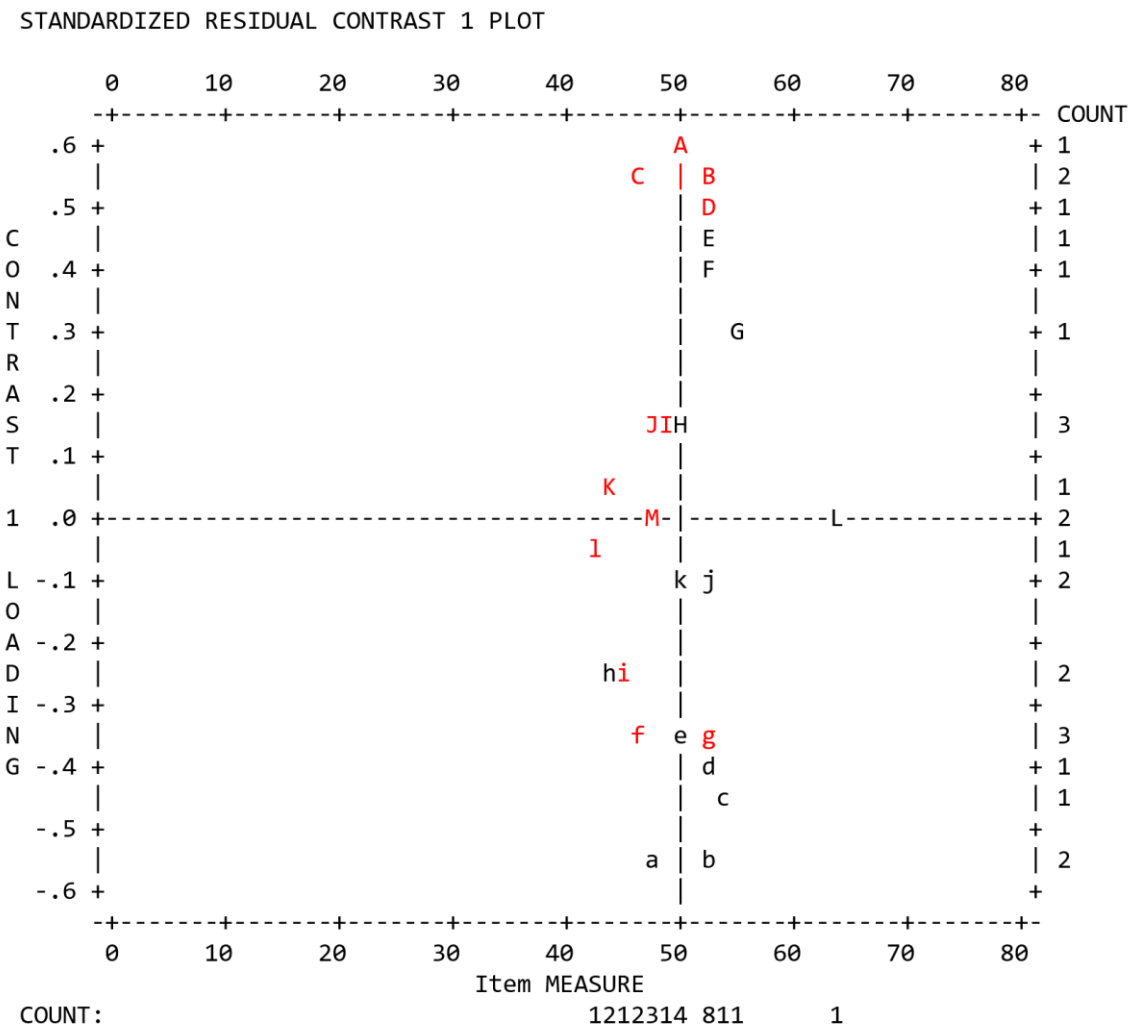


Figure 6.6 Standardised residual data plot for VRD-25. Frequency items are in red. Letter codes are explained in table 6.8.

Table 6.8 Letter codes, item content and fit statistics for the standardised residual contrast plot for VRD-25**.**

Map code	Item number	Content	Infit MNSQ	Outfit MNSQ	Loading	Measure
A	2f	Walking alongside a busy road	1.19	1.13	1.58	50.6
B	8f	Stepping onto or off an escalator	1.25	1.13	0.56	52.9
C	6f	Walking on uneven or sloping surfaces	0.96	0.88	0.53	45.7
D	7f	Walking up or down stairs	1.28	1.20	0.51	52.5
E	8s	Stepping onto or off an escalator	1.01	0.94	0.43	53.0
F	2s	Walking alongside a busy road	0.84	0.88	0.41	52.3
G	7s	Walking up or down stairs	0.73	0.79	0.31	55.3
H	6s	Walking on uneven or sloping surfaces	0.64	0.62	0.17	50.2
I	1f	Watching moving traffic/trains/crossing roads	1.28	1.23	0.15	48.5
J	5f	Walking down a supermarket aisle	1.22	1.12	0.15	47.6
K	3f	Problems moving around but okay when seated	1.38	1.30	0.03	43.8
L	10s	Hand/eye coordination	1.07	1.11	-0.02	63.7
M	4f	Moving around the home	1.20	1.16	-0.02	47.0
a	9s	Job or household responsibilities	0.75	0.79	-0.56	47.4
b	11s	Concentration	0.73	0.78	-0.55	51.9
c	12s	Feeling confused/disorientated	0.82	0.90	-0.45	53.6
d	4s	Moving around the home	0.67	0.86	-0.40	51.9
e	3s	Problems moving around but okay when seated	0.66	0.92	-0.37	49.5
f	11f	Concentration	1.06	0.99	-0.34	46.8
g	12f	Feeling confused/disorientated	1.21	1.15	-0.33	52.3
h	13s	Social activities, sports & pastimes	1.00	0.99	-0.24	43.7
i	9f	Job or household responsibilities	1.04	0.97	-0.23	45.1
j	1s	Watching moving traffic/trains/crossing roads	0.87	1.04	-0.10	52.0
k	5s	Walking down a supermarket aisle	0.79	0.77	-0.09	50.3
l	13s	Social activities, sports & pastimes	1.12	1.01	-0.06	42.5

When the frequency items alone were considered, and the responses analysed by Winsteps, the patient separation was 2.65 (SD 1.72) and the item separation was 4.69 (SD 0.30) with reliabilities of 0.88 and 0.96 respectively. Raw variance explained by the measure was 57.6%. The unexplained variance values are presented below:

Raw unexplained variance	1st contrast eigenvalue	1.92
	2nd contrast eigenvalue	1.72
	3rd contrast eigenvalue	1.53
	4th contrast eigenvalue	1.11
	5th contrast eigenvalue	1.03

All eigenvalues were <3 and also below the more stringent value of <2 which has been used in many studies (Smith 2002; Gothwal et al. 2009; Pesudovs et al. 2010; Vianya-Estopa et al. 2010; Latham et al. 2015) indicating that these factors were not significant, and the scale was unidimensional. The

standardised residual plot is shown in (figure 6.7).

The contrast plot showed that there were two questions loading most heavily onto the first contrast (>0.40 eigenunits). These were:

- 7f - 7f, Is it difficult for you to walk up or down stairs because of your dizziness?
- 6f, Does your dizziness make it difficult to walk on uneven or sloping surfaces?

The common factor linking these two questions is locomotion, however, other questions that also involve locomotion were included in the subscale that had lighter or negative loadings, indicating again that this would not be a logical way to divide the questions.

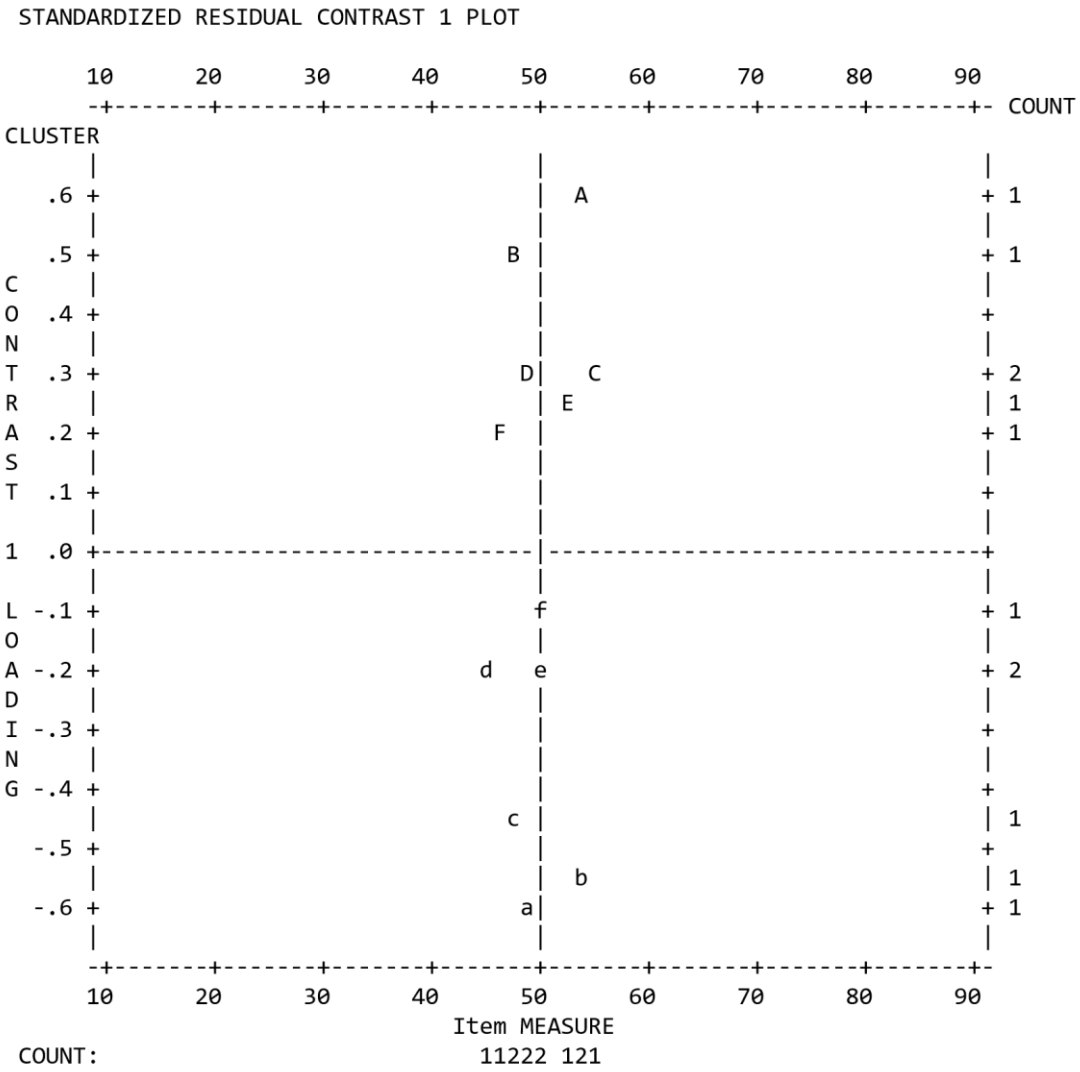


Figure 6.7 Standardised residual data plot for VRD-12f. The items are reasonably spread and close to the centre of the item measure. Letter codes are explained in table 6.9.

Table 6.9 Letter codes, and fit statistics for the standardised residual contrast plot for VRD-12f**.**

Map code	Item number	content	Infit MNSQ	Outfit MNSQ	Loading	Measure
A	7f	Walking up or down stairs	1.07	1.04	0.62	54.2
B	6f	Walking on uneven or sloping surfaces	0.75	0.70	0.52	47.8
C	8f	Stepping onto or off an escalator	1.17	1.03	0.32	54.6
D	4f	Moving around the home	0.97	10.5	0.30	49.2
E	2f	Walking alongside a busy road	0.98	0.98	0.27	52.5
F	3f	Problems moving around but OK when seated	1.06	1.20	0.20	46.3
a	11f	Concentration	0.93	0.93	-0.60	49.0
b	12f	Feeling confused/disorientated	1.19	1.13	-0.53	54.0
c	9f	Job or household responsibilities	0.89	0.83	-0.46	47.4
d	13f	Social activities, sports & pastimes	0.94	0.89	-0.19	45.0
e	1f	Watching moving traffic/trains/crossing roads	1.10	1.11	-0.18	50.5
f	5f	Walking down a supermarket aisle	1.02	1.03	-0.11	49.7

When the severity items were considered separately, patient separation was 3.07 (SD 1.66) and item separation was 7.14 (SD 0.53) with reliabilities being 0.90 and 0.98 respectively. Raw variance explained by the measure was 58.9% with the eigen values as below:

Raw unexplained variance	1st contrast eigenvalue	1.91
	2nd contrast eigenvalue	1.66
	3rd contrast eigenvalue	1.56
	4th contrast eigenvalue	1.42
	5th contrast eigenvalue	1.02

Again, all eigenvalues were <2 indicating the scale was unidimensional. The item map was very good (figure 6.8) with only a slight floor effect. The infit and outfit values for the severity scale were within 0.6-1.4.

Again, there were two items that showed a loading of >0.40 eigenunits on the residual plot. These were:

> 4s, How severe is the dizziness that you experience when you are moving around your home?

3s, How severe is the dizziness that you experience when you are moving around?

These two questions both involve moving around or locomotion however, other questions that also involve locomotion were included in the subscale that had lighter or negative loadings, indicating once again that this would not be a logical way to divide the questions.

-

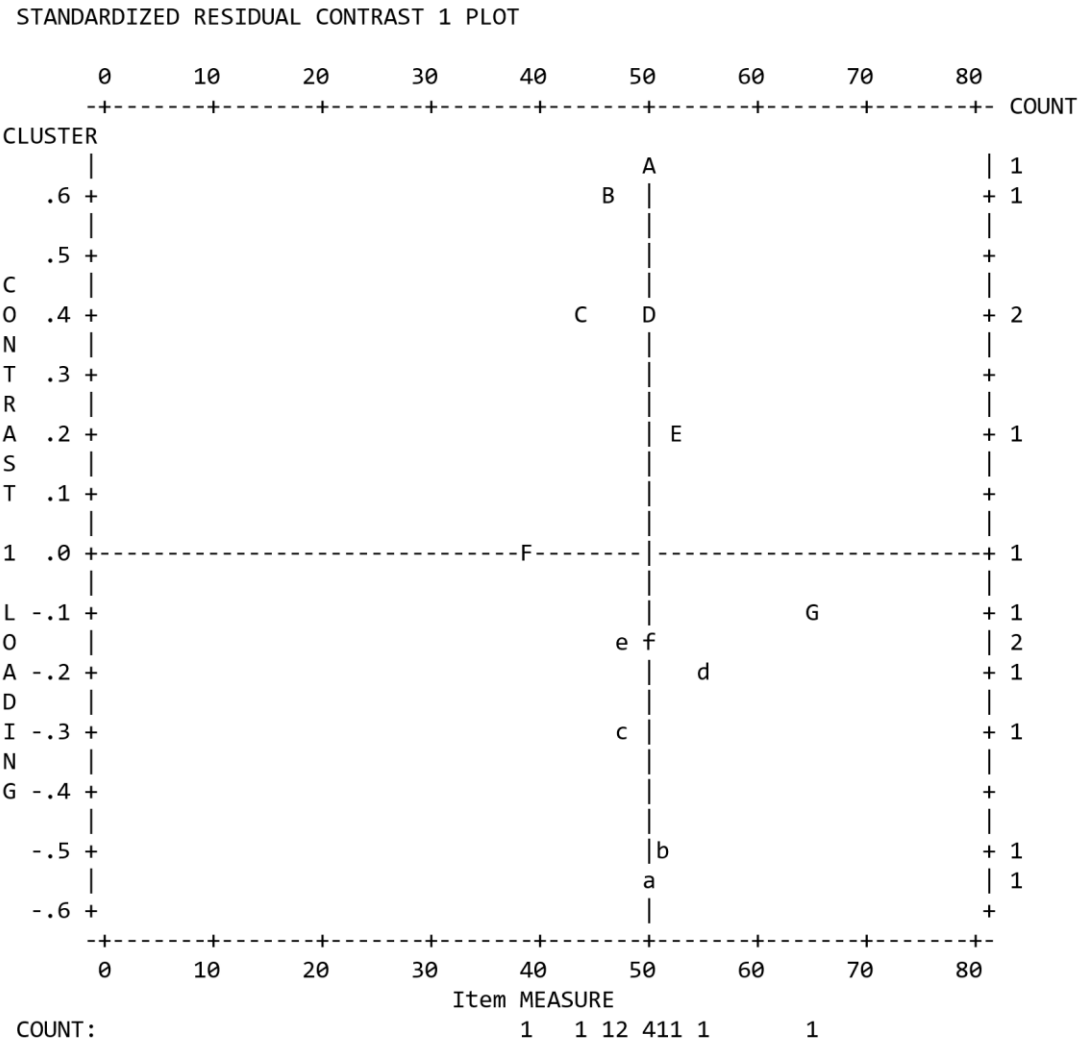


Figure 6.8 Standardised residual data plot for VRD-12s. The items are reasonably spread and close to the centre of the item measure, although not as close as the items in VRD-12f. Letter codes are explained in table 6.10

Table 6.10 Letter codes, and fit statistics for the standardised residual contrast plot for VRD-13s.

Map code	Item number	content	Infit MNSQ	Outfit MNSQ	Loading	Measure
A	4s	Moving around the home	0.73	0.77	0.64	50.2
B	3s	Problems moving around but OK when seated	0.73	0.77	0.60	46.8
C	9s	Job or household responsibilities	0.90	0.89	0.40	44.0
D	11s	Concentration	0.81	0.78	0.38	50.1
E	12s	Feeling confused/disorientated	0.91	0.96	0.21	52.4
F	13s	Social activities, sports & pastimes	1.34	1.30	-0.02	68.8
G	10s	Hand/eye coordination	1.21	1.23	-0.10	65.2
a	2s	Walking alongside a busy road	1.18	1.18	-0.57	50.4
b	8s	Stepping onto or off an escalator	1.26	1.19	-0.52	51.8
c	6s	Walking on uneven or sloping surfaces	0.80	0.79	-0.03	49.9
d	7s	Walking up or down stairs	0.91	0.90	-0.22	54.6
e	5s	Walking down a supermarket aisle	1.07	1.03	-0.17	47.8
f	1s	Watching moving traffic/trains/crossing roads	1.11	1.14	-0.14	50.2

The data from the PCA suggested that use of all the data of VRD-25 would give an indication of a patients' overall dizziness, however for more diagnostic accuracy, the data should be split into VRD-12f and VRD-13s.

An alternative way of splitting the VRD-25 would have been to use the three domains of activity limitation, symptoms and psychosocial mentioned in 6.3.6. This analysis was undertaken to investigate how dividing VRD-25 into three domains would affect the unidimensionality of the subscales.

All three subscales showed infit values within the acceptable values of 0.6-1.4.

Person and item separation for the three subscales remained good as presented in table 6.11

Table 6.11 Person and item separation and reliabilities for the three subscales of Activity limitation, Symptoms and Psychosocial**.**

	Activity limitation	Symptoms	Psychosocial
Patient separation	2.37	2.69	2.41
Patient reliability	0.85	0.88	0.85
Item separation	4.13	6.28	7.11
Item reliability	0.94	0.98	0.98

Raw variance explained by measures was close to the 60% value that indicates scale unidimensionality (Linacre 2009) for the activity limitation and symptoms subscales. For the psychosocial subscale, raw variance explained by measures was above the 60% value indicating scale unidimensionality. The unexplained variance explained by the first contrast for the activity limitation and symptoms subscales was less than two eigenvalues indicating that satisfactory unidimensionality was present (Gothwal et al. 2009; Vianya-Estopa et al. 2010; Smith, 2002 and Pseudovs et al. 2010; Latham et al. 2015). These data are presented in table 6.12

Table 6.12 Explained and unexplained variance in measures for the three subscales of activity limitation, symptoms and psychosocial**.**

	Activity limitation	Symptoms	Psychosocial
Raw variance explained by measures (%)	58.7	58.7	64.7
1st contrast eigenvalue	1.77	1.93	2.08
2nd contrast eigenvalue	1.69	1.69	1.83
3rd contrast eigenvalue	1.23	1.25	1.01
4th contrast eigenvalue	1.01	1.07	0.61
5th contrast eigenvalue	0.95	1.01	0.45

Although the PCA indicated unidimensionality for each of the three sub-scales Residual contrast plots for activity limitation and symptoms showed a split

between questions 3 and 4 and the rest of the items (figures 6.10 and 6.11), with these two items loading most heavily for both subscales, indicating that these items may load on a lightly different factor than the rest. This may have been because both questions used the term ‘moving around’. (tables 6.13 and 6.14).

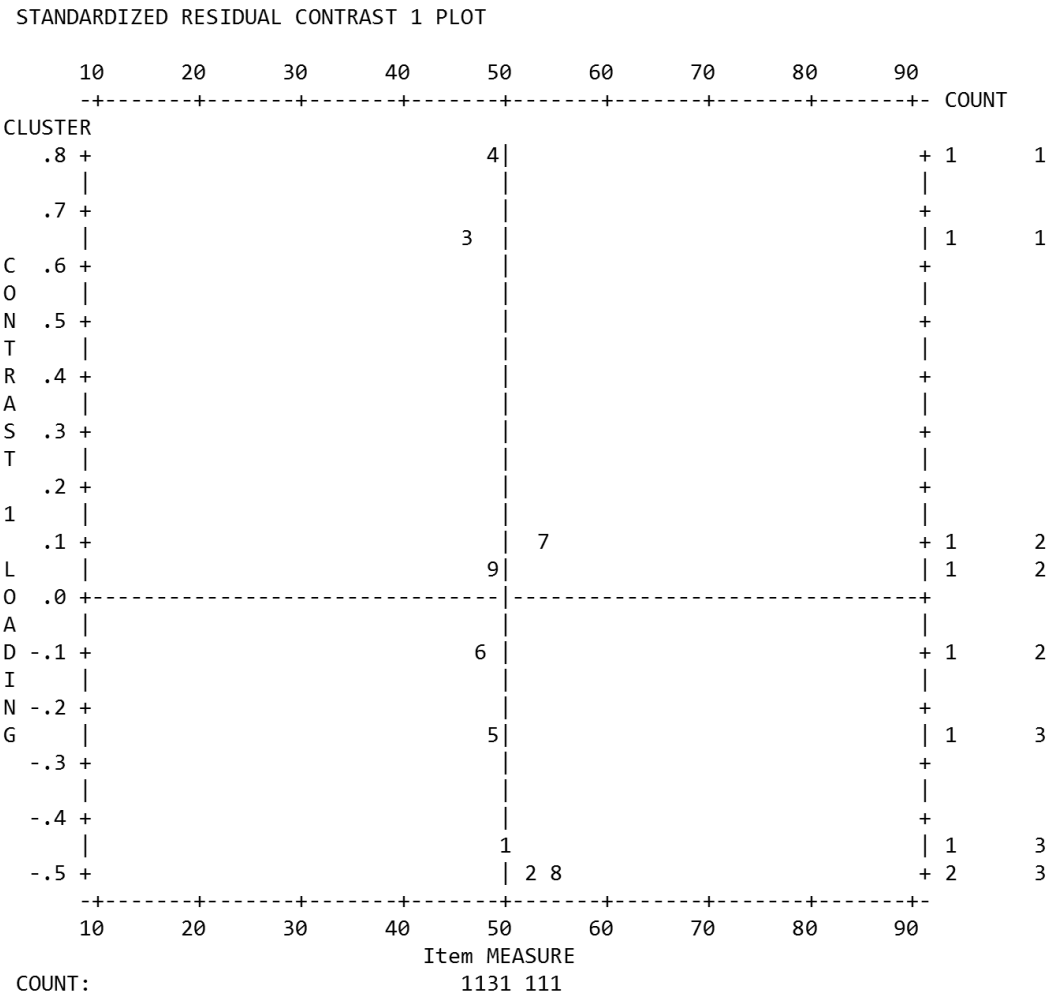


Figure 6.9 Residual contrast plot for the activity limitation domain.

Table 6.13 Letter codes, item content and fit statistics for the standardised residual contrast plot for the activity limitation domain**.**

Map code	Item number	Content	Infit MNSQ	Outfit MNSQ	Loading	Measure
4	4f	Moving around the home	0.95	1.03	0.78	48.70
3	3f	Problems moving around but OK when seated	1.04	1.16	0.65	45.67
7	7f	Walking up or down stairs	1.00	0.94	0.12	53.94
9	11f	Concentration	1.12	1.17	0.07	48.48
2	2f	Walking alongside a busy road	0.92	0.90	-0.48	52.22
8	8f	Stepping onto or off an escalator	1.16	1.02	-0.48	54.41
1	1f	Watching moving traffic/trains/crossing roads	1.13	1.12	-0.44	50.04
5	5f	Walking down a supermarket aisle	1.04	1.02	-0.24	49.23
6	6f	Walking on uneven or sloping surfaces	0.72	0.67	-0.11	47.30

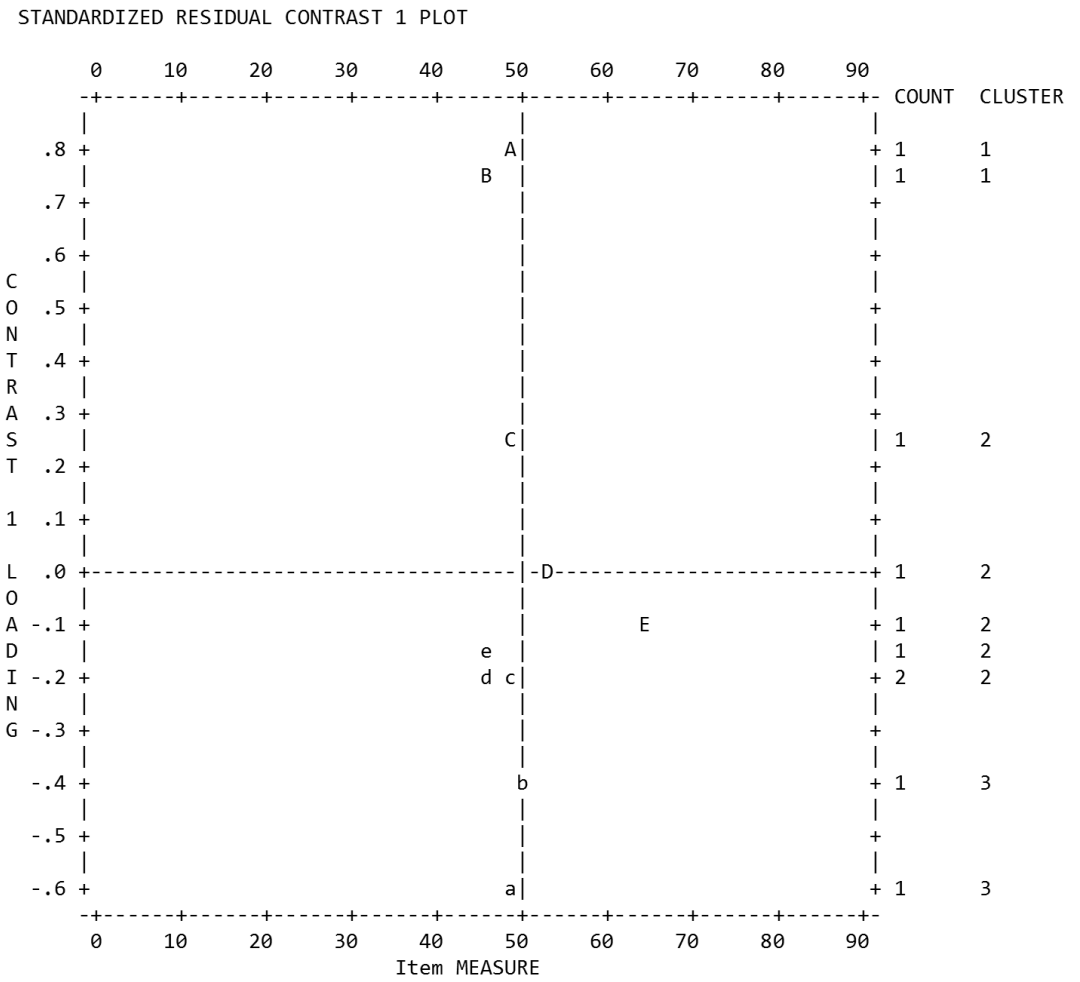


Figure 6.10 Residual contrast plot for the symptoms domain.

Table 6.14 Letter codes, item content and fit statistics for the standardised residual contrast plot for the symptoms domain**.**

Map code	Item number	Content	Infit MNSQ	Outfit MNSQ	Loading	Measure
A	4s	Moving around the home	0.75	0.77	0.82	48.66
B	3s	Problems moving around but OK when seated	0.74	0.78	0.75	45.05
C	11s	Concentration	0.94	0.91	0.25	48.56
a	2s	Walking alongside a busy road	1.15	1.14	-0.59	48.79
b	8s	Stepping onto or off an escalator	1.23	1.18	-0.42	50.25
c	1s	Watching moving traffic/trains/crossing roads	1.12	1.12	-0.20	48.63
d	5s	Walking down a supermarket aisle	1.11	1.09	-0.20	46.15
e	6s	Walking on uneven or sloping surfaces	0.85	0.84	-0.15	46.22
E	10s	Hand/eye coordination	1.21	1.23	-0.08	64.43
D	7s	Walking up or down stairs	0.88	0.84	-0.02	53.28

The residual contrast plot for the psychosocial scale (figure 6.12) also showed two items (questions 12f and 12s) loading more heavily than the other items indicating that these items may be loading on a slightly different factor to the rest (table 6.15). These items focussed on anxiety whereas the other items in the subscale focussed more on social activities.

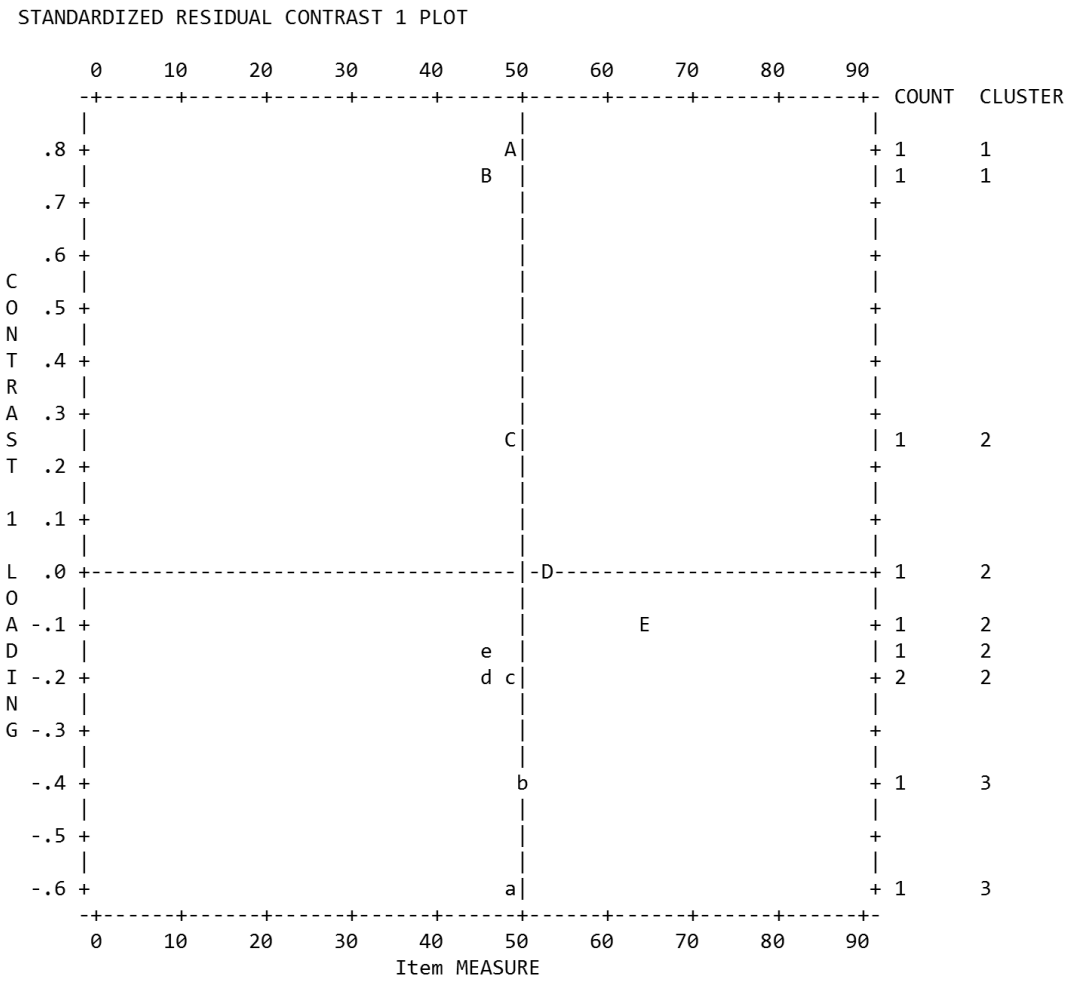


Figure 6.11 Residual contrast plot for the psychosocial domain.

Table 6.15 Letter codes, item content and fit statistics for the standardised residual contrast plot for the symptoms domain**.**

Map code	Item number	Content	Infit MNSQ	Outfit MNSQ	Loading	Measure
3	12f	Feeling confused/disorientated	1.16	1.16	0.81	56.23
4	12s	Feeling confused/disorientated	0.86	0.97	0.80	58.09
5	13f	Social activities, sports & pastimes	1.13	1.04	-0.60	43.59
6	13s	Social activities, sports & pastimes	0.90	0.92	-0.59	45.19
1	9f	Job or household responsibilities	1.10	1.01	-0.21	46.93
2	9s	Job or household responsibilities	0.71	0.76	-0.16	49.98

The use of two subscales rather than three was decided upon due the three scales having items that appeared to load on a different factor to the rest and because the two-scale split seemed more logical and user friendly.

Many of the frequency and severity questions demonstrated similar difficulties when viewed on the person - item map (figure 6.5b). Therefore, convergent validity of the scales was assessed. A Komolgorov-Smirnov test was performed using SPSS statistics for Windows (version 23.0; Armonk, NY:IBM Corp) to determine normality for each of the two Rasch analysed scales. These showed that the frequency scale data were normal (ρ=0.084) but the severity scale data were not (ρ=0.049). Spearman's rho was 0.915 (ρ<0.05) indicating a high level of correlation between the scales. The correlation coefficient may have been affected by the wide range of scores for the scales since a higher variability in scores gives a higher correlation coefficient (Haegerstrom-Portnoy et al. 2000). In addition, a high correlation between measures cannot be used to predict correlation for an individual for the frequency and severity scales, since a person may suffer infrequently from high levels of dizziness or from frequent low-level dizziness. Both sets of questions were retained since removing one of the scales would have eliminated the ability of the instrument to discriminate between people with different aspects of dizziness.

6.6.5 Differential item functioning

DIF was analysed for age and gender and location of the participant to investigate if these factors had any influence on the way people answered each question.

6.6.5.1 DIF for age

First, the respondent data were split into older people - those above the median age of 57 years, and younger people – those of 57 years or younger. This resulted in 175 people in the older age group and 160 in the younger age group. Although there were many items where the DIF contrast was >0.50, none of these had a t -value of ≥±2, indicating the DIF contrasts were not significant (section 6.5.3). DIF contrast and significance values are presented in table 6.16.

Table 6.16 DIF (age) contrast and significance values for each item in VRD-25. Group A represents people of ≤57 years and group (B) represents people of ≥58 years.

Item number	Content	Group A DIF measure	Group B DIF measure	DIF contrast	Significance (t)
1f	Watching moving traffic etc.	48.9	48.2	0.65	0.50
1s	Watching moving traffic etc.	52.2	52.0	0.23	0.17
2f	Walking alongside a busy road	59.6	51.5	-1.95	-1.42
2s	Walking alongside a busy road	51.4	53.1	-1.78	-1.28
3f	Problems moving, OK seated	44.3	43.5	0.72	0.56
3s	Problems moving, OK seated	49.4	49.4	0.00	0.00
4f	Moving around the home	47.3	17.1	0.22	0.17
4s	Moving around the home	52.6	51.3	1.25	0.96
5f	Supermarket aisle	47.6	47.6	0.00	0.00
5s	Supermarket aisle	49.6	50.9	-1.29	--1.00
6f	Uneven/sloping surfaces	45.2	46.0	-0.83	-0.64
6s	Uneven/sloping surfaces	50.9	49.6	1.25	0.97
7f	Walking up or down stairs	52.5	52.5	0.00	0.00
7s	Walking up or down stairs	55.8	54.8	0.92	0.68
8f	Onto/off and escalator	51.6	54.2	-2.62	-1.88
8s	Onto/off and escalator	52.0	54.0	-1.94	-1.40
9f	Job/household responsibilities	45.5	44.7	0.74	0.58
9s	Job/household responsibilities	48.2	46.8	1.37	1.07
10s	Hand/eye coordination	63.4	63.9	-0.54	-0.35
11f	Concentration	47.2	46.5	0.73	0.57
11s	Concentration	51.6	52.1	-0.47	-0.37
12f	Confused/disorientated	51.7	52.7	-1.09	-0.83
12s	Confused/disorientated	52.8	54.3	-1.50	-1.14
13f	Social activities etc.	43.6	41.5	2.11	1.64
13s	Social activities etc.	44.8	42.8	2.01	1.56

A DIF plot was generated by Winsteps which provides an easily readable interpretation of the DIF contrast for each item (figure 6.13).

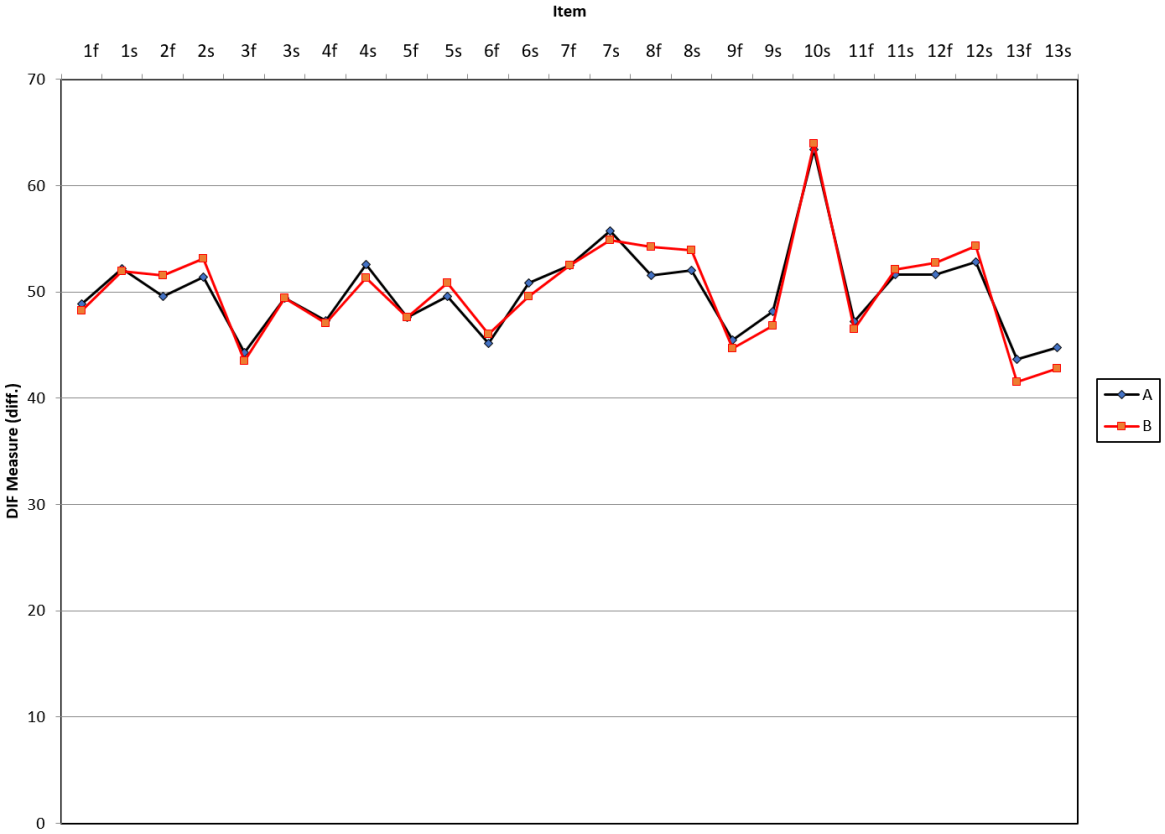


Figure 6.12 DIF measure for each item of VRD-25 for age. The blue line (A) represents people of ≤57 years and the red line (B) represents people of ≥58 years.

6.6.5.2 DIF for gender

When respondent data were split by gender, there were 266 females, 67 males and 2 preferred not to say.

DIF contrast and significance values are presented in table 6.17.

Table 6.17 DIF contrast and significance values for each item in VRD-25 for females versus males. The questions that showed significant DIF contrasts are highlighted in red.

Item number	Content	Females DIF measure	Males DIF measure	DIF contrast	Significance (t)
1f	Watching moving traffic etc.	48.0	50.7	-2.63	-1.55
1s	Watching moving traffic etc.	51.5	54.2	-1.70	-1.56
2f	Walking alongside a busy road	50.6	51.2	-0.65	-0.38
2s	Walking alongside a busy road	52.3	52.7	-0.46	-0.26
3f	Problems moving, OK seated	44.4	41.6	2.87	1.76
3s	Problems moving, OK seated	49.9	47.5	2.35	1.47
4f	Moving around the home	47.9	43.6	4.35	2.70
4s	Moving around the home	52.2	50.9	1.32	0.81
5f	Supermarket aisle	47.8	46.7	1.14	0.71
5s	Supermarket aisle	50.3	50.8	-0.58	-0.35
6f	Uneven/sloping surfaces	45.9	44.7	1.18	0.72
6s	Uneven/sloping surfaces	49.8	51.9	-2.14	-1.32
7f	Walking up or down stairs	52.9	50.7	2.28	1.38
7s	Walking up or down stairs	55.3	55.3	0.00	0.00
8f	Onto/off and escalator	52.6	54.5	-1.93	-1.11
8s	Onto/off and escalator	52.0	57.3	-5.26	-2.91
9f	Job/household responsibilities	45.1	44.8	0.31	0.19
9s	Job/household responsibilities	47.8	46.0	1.70	1.05
10s	Hand/eye coordination	64.3	61.0	3.35	1.78
11f	Concentration	47.2	45.4	1.74	1.08
11s	Concentration	51.9	51.9	0.00	0.00
12f	Confused/disorientated	52.0	53.4	-1.48	-0.90
12s	Confused/disorientated	53.6	54.2	-0.52	-0.31
13f	Social activities etc.	42.3	43.5	-1.22	-0.75
13s	Social activities etc.	43.0	46.7	-3.73	-2.30

There were three questions that showed DIF for gender:

4f – DIF contrast shows that males were more likely to have a greater frequency of dizziness when moving around their home. Perhaps this is when males are more likely to notice their dizziness, or females may be less anxious than males when in their home so notice their dizziness less frequently. When DIF for gender was carried out on the same question using the data collected in the validation study (Chapter 7), this item did not show DIF, suggesting that this may be a chance, non-repeatable finding.

8s – DIF contrast shows that females were more likely to have a greater

severity of dizziness symptoms than males when stepping on to or off an escalator. This may be because females are likely to be more anxious about their dizziness and situations (such as using an escalator) that may trigger dizziness than males (Armstrong and Khawaja 2002; Asher et al. 2017). This was demonstrated to be a repeatable finding when DIF was investigated using the data collected during the validation study (Chapter 7).

13s – DIF contrast shows that females were more likely to have a greater severity of dizziness symptoms than males when dizziness interfered with their ability to enjoy or participate in social activities, sports or pastimes. This may be due to females being more subject to anxiety (Armstrong and Khawaja 2002; Asher et al. 2017) and having more concern associated with the consequences of their dizziness in social situations than males (Armstrong and Khawaja 2002; Asher et al. 2017), however, this was a non-repeatable finding when DIF was carried out on the validation data (Chapter 7), suggesting that this may be a chance finding.

The DIF plot for gender (figure 6.14) shows where the DIF contrast is highest by the position of the plot lines. The items that have the greatest DIF contrast have the two lines furthest apart.

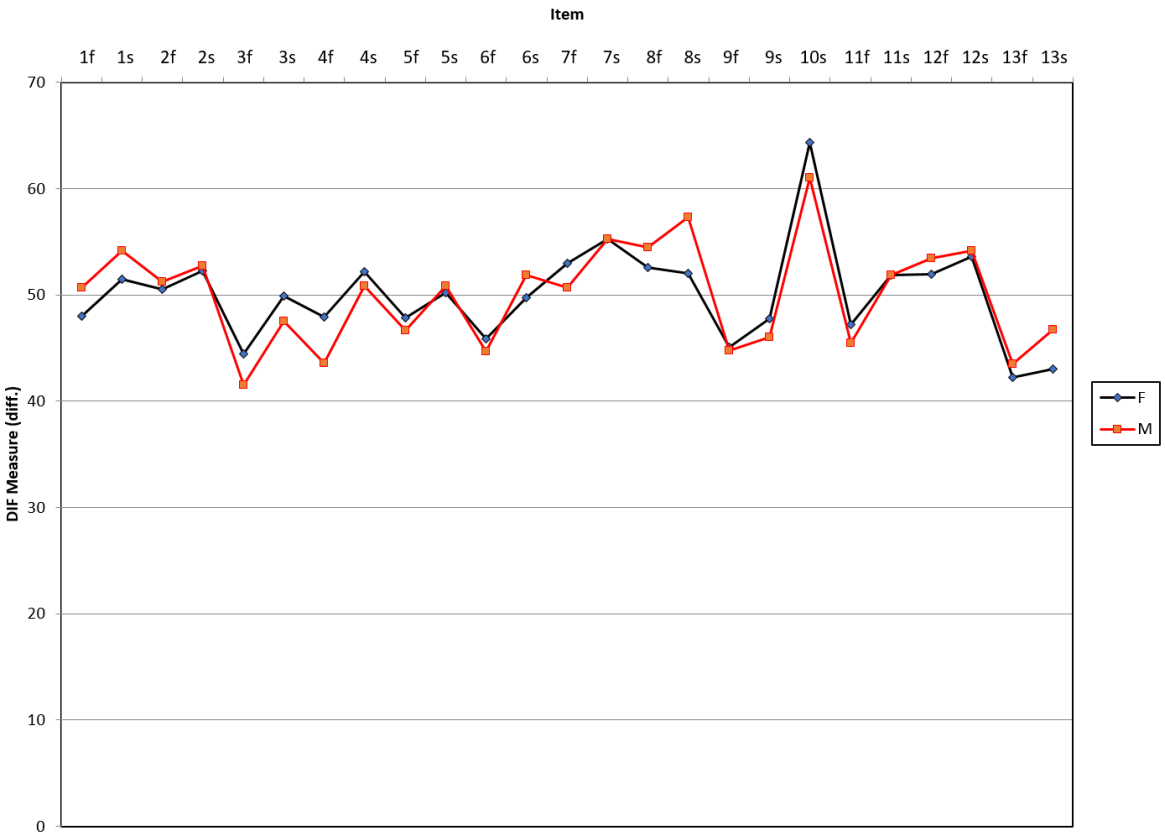


Figure 6.13 DIF measure for each item of VRD-25 for gender. The blue line (Females) represents females and the red line (Males) represents males.

6.6.5.3 DIF for location

It was decided to investigate whether the location of the respondent caused DIF. The data were split into two groups of people from the USA and people from the rest of the world (the 'rest of the world' group being predominantly (84%) European). Other splits were impractical due to the numbers of respondents in each area of the world being extremely different. DIF contrast and significance values are presented in table 6.18.

Table 6.18 DIF contrast and significance values for each item in VRD-25 for 'the rest of the world' versus the USA. The question that showed significant DIF contrast is highlighted in red.

Item number	Content	Rest of world DIF measure	USA DIF measure	DIF contrast	Significance (t)
1f	Watching moving traffic etc.	48.5	48.5	0.00	0.00
1s	Watching moving traffic etc.	52.0	52.4	-1.37	-0.96
2f	Walking alongside a busy road	50.6	50.6	0.00	0.00
2s	Walking alongside a busy road	52.3	52.3	0.40	0.27
3f	Problems moving, OK seated	43.9	43.9	0.00	0.00
3s	Problems moving, OK seated	48.3	49.9	-1.57	-1.14
4f	Moving around the home	48.1	46.6	1.44	1.05
4s	Moving around the home	51.9	51.9	0.00	0.00
5f	Supermarket aisle	48.4	47.3	1.12	0.81
5s	Supermarket aisle	49.8	50.5	-0.71	-0.51
6f	Uneven/sloping surfaces	48.2	44.5	3.75	2.65
6s	Uneven/sloping surfaces	51.5	49.6	2.06	1.46
7f	Walking up or down stairs	52.5	52.5	0.00	0.00
7s	Walking up or down stairs	55.3	55.3	0.00	0.00
8f	Onto/off and escalator	52.9	52.9	0.000	0.00
8s	Onto/off and escalator	52.0	53.5	-1.54	-1.04
9f	Job/household responsibilities	44.1	45.5	-1.43	-1.05
9s	Job/household responsibilities	45.9	48.1	-2.25	-1.64
10s	Hand/eye coordination	62.3	64.3	-1.96	-1.20
11f	Concentration	46.4	47.1	-0.66	-0.48
11s	Concentration	51.1	52.2	-1.12	-0.80
12f	Confused/disorientated	51.8	52.5	-0.70	-0.50
12s	Confused/disorientated	53.6	53.6	0.00	0.00
13f	Social activities etc.	44.2	41.7	2.42	1.76
13s	Social activities etc.	44.3	43.5	0.89	0.64

Item 6f was identified as having significant DIF (figure 6.14 and table 6.18). This item asked about the frequency of dizziness that made it difficult for the respondent to walk on uneven or sloping surfaces. The 'rest of world' group had symptoms of dizziness more frequently when undertaking this task than the USA group. We hypothesised that this may be because the USA group might be less likely than the 'rest of world' group to walk for short journeys, since walking in Europe has been found to be three to five times higher than in the USA (Pucher et al. 2011) this may be due to US public policy favouring cars over pedestrians (whereas public policy in Europe encourages people to walk) (Pucher 1988; Giuliano and Narayan 2002). US participants, therefore,

would have a lower frequency of dizziness symptoms since they walk less. In addition, many areas of the USA don't have municipal funding of pavements and walkways, with priority for infrastructure funding being given to roads and cars. This lack of funding leads to a lack of maintenance (Evans-Cowley 2006). This might mean that uneven or sloping surfaces are common in the USA and people don't regard them as an issue whereas they are less common in Europe leading to them to present more of a problem.

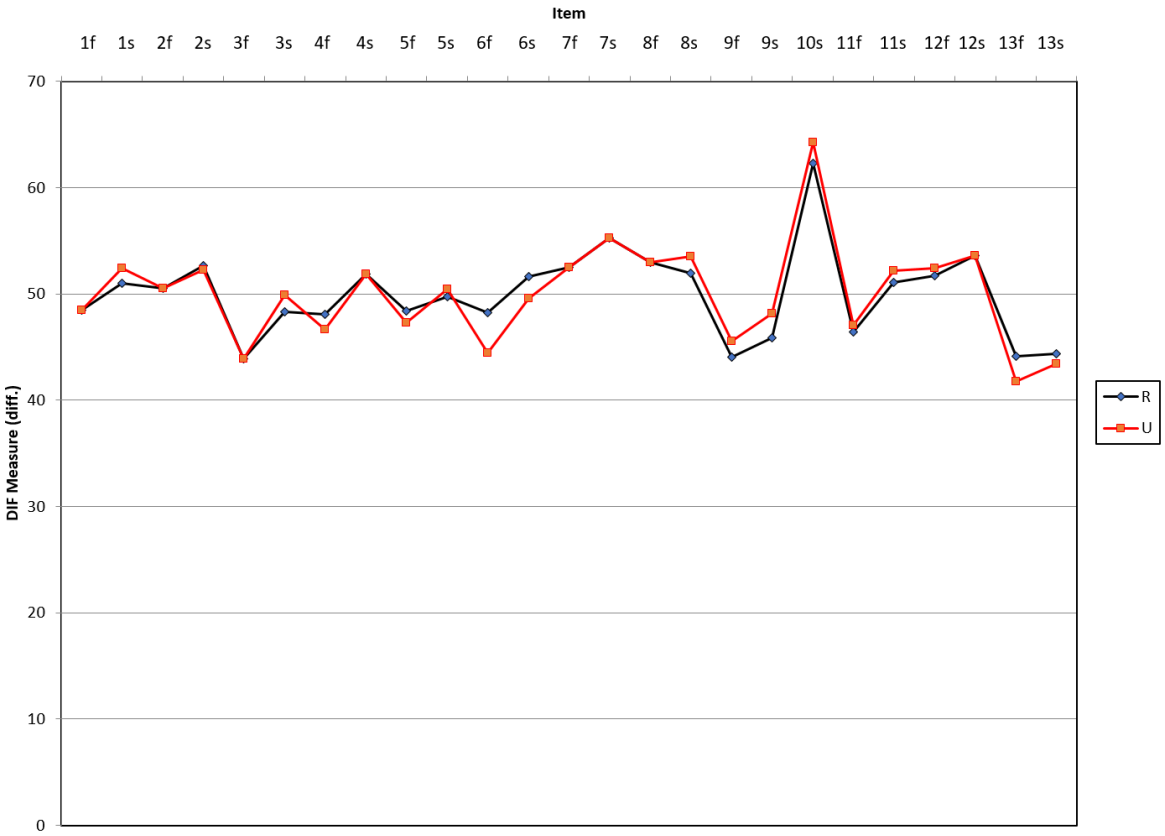


Figure 6.14 DIF (location) measure for each item of VRD-25. The blue line (R) represents people from areas outside the USA (given the description of 'the rest of the world') and the red line (U) represents people from the US.

Although there were items that exhibited DIF, the research team felt that removal of these items would adversely affect the ability of the PROM to investigate visually-related dizziness, so they were retained in VRD-25.

6.7 Limitations

A limitation of this study was that the respondents who completed the pilot study may not be representative of patients with vision-related dizziness. 58% of respondents reported that they believed their dizziness was caused by vestibular disease (including Ménière's disease, Vertigo and Labrynthitis) and only 5% reported their dizziness was mainly due to a vision problem (table 6.4). Dizziness, however, is multifactorial, (Colledge et al. 1996; Tinetti et al. 2000; Neuhauser et al. 2008; Ciorba et al. 2017) vision plays a greater role in balance control when the vestibular system is impaired (Redfern et al. 2001) and dizziness symptoms may be visually induced in vestibular patients (Vuralli et al. 2017). Patients might be unaware of this, so may categorise their dizziness as wholly vestibular in origin when, in fact, there may be a vision-related element. This is demonstrated by the condition of 'Visual Vertigo' (1.7.1). There is little high quality epidemiological data investigating the link between vision and dizziness (Armstrong et al. 2016) which may lead to the prevalence of vision-related dizziness being under-diagnosed.

Another limitation may be that 95% of respondents completed the pilot questionnaire online. The majority of respondents, therefore, were able to use a computer. This might have unintentionally excluded potential participants. Questionnaires always exclude people with cognitive impairment since one must understand a question to be able to answer it.

It is worth noting that the item asking about difficulties when using a lift might have been misunderstood by respondents from the USA since the word 'elevator' is commonly used for this in the USA. Had this item been retained in the final VRD-25, both words would have been included in the question to

avoid any misunderstanding.

When more is known about the influence of the visual system on symptoms of dizziness, it may be possible to develop an improved vision-related dizziness PROM.

6.8 VRD-25 (validation study version) questionnaire

Having undergone appropriate analysis and manipulation of the pilot questionnaire, VRD-25 was ready to be validated and tested for repeatability (Chapter 7).

Chapter 7.

The validation and repeatability of the Vision-Related Dizziness questionnaire (VRD-25)

Having constructed the VRD-25 questionnaire in accordance with Pesudovs et al. (2007) method, (Chapter 6) the next stage in the development process was to test the validity and repeatability of the instrument. An online version of VRD-25 was created and potential participants were asked to complete both the new questionnaire and the Dizziness Handicap Inventory (DHI) (Appendix A1).

The VRD-25 questions each had two parts, the 'f' questions refer to the frequency of dizziness and 's' questions refer to the severity of dizziness for the scenarios in the question descriptions. The complete VRD-25 used in the validation study can be found in Appendix D2.

7.1 Participant recruitment

The procedure detailed in Chapter 6 (6.4.7) for patient recruitment, for online completion of VRD-25 was followed again, with the explanation being amended to inform the potential participant that a newly developed questionnaire was being validated and tested for repeatability. Participants were invited to participate in both the validity and repeatability studies. They were asked to provide their date of birth (in the format MM/DD/YYYY) and full initials, creating a unique code so answers from the same respondent for the validity and repeatability studies could be paired. The option of providing an email address through which a reminder to complete the repeatability study would be sent was given with the assurance that the email address would not

be used for any other purpose.

VRD-25 was available for completion between 1st November 2016 and 21st April 2017. Where a respondent had requested a reminder email, it was sent one month after the completion of the first questionnaire. If the participant had not completed a second questionnaire within one month of the reminder email, a second email was sent.

7.2 Assessment of VRD-25 performance

The performance of VRD-25 was determined by assessments of validity (using convergent validity), discriminative ability (using person and item separation) and reliability (using test-retest agreement).

Convergent validity is a measure of how well two related measures correlate. In this case, the new instrument was correlated with an existing, well established instrument – the DHI. The DHI was chosen because it measured a similar construct – dizziness. Since VRD-25 was intended to measure vision-related dizziness and the DHI measures dizziness of vestibular origin, one would expect them to have a moderate correlation between 0.3 and 0.9 (Pesudovs et al. 2007). A high correlation of ≥ 0.90 would indicate that VRD-25 was, in effect, redundant since it measured the same thing as the DHI. A correlation of ≤ 0.30 would indicate that the two measures were not, in fact, related and that they were supplying different information (Pesudovs et al. 2007).

Discriminative ability is a measure of how well the instrument differentiates between people with different levels of dizziness. Person separation in this case indicates the difference in scores between a person with low and high

levels of dizziness. A person separation of >2.0 indicates that the instrument can discriminate between those with high and low symptom levels. Item separation indicates whether the items are of sufficiently different difficulties. An item separation of >3.0 indicates that there are items of an appropriate spread of difficulties (Linacre no date b; Bond and Fox 2013).

The test-retest reliability of an instrument is its ability to measure the same concept each time it is used. Intra-class correlation is the ratio of the variance between the two test administrations and the total variance. Bland-Altman limits of agreement indicate the range over which 95% of the values lie. A good performance for intra-class correlation is > 0.8 (Pesudovs et al. 2007).

7.3 Results

Since data for both studies were collected by the same Wufoo questionnaire, separation of the responses for the validation and repeatability sections was carried out by hand using the unique code system as described in 7.1.

7.3.1 Results – validation study

There were 224 respondents to the validation study, 223 reported suffering from dizziness within the past month. 83% were female. The age range of respondents was 18-78 years (mean age 48.0 SD 12.3 years). Details of the geographic origin of the participants is presented in table 7.1.

Table 7.1 The geographical origins of 224 respondents for the validation of VRD-25**.**

Continent	**Number of respondents**	**Percentage of respondents**
North America	125 (107 USA)	56% (48% USA)
Europe	65 (58 UK)	29% (26% UK)
Oceania	16	7%
Unknown	10	5%
Africa	5	2%
Asia	3	1%

7.3.2 Results – repeatability study

The validation study asked if the participant was willing to complete VRD-25 and the DHI in one months' time for the repeatability study and offered to send a reminder email to the participant. 137 reminder emails were requested and sent to invite participants to complete a second questionnaire to test repeatability. These reminder emails were sent one month after the first questionnaire was completed. 4 of the email addresses were invalid, and 62 people replied. 71 second reminder emails were sent which resulted in a further 20 questionnaires being completed. The majority of participants who repeated the questionnaire responded to the reminder email, however there were five participants who completed the questionnaire for a second time between 18 and 24 days after the first response. The mean number of days between completing the first and second questionnaires was 36 days (minimum 18 days, maximum 80 days, SD 12). There were 82 respondents

to the repeatability study, all reported suffering from dizziness within the past month. 90% were female. The age range of respondents was 28-76 years (mean age 51.1 SD 10.9 years). Details of the geographic origin of the participants is presented in table 7.2.

Table 7.2 The geographical origins of 82 respondents for the repeatability of VRD-25 and the DHI**.**

Continent	**Number of respondents**	**Percentage of respondents**
North America	44 (37 USA)	54% (45% USA)
Europe	22 (17 UK)	29% (21% UK)
Oceania	9	11%
Unknown	4	5%
Asia	2	2%
Africa Analysis	1	1%

7.4 Analysis

The most commonly used dizziness PROM is the DHI (Fong et al. 2015) and its correlation with VRD-25 was assessed to investigate convergent validity. VRD-25 and the DHI were both designed to measure dizziness, however the DHI was not designed to be specific to vision-related dizziness, therefore one would expect them to be correlated, but not highly (>0.9). An acceptable performance would be a correlation coefficient between the two PROMs between 0.30 to 0.90 (Pesudovs et al. 2007). Intra-class correlation was assessed using SPSS statistics for Windows (version 23.0; Armonk, NY:IBM

Corp) and good performance for these indices would be ≥0.80 (Pesudovs et al. 2007). Bland-Altman plots to explore agreement between measures and intra-class correlations were generated using Microsoft Excel 2016.

Subsequently, Rasch analysis was used to determine category probability curves, fit statistics, principal component analysis (PCA) to test for unidimensionality and differential item functioning (DIF) to assess whether differing groups answered the questions differently, using Winsteps version 3.91.0; Chicago, IL.

7.4.1 Convergent validity

One participant's data was removed from the analysis as they had not reported being dizzy in the past month. None of the remaining participants had >33% missing data (Pesudovs et al. 2004), therefore all other datasets were used in the validation analysis. When performing analyses on DHI data, any missing values were replaced by the mode value for that subdomain (Tamber et al. 2009). Missing values from the Rasch analysed data were dealt with by Rasch as described in Chapter 6 (6.5).

A Kolmogorov-Smirnov test (using IBM SPSS statistics version 23) was used to evaluate normality of the data. The frequency and severity scales of VRD-25 had data that were normally distributed (p>0.10) but the DHI data were not (p=0.021). This indicated that a non-parametric test of correlation was suitable when assessing correlation therefore Spearman correlation coefficients were generated for VRD-25 and DHI. Pesudovs et al. (2007), suggested that correlation coefficients between the gold standard measure and the newly developed instrument should be between 0.3 and 0.9. A very high correlation

coefficient would indicate that the information provided by VRD-25 corresponded very highly with that provided by the DHI, (McAlinden et al. 2010) in other words, that it wouldn't supply any additional information. This would make the instrument redundant. A very low correlation coefficient would signify that VRD-25 and the DHI (which we have hypothesized to be associated to a moderate degree as they both measure patient-reported dizziness) showed no significant association.

Scatterplots of VRD-25, VRD-12f and VRD-13s versus DHI are shown in figures 7.1a, b and c showing Spearman correlation coefficients between the two of 0.78 (VRD-25 vs DHI), 0.75 (VRD-12f vs DHI) and 0.75 (VRD-13s vs DHI), indicating suitably moderate to good correlations.

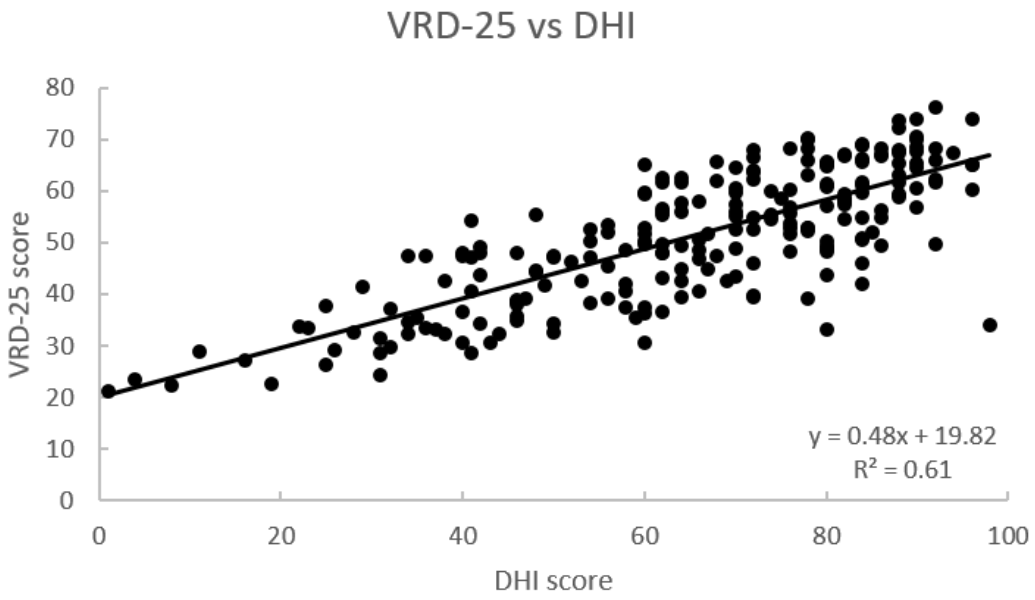


Figure 7.1a Correlation scatterplot for VRD-25 vs. DHI. Spearman's Rho = 0.78.

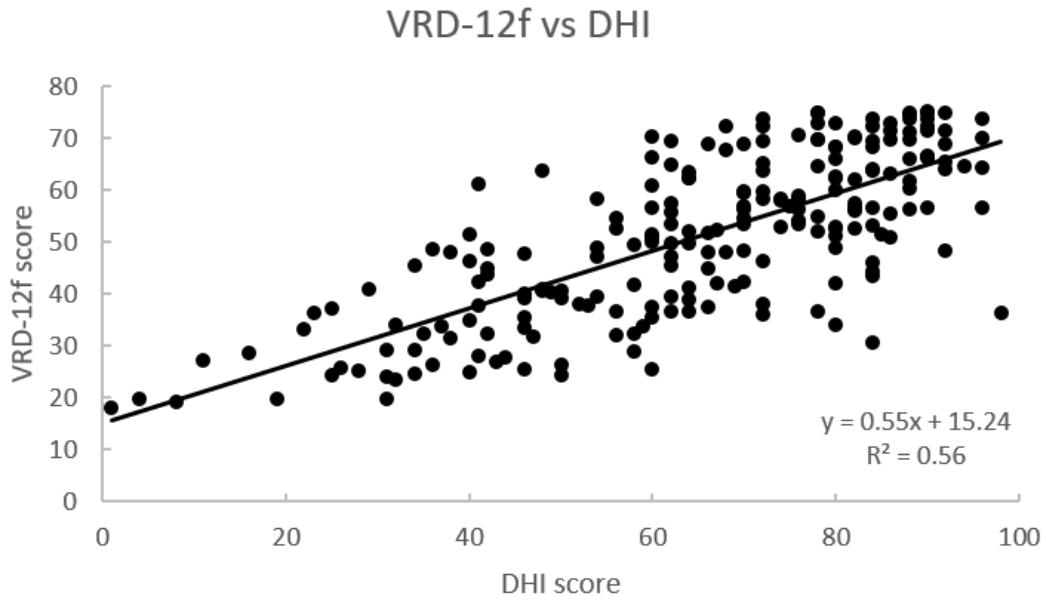


Figure 7.1b Correlation scatterplot for VRD-12f vs. DHI. Spearman's Rho = 0.75.

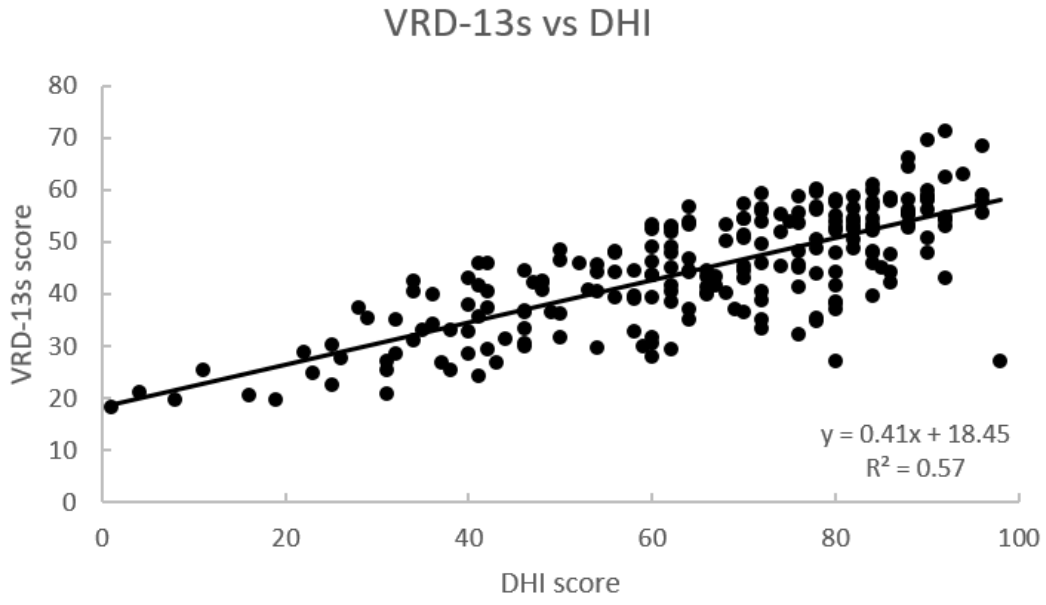


Figure 7.1c Correlation scatterplot for VRD-13s vs. DHI. Spearman's Rho = 0.75.

7.4.2 Discriminative ability (person-item separation)

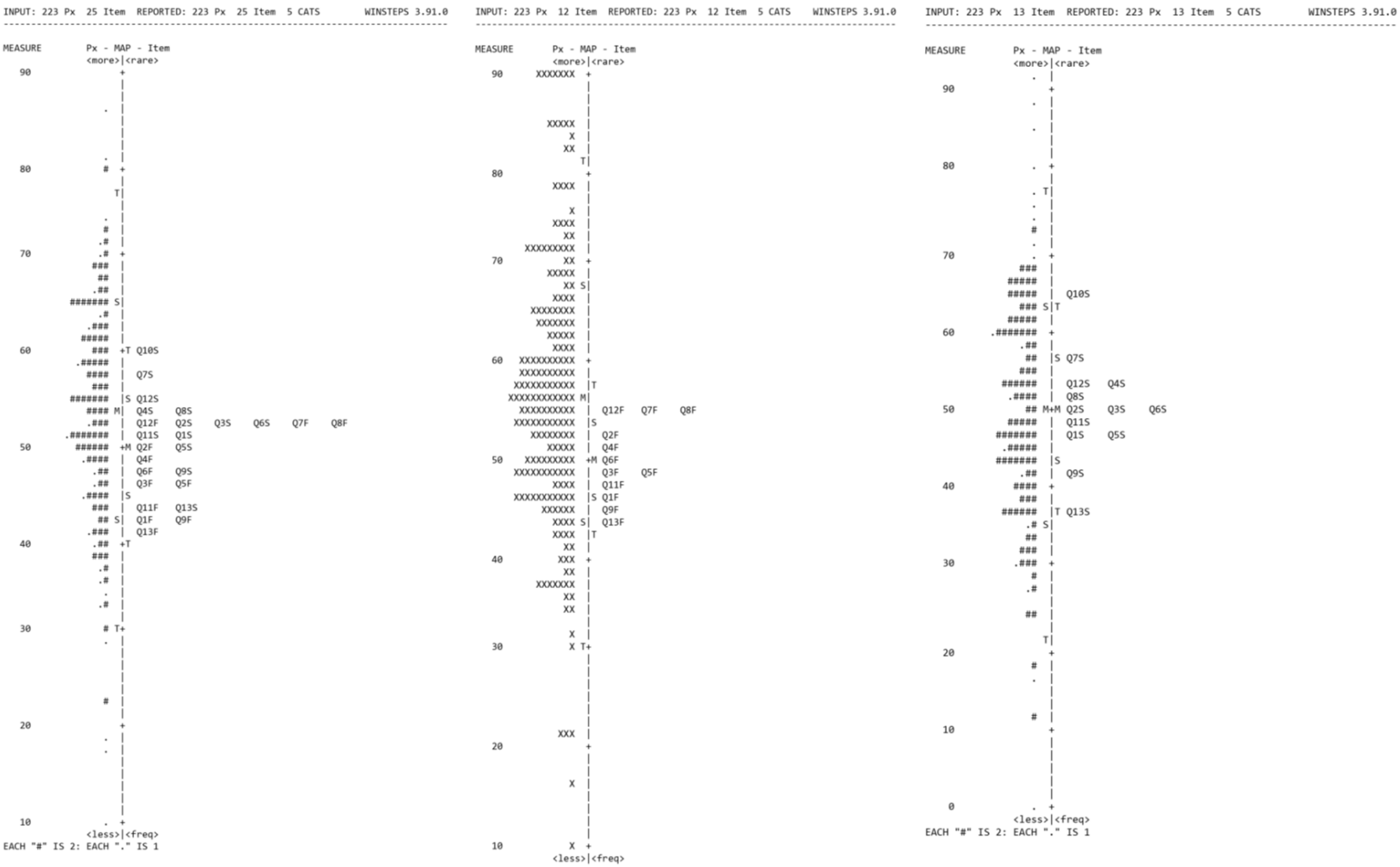
During the development stage of VRD-25, it was established that using the data gathered by all the items would give a general overview of the patient's dizziness status, however, it was recommended that using the frequency (VRD-12f) and severity (VRD-12s) scales separately would give more diagnostic accuracy (section 6.7.4).

Person-item separations for the validation data were very good (Linacre 2009) and were comparable to those from the data collected during the pilot study. The values remained good for the two subscales of VRD-12f and VRD-13s. Table 7.3 presents the person/item separation indices and differences in measures for VRD-25, VRD-12f and VRD-13s.

Table 7.3 The person-item separation indices for VRD-25 and its subscales.

Scale	Person separation	Person reliability	Item separation	Item reliability	Difference in measures (logits)
VRD-25	3.96	0.94	5.74	0.97	0.33
VRD-12f	2.67	0.88	6.12	0.97	0.70
VRD-13s	2.97	0.90	5.11	0.96	0.06

The Person-item Maps for VRD-25, VRD-12f and VRD-13s were generated and they are presented in figures 7.2 a, b and c.



Figures 7.2 a, b and c Person-item Maps for VRD-25, VRD-12f and VRD-13s using the data gathered during the validation study. Items are shown on the right of the dashed line with the items that people with dizziness found more difficult nearer the top. People are shown on the left of the dashed line with those who suffered from more dizziness located nearer the top of the map**.**

There was a very small ceiling effect for the VRD-12f scale, but VRD-25 and VRD-13s showed a good distribution of persons and items. The ceiling effect indicated that person ability was less than item difficulty - indicating the possibility that the assessment of those with higher frequency or severity of dizziness may be less accurate.

7.4.3 Intra-class correlation (test-retest repeatability)

Three participants' data were discarded from the test-retest analysis. Two participants showed major changes in dizziness scores and the other gave answers that made no sense. A major change was defined as a change of greater than 33 on the 0-100 scale – well above the ≥20 that indicated being above a measurement error (Tamber et al. 2009).

The participants who showed major changes in dizziness scores were as follows:

Participant number 133 had DHI scores in test 1 of 52 and test 2 of 1.

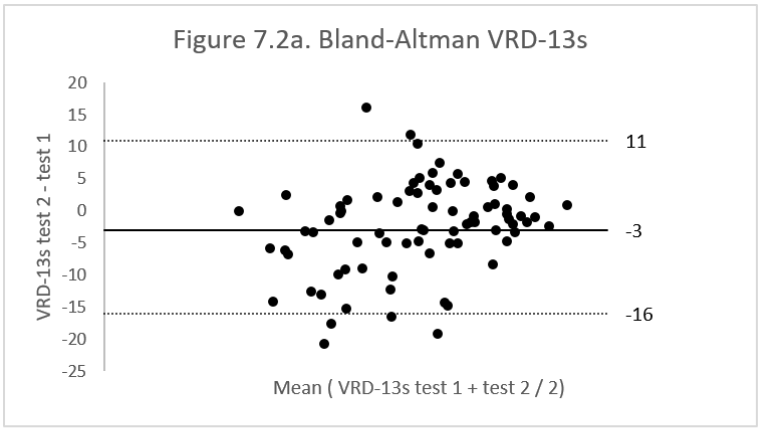
Participant number 209 had DHI scores in test 1 of 82 and test 2 of 42.

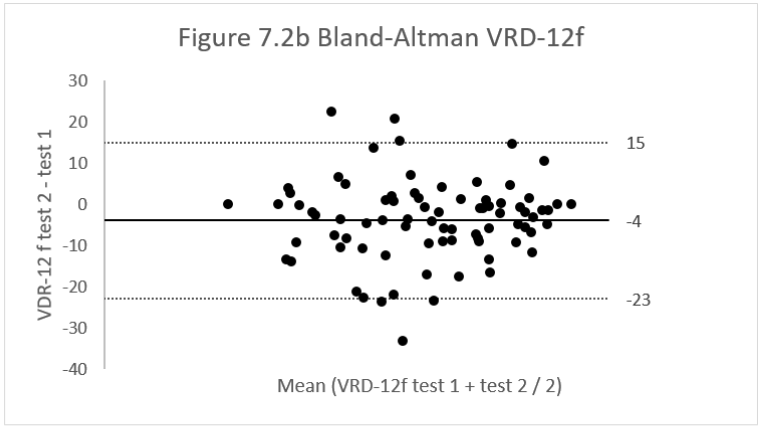
Participant number 59 gave answers indicating a high degree of dizziness for DHI test 1 and 2 and for VRD-25 test one but indicated hardly any dizziness on VRD-25 test 2. In addition, this person gave contradictory answers for three questions that were similar in content for VRD-25 and DHI.

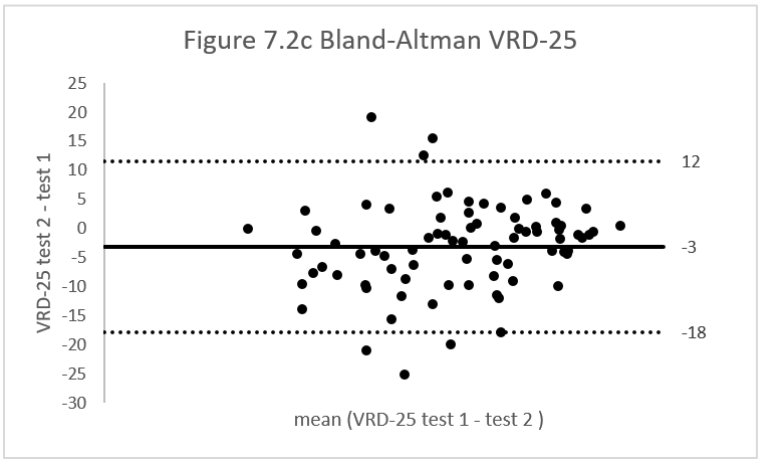
Bland-Altman plots were used to analyse agreement between VRD-25 test one and test two and DHI test one and test two, and to identify any outliers in the data. The Bland-Altman method of assessing agreement plots the difference between the test one and test two against the average of test one and test two (Altman and Bland 1983; Bland and Altman 1986). 95% of the

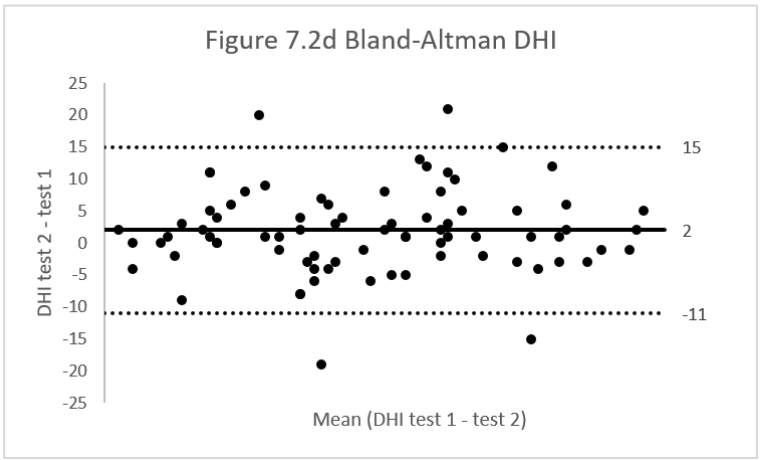
differences between test one and test two fall within the upper and lower limits of agreement (Bland and Altman 1999). This allows one to estimate the size of any sampling error (Giavarina 2015). The Bland-Altman plots for VRD-25, VRD-12f, VRD-13s and DHI are presented in figures 7.3 a, b, c and d respectively.

The test-retest repeatability of VRD-25 was above the good performance level of 0.80 (Pesudovs et al., 2007) for test-retest intra-class correlation coefficients, at 0.88 with the test-retest intra-class correlation coefficient of the DHI being 0.92. The DHI repeatability data was comparable to that reported when the instrument was developed (Jacobson and Newman 1990) with a morning-afternoon test-retest and 14 participants of ±18 limits of agreement and a test-retest correlation coefficient of 0.97.









Figures 7.3 a, b, c and d Bland-Altman plots for VRD-25, VRD-12f, VRD 13s and DHI respectively. 95% confidence limits of agreement were similar, at ±15 (VRD-25), ±19 (VRD-12f), ±13 (VRD13-s) and ±13 (DHI).

7.4.4 Rasch analysis (category probability curves)

The category probability curves for the validation data showed that the categories were well ordered and that all categories were properly utilized. This information is presented in figure 7.4.

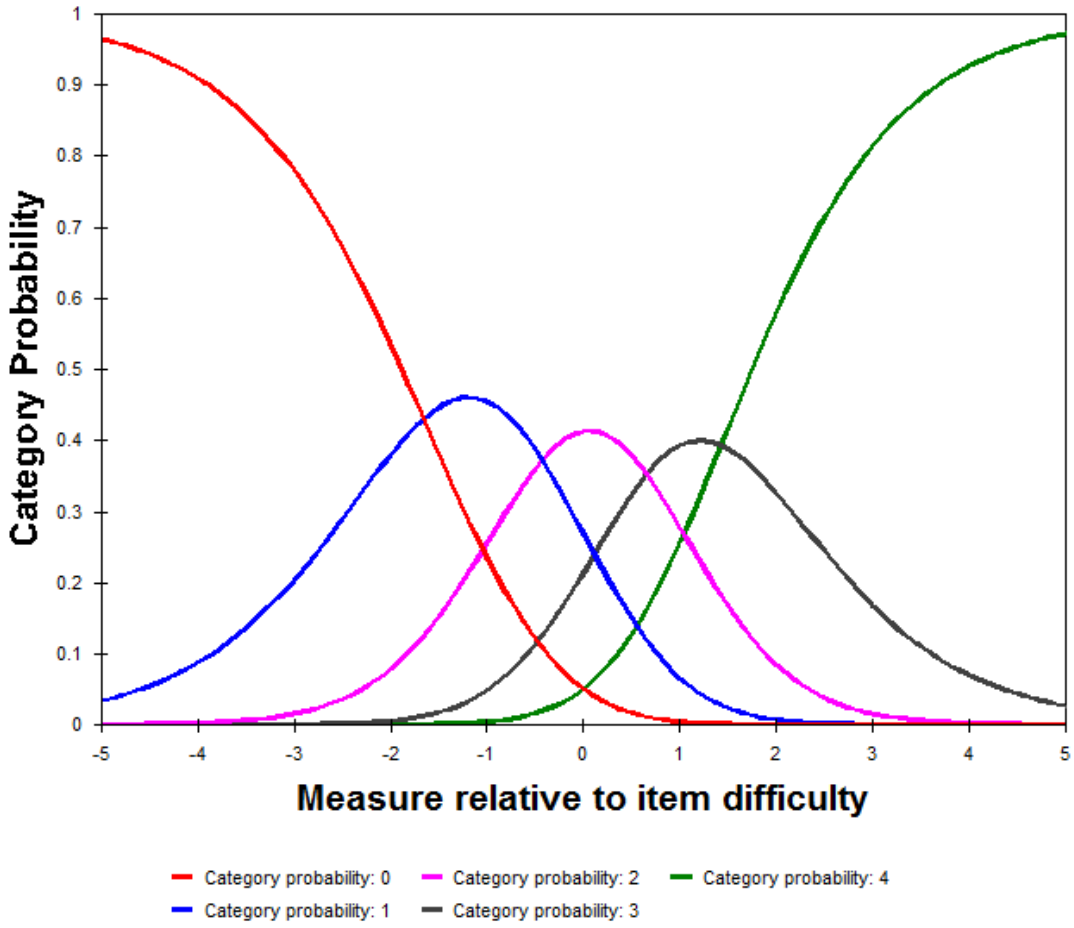


Figure 7.4 Category probability curves for the five Likert scales from the 223 responses to the validation version of VRD-25**.**

7.4.5 Fit statistics

When the infit and outfit mean square values for the validation data for VRD-25 were examined it was found that three items – 1f, 3f and 10s (items dealing with watching moving traffic, moving around and hand/eye coordination) had infit mean square values outside the range of 0.6-1.4, however, when the data were split into VRD-12f and VRD-13f, all the values were within the specified range, emphasising the importance of considering VRD-25 as two scales of data. The fit statistics for VRD-25, VRD-12f and VRD-13s are presented in tables 7.4, 7.5 and 7.6 respectively.

Table 7.4 Fit statistics for VRD-25. Mis-fitting items are in red.

Item	Content	Measure	Infit mean square	Outfit mean square
1f	Watching moving traffic etc.	42.6	1.41	1.25
1s	Watching moving traffic etc.	50.9	0.87	0.99
2f	Walking alongside a busy road	50.3	1.10	1.05
2s	Walking alongside a busy road	52.9	0.81	0.83
3f	Problems moving, OK seated	46.2	1.57	1.56
3s	Problems moving, OK seated	52.5	0.62	0.72
4f	Moving around the home	48.4	1.19	1.13
4s	Moving around the home	54.5	0.52	0.62
5f	Supermarket aisle	45.9	1.18	1.10
5s	Supermarket aisle	50.0	0.76	0.74
6f	Uneven/sloping surfaces	47.9	0.91	0.80
6s	Uneven/sloping surfaces	52.7	0.61	0.60
7f	Walking up or down stairs	53.2	1.32	1.36
7s	Walking up or down stairs	57.5	0.75	0.77
8f	Onto/off and escalator	52.8	1.40	1.37
8s	Onto/off and escalator	53.9	1.08	1.09
9f	Job/household responsibilities	42.0	0.91	0.77
9s	Job/household responsibilities	47.6	0.65	0.70
10s	Hand/eye coordination	60.9	1.57	1.53
11f	Concentration	43.8	1.11	1.03
11s	Concentration	51.5	0.81	0.86
12f	Confused/disorientated	52.5	1.07	1.06
12s	Confused/disorientated	55.5	0.91	0.94
13f	Social activities etc.	40.6	1.01	0.92
13s	Social activities etc.	43.7	0.84	0.87

Table 7.5 Fit statistics for VRD-12f showing all items to be within the 0.6-1.4 range**.**

Item	Content	Measure	Infit mean square	Outfit mean square
1f	Watching moving traffic etc.	45.8	1.17	1.11
2f	Walking alongside a busy road	52.9	0.91	0.90
3f	Problems moving, OK when seated	49.0	1.24	1.36
4f	Moving around the home	51.1	0.92	0.91
5f	Supermarket aisle	48.8	1.00	0.95
6f	Uneven or sloping surfaces	50.6	0.71	0.78
7f	Walking up or down stairs	55.7	1.14	1.23
8f	Onto or off an escalator	55.1	1.30	1.37
9f	Job or household responsibilities	45.3	0.81	0.75
11f	Concentration	46.8	0.99	0.94
12f	Confused/disorientated	55.0	1.04	1.07
13f	Social activities etc.	43.9	0.82	0.80

Table 7.6 Fit statistics for VRD-13s showing all items to be within the 0.6-1.4 range**.**

Item	Content	Measure	Infit mean square	Outfit mean square
1s	Watching moving traffic etc.	47.3	1.16	1.24
2s	Walking alongside a busy road	50.1	1.11	1.11
3s	Problems moving, OK when seated	49.5	0.73	0.75
4s	Moving around the home	52.5	0.60	0.62
5s	Supermarket aisle	46.0	1.00	0.97
6s	Uneven or sloping surfaces	49.9	0.81	0.80
7s	Walking up or down stairs	56.6	0.94	0.97
8s	Onto or off an escalator	51.8	1.39	1.42
9s	Job or household responsibilities	42.5	0.86	0.85
10s	Hand/eye coordination	64.8	1.37	1.41
11s	Concentration	48.2	0.88	0.87
12s	Confused/disorientated	53.9	1.00	1.00
13s	Social activities etc.	36.8	1.20	1.14

7.4.6 Principal components analysis

Principal components analysis (PCA) was performed on the validation study data for comparison with the pilot data. PCA of VRD-25 again showed that the data were not unidimensional with 54% of the variance explained by measures. The eigenvalues are presented below:

Raw unexplained variance	1st contrast eigenvalue	3.63
	2nd contrast eigenvalue	2.78
	3rd contrast eigenvalue	2.39
	4th contrast eigenvalue	2.15
	5th contrast eigenvalue	1.74

The first contrast was above the cut-off of 3.0 (Pesudovs et al. 2007; Linacre 2009) and the first four contrasts were above the more stringent cut-off value of 2.0 (Smith 2002; Gothwal et al. 2009; Pesudovs et al. 2010; Vianya-Estopa al. 2010; Latham et al. 2015) indicating that more than one construct was being measured by the instrument. The item map for the analysis is shown in figure 7.5.

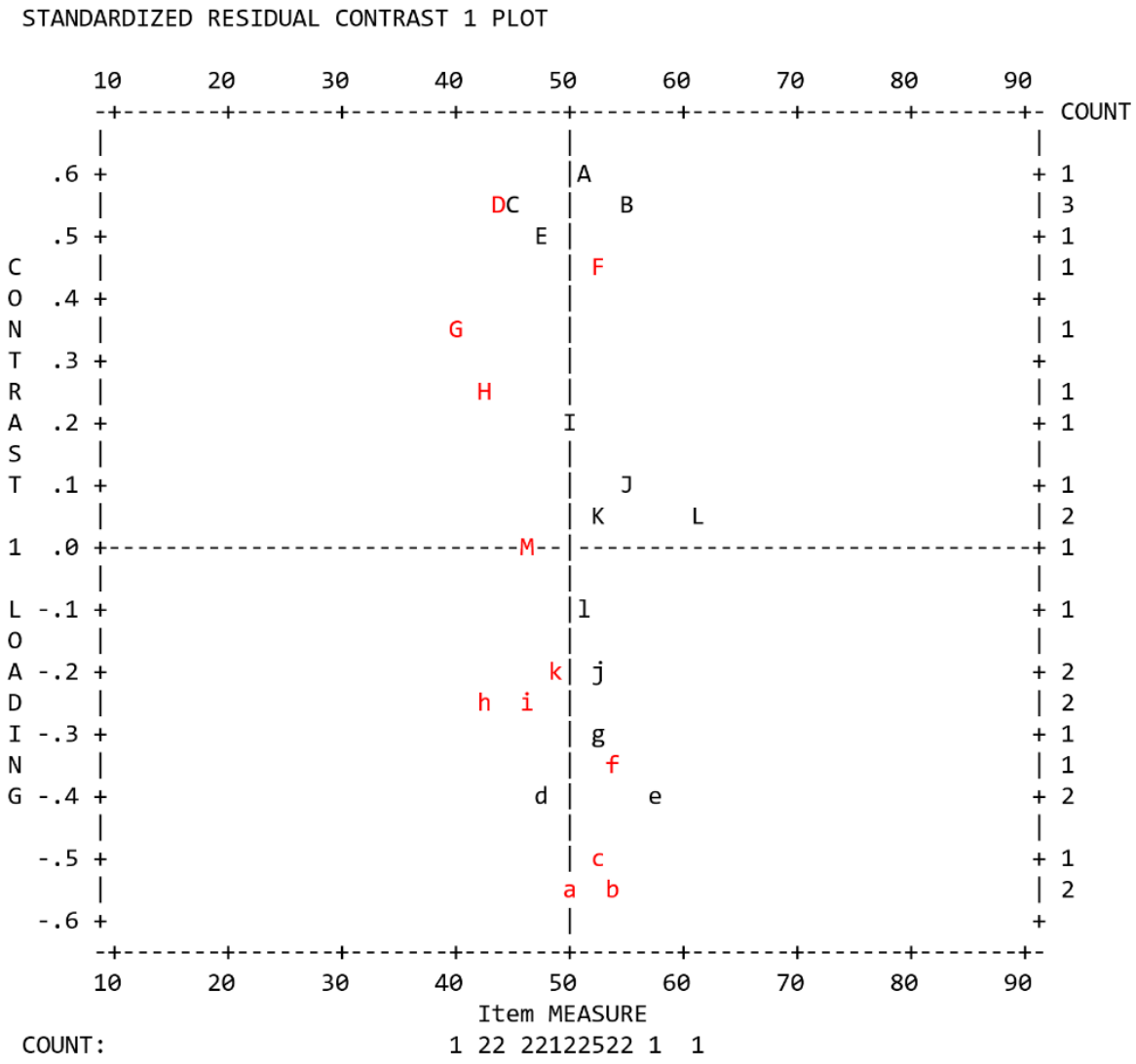


Figure 7.5 Standardised residual data plot for VRD-25. Frequency items are in red. Letter codes are explained in table 7.7.

Table 7.7 Letter codes, and fit statistics for the standardised residual contrast plot for VRD-25**.**

Map Code	Item number	Item content	Infit MNSQ	Outfit MNSQ	Loading	Measure
A	11s	Concentration	0.81	0.86	0.62	51.5
B	12s	Feeling confused/disorientated	0.91	0.94	0.57	55.5
C	13s	Social activities, sports, pastimes	0.84	0.87	0.56	43.7
D	11f	Concentration	1.11	1.03	0.54	43.8
E	9s	Job or household responsibilites	0.65	0.70	0.49	47.6
F	12f	Feeling confused/disorientated	1.07	1.06	0.46	52.5
G	13f	Social activities, sports, pastimes	1.01	0.92	0.37	40.6
H	9f	Job or household responsibilites	1.01	0.91	0.25	42.0
I	5s	Walking down a supermarket aisle	0.76	0.74	0.21	50.0
J	4s	Moving around the home	0.52	0.62	0.11	54.5
K	3s	Problems moving around but OK when seated	0.62	0.72	0.03	52.5
L	10s	Hand/eye coordination	1.57	1.53	0.03	60.9
M	5f	Walking down a supermarket aisle	1.18	1.10	0.02	45.9
a	2f	Walking alongside a busy road	1.10	1.05	-0.55	50.3
b	7f	Walking up or down stairs	1.31	1.36	-0.53	53.2
c	8f	Stepping onto or off an escalator	1.40	1.37	-0.49	52.8
d	6f	Walking on uneven or sloping surfaces	0.91	0.85	-0.42	48.9
e	7s	Walking up or down stairs	0.75	0.77	-0.38	57.5
f	8s	Stepping onto or off an escalator	1.08	1.09	-0.36	53.9
g	2s	Walking alongside a busy road	0.81	0.83	-0.32	52.9
h	1f	Watching moving traffic/trains/crossing roads	1.42	1.28	-0.27	42.6
i	3f	Problems moving around but OK when seated	1.57	1.56	-0.25	46.2
j	6s	Walking on uneven or sloping surfaces	0.61	0.60	-0.22	52.7
k	4f	Moving around the home	1.19	1.13	-0.18	48.4
l	1s	Watching moving traffic/trains/crossing roads	0.87	0.99	-0.12	50.9

In keeping with the development data, the item map showed that there was no common factor to explain the split between questions. The loading, measure, infit mean square and outfit mean square values shown in table 7.7. Infit and outfit values for the VRD-25 items were all within 0.6-1.4. The logical way for the data to be split (as for the pilot study) was by questions relating to frequency and severity. These data were split in this way and the two subscales re-analysed.

When the frequency items alone were considered, and the responses analysed by Winsteps, the person separation was 2.47 (SD 1.37) and the item separation was 4.69 (SD 0.38) with reliabilities of 0.86 and 0.96 respectively. Raw variance explained by the measure was 57 %.

The unexplained variance values are presented below:

Raw unexplained variance	1st contrast eigenvalue	2.32
	2nd contrast eigenvalue	1.61
	3rd contrast eigenvalue	1.46
	4th contrast eigenvalue	1.13
	5th contrast eigenvalue	1.08

The first contrast was below the cut-off value of 3.0 (Linacre 2009; Khadka et al. 2017) but slightly above the more stringent, but often used cut-off value of 2.0 (Smith 2002; Gothwal et al. 2009; Pesudovs et al. 2010; Vianya-Estopa, 2010; Latham et al. 2015) indicating that there was a possibility that more than one construct was being measured by the subscale. This is contrary to the findings from the data for the development study.

The item map for the analysis is shown in figure 7.6. Letter codes and fit statistics are provided in table 7.8.

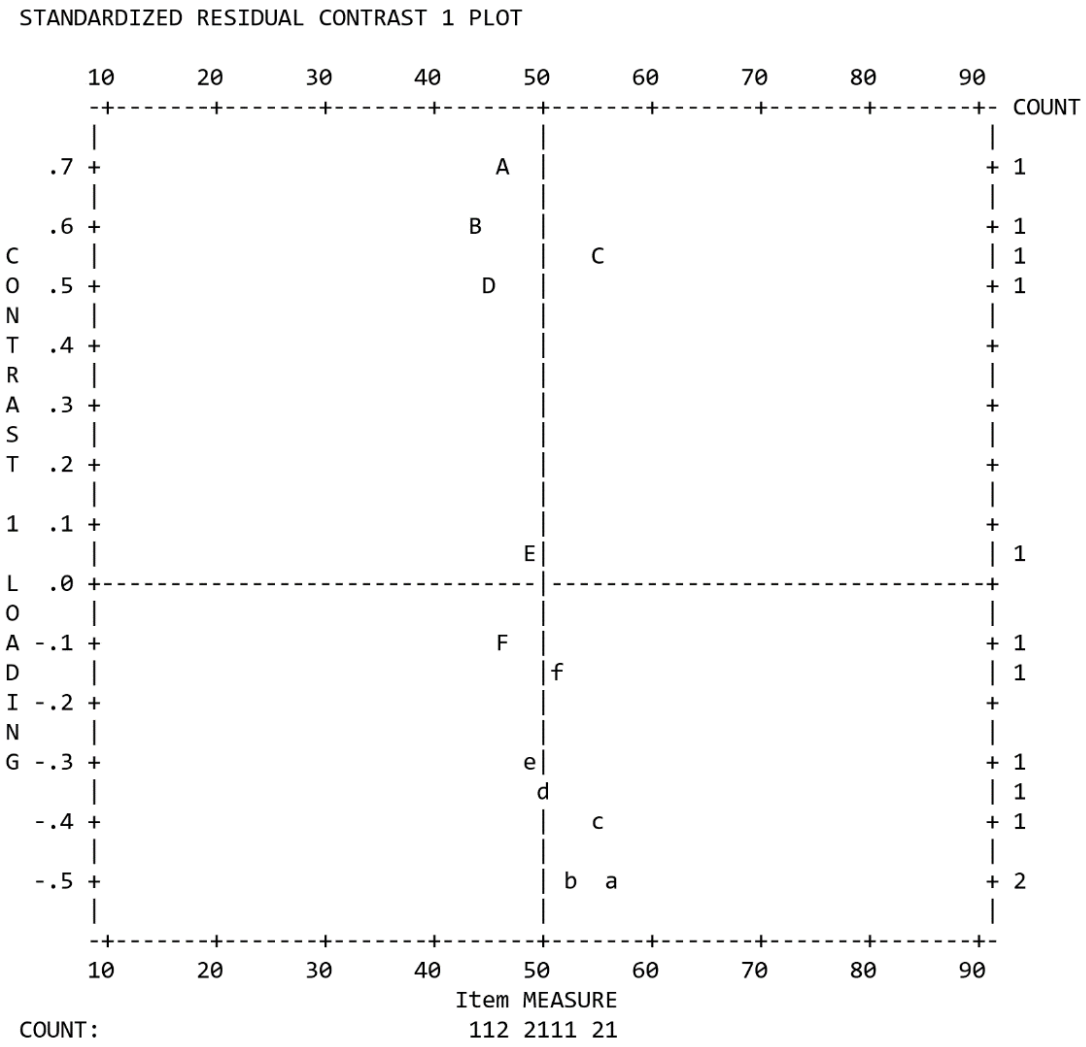


Figure 7.6 Standardised residual data plot for VRD-12f showing a grouping of items A, B, C and D near the top of the map and the other items grouped towards the bottom.

Points A, B, C and D identify items that may have an emotional (anxiety) component (ability to concentrate, interfering with social activities, being confused and interfering with a job or household responsibilities). The other points identify items that deal with movement in the visual scene (stairs, walking alongside a busy road, using an escalator, walking on an uneven or sloping surface, moving around, moving around the home and watching moving traffic) although these situations could also have an element of anxiety

involved in them, and this may be the additional construct being highlighted by the PCA. This additional construct was not identified during the development PCA suggesting that this may be a weak contributory factor with slightly overlapping factors in the overall construct or it may be due to random chance.

Table 7.8 Letter codes, and fit statistics for the standardised residual contrast plot for VRD-12f**.**

Map code	Item number	Item content	Infit MNSQ	Outfit MNSQ	Loading	Measure
A	11f	Concentration	0.99	0.94	0.71	46.8
B	13f	Social activities, sports, pastimes	0.82	0.80	0.60	43.9
C	12f	Feeling confused/disorientated	1.04	1.07	0.55	55.0
D	9f	Job or household responsibilities	0.81	0.75	0.50	45.3
E	5f	Walking down a supermarket aisle	1.00	0.95	0.06	48.8
F	1f	Watching moving traffic/trains/crossing roads	1.17	1.11	-0.12	45.8
a	7f	Walking up or down stairs	1.14	1.23	-0.51	55.7
b	2f	Walking alongside a busy road	0.91	0.90	-0.48	52.9
c	8f	Stepping onto or off an escalator	1.30	1.37	-0.39	55.1
d	6f	Walking on uneven or sloping surfaces	0.71	0.65	-0.34	50.6
e	3f	Problems moving around but OK when seated	1.24	1.36	-0.30	49.0
f	4f	Moving around the home	0.92	0.91	-0.13	51.1

When the severity items were considered separately, patient separation was 2.98 (SD 1.38) and item separation was 6.44 (SD 0.64) with reliabilities being 0.90 and 0.98 respectively. Raw variance explained by the measure was 56% with the eigen values as below:

Raw unexplained variance	1st contrast eigenvalue	2.20
	2nd contrast eigenvalue	1.83
	3rd contrast eigenvalue	1.52
	4th contrast eigenvalue	1.28
	5th contrast eigenvalue	1.13

The first contrast was within the cut off value of 3.0 (Linacre 2009, Khadka et al. 2017) but slightly above the more stringent cut-off value of 2.0 (Smith 2002; Gothwal et al. 2009; Pesudovs et al. 2010; Vianya-Estopa et al. 2010; Latham

et al. 2015) indicating that more than one construct was being measured by the subscale. Once again, this is contrary to the findings from the data for the development study.

The item map for the analysis is shown in figure 7.7. Letter codes and fit statistics are presented in table 7.9.

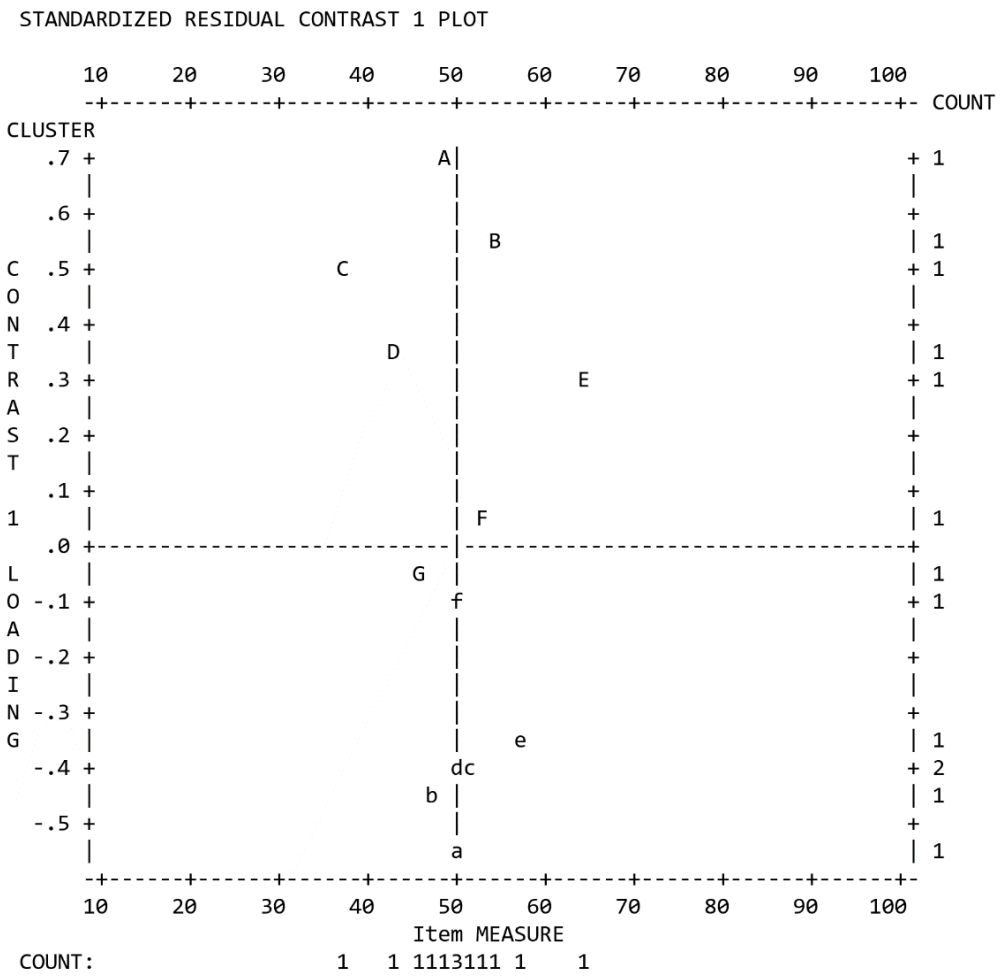


Figure 7.7 Standardised residual data plot for VRD-12s. Letter codes are explained in table 7.9.

As with the frequency sub-scale, the items may be broadly divided into those which have an emotional (anxiety) component and those that deal with

movement in the visual scene. This may be a weak contributory factor or may be a chance finding since the pilot study data did not highlight this as a possible second factor.

Table 7.9 Letter codes, and fit statistics for the standardised residual contrast plot for VRD-12s**.**

Map code	Item number	Item content	Infit MNSQ	Outfit MNSQ	Loading	Measure
A	11s	Concentration	0.88	0.87	0.68	48.2
B	12s	Feeling confused/disorientated	1.00	1.00	0.56	53.9
C	13s	Social activities, sports & pastimes	1.20	1.14	0.48	36.8
D	9s	Job or household responsibilities	0.86	0.85	0.34	42.5
E	10s	Hand/eye coordination	1.37	1.41	0.29	64.8
F	4s	Moving around the home	0.60	0.62	0.05	52.5
G	5s	Walking down a supermarket aisle	1.00	0.97	-0.03	46.0
a	2s	Walking alongside a busy road	1.11	1.11	-0.55	50.1
b	1s	Watching moving traffic/trains/crossing roads	1.16	1.24	-0.46	47.3
c	8s	Stepping onto or off an escalator	1.39	1.42	-0.42	51.8
d	6s	Walking on uneven or sloping surfaces	0.81	0.80	-0.41	49.9
e	7s	Walking up or down stairs	0.94	0.97	-0.36	56.6
f	3s	Problems moving around but OK when seated	0.73	0.75	-0.12	49.5

Since quality of life assessment was part of the aims of the instrument it is perhaps inevitable that there would be an emotional factor incorporated into the analysis.

7.4.7 Differential Item Functioning (DIF)

DIF was once again analysed for age, gender and location.

7.4.7.1 DIF for age

Respondent data were split into older people - those above the median age of 48 years, and younger people – those of 48 years or younger. This resulted in 112 people in the older age group and 108 in the younger age group, with 3 people preferring not to say.

There were two items where the DIF contrast was >0.50, and these items (3F

and 7F) had a t value of ≥±2, indicating the DIF contrast was significant (section 6.5.3). Item 3F asked about dizziness frequency when moving around and item 7F asked about frequency of dizziness when walking up and down stairs. The older group of respondents were more likely to have greater frequency of dizziness when in these situations. This may be due to an increase in problems with the proprioceptive (Kaplan et al. 1985; Ribeiro and Oliveira 2007) vestibular (Allen et al. 2017) and visual systems (Horowitz et al. 2005; Martinez-Roda et al. 2016) with age leading to a reduction in overall postural stability (Lord et al. 1991). These problems would be further exacerbated by dizziness. Since there was no DIF for these items using the data collected in the pilot study, this result could also be due to chance.

A DIF plot was generated by Winsteps which provides an easily readable interpretation of the DIF contrast for each item (figure 7.8). DIF contrast and significance values are presented in table 7.10.

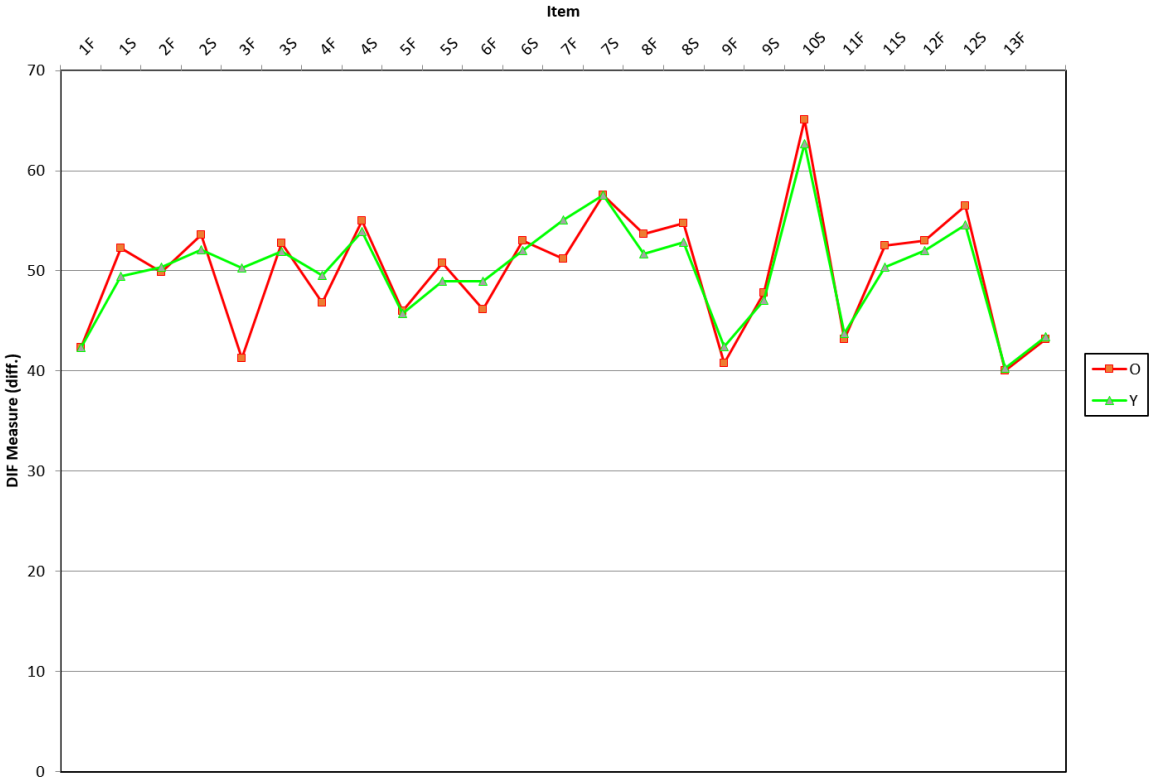


Figure 7.8 DIF (age) measure for each item of VRD-25. The red line (O) represents the older group of respondents and the green line (Y) represents the younger group of respondents. The points where the lines are furthest apart indicate the items where DIF was found.

Table 7.10 DIF (age) contrast and significance values for each item in VRD-25. The older group represents people of ≤47 years and the younger group represents people of ≥48 years. Items in red show DIF.

Item number	Item content	Older group DIF measure	Younger group DIF measure	DIF contrast	Significance (t)
1f	Watching moving traffic etc.	42.4	42.4	0.00	0.00
1s	Watching moving traffic etc.	52.3	49.5	2.82	1.76
2f	Walking alongside a busy road	49.9	50.4	-0.51	-0.30
2s	Walking alongside a busy road	53.6	52.1	1.48	0.87
3f	Problems moving, OK seated	41.3	50.3	-9.02	-5.34
3s	Problems moving, OK seated	52.8	52.0	1.58	0.51
4f	Moving around the home	46.8	49.6	-2.78	-1.73
4s	Moving around the home	55.0	53.9	1.09	0.69
5f	Supermarket aisle	46.0	45.7	0.28	0.17
5s	Supermarket aisle	50.8	49.0	1.80	1.13
6f	Uneven/sloping surfaces	46.1	48.9	-2.82	-1.74
6s	Uneven/sloping surfaces	53.0	52.0	0.95	0.60
7f	Walking up or down stairs	51.2	55.1	-3.88	-2.42
7s	Walking up or down stairs	57.6	57.6	0.00	0.00
8f	Onto/off and escalator	53.7	51.7	2.01	1.16
8s	Onto/off and escalator	54.8	52.9	1.89	1.10
9f	Job/household responsibilities	40.8	42.4	-1.64	-0.95
9s	Job/household responsibilities	47.8	47.0	0.76	0.48
10s	Hand/eye coordination	65.1	62.7	2.42	1.43
11f	Concentration	43.2	43.8	-0.57	-0.34
11s	Concentration	52.5	50.4	2.16	1.37
12f	Confused/disorientated	53.0	52.0	1.03	0.65
12s	Confused/disorientated	56.5	54.6	1.90	1.19
13f	Social activities etc.	40.0	40.3	-0.25	-0.14
13s	Social activities etc.	43.2	43.5	-0.24	-0.15

7.4.7.2 DIF for gender

When respondent data were split by gender, there were 266 females, 67 males and 2 preferred not to say. There were two questions that showed significant DIF for gender – 8F and 8S, these questions ask about the frequency and severity of dizziness when stepping onto or off an escalator. DIF shows that females have greater frequency and severity of dizziness symptoms when performing this task than males. This may be because females are likely to be more anxious about their dizziness and situations (such as using an escalator) that may trigger dizziness than males (Hewitt and Norton 1993; Armstrong and Khawaja 2002). This finding was also present in

the pilot study, however dizziness while stepping onto or off an escalator was a very common theme reported by dizziness sufferers during the development stage of VRD-25, therefore it was deemed appropriate for this item to be retained in the instrument. The DIF plot for gender is presented in figure 7.9. DIF contrast and significance values for gender are presented in table 7.11.

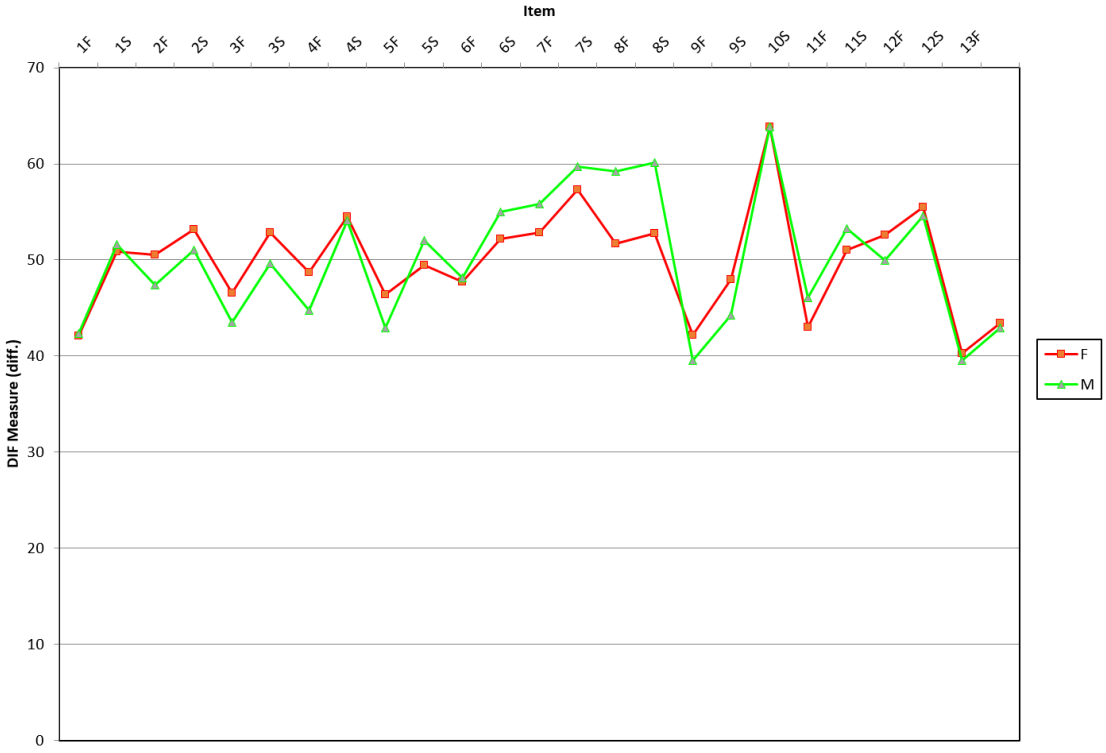


Figure 7.9 DIF (gender) measure for each item of VRD-25. The red line (F) represents the female group of respondents and the green line (M) represents the male group of respondents.

Table 7.11 DIF contrast and significance values for each item in VRD-25 when comparing the responses of females and males**.** Items in red show DIF.

Item number	Item content	Female DIF measure	Male DIF measure	DIF contrast	Significance (t)
1f	Watching moving traffic etc.	42.1	42.4	-0.22	-0.09
1s	Watching moving traffic etc.	50.8	51.6	-0.78	-0.35
2f	Walking alongside a busy road	50.5	47.4	3.14	1.35
2s	Walking alongside a busy road	53.2	51.0	2.13	0.92
3f	Problems moving, OK seated	46.5	43.5	3.01	1.30
3s	Problems moving, OK seated	52.9	49.6	3.20	1.42
4f	Moving around the home	48.7	44.7	3.97	1.74
4s	Moving around the home	54.5	54.1	0.35	0.16
5f	Supermarket aisle	46.4	42.9	3.46	1.49
5s	Supermarket aisle	49.4	52.0	-2.59	-1.16
6f	Uneven/sloping surfaces	47.7	48.2	-0.47	-0.21
6s	Uneven/sloping surfaces	52.2	55.0	-2.76	-1.24
7f	Walking up or down stairs	52.9	55.8	-2.96	-1.33
7s	Walking up or down stairs	57.3	59.7	-2.41	-1.06
8f	Onto/off and escalator	51.7	59.2	-7.47	-2.94
8s	Onto/off and escalator	52.8	60.1	-7.35	-2.94
9f	Job/household responsibilities	42.2	39.6	2.64	1.09
9s	Job/household responsibilities	48.0	44.3	3.72	1.63
10s	Hand/eye coordination	63.9	63.9	0.00	0.00
11f	Concentration	43.0	46.1	-3.05	-1.33
11s	Concentration	51.0	53.3	-2.25	-1.02
12f	Confused/disorientated	52.6	49.9	2.71	1.22
12s	Confused/disorientated	55.5	54.6	0.97	0.44
13f	Social activities etc.	40.3	39.6	0.70	0.29
13s	Social activities etc.	43.5	42.9	0.55	0.24

7.4.7.3 DIF for location

DIF due to location of the respondent was investigated. Again, the data were split into two groups – people from the USA and people from the rest of the world. There were 107 people from the USA and, 116 people from the 'rest of the world'. There were three items (5s, 10s and 12f) that exhibited a DIF contrast of >0.50 with a significance (t) of ≥±2.

DIF for item 5s (How severe is the dizziness that you experience when you are moving around?) indicated that people from the USA were more likely to report a greater severity of symptoms. DIF for item 10s (How severe is the dizziness that you experience when you are walking up or down stairs?)

indicated that people from the ‘rest of the world’ group were more likely to have more severe symptoms.

DIF for item 12f (Does your dizziness cause you to be confused or disorientated?) indicated that people from the USA were more likely to have greater frequency of dizziness.

There was no DIF for either of these items when the data from the pilot study was analysed, this could also be due to random chance since there are 25 items being subject to DIF analysis. With the number for DIF analyses >20, at least one of these is likely to be $p<0.05$ due to chance.

The DIF plot demonstrating this is presented in figure 7.10. DIF contrast and significance values for location are presented in table 7.12.

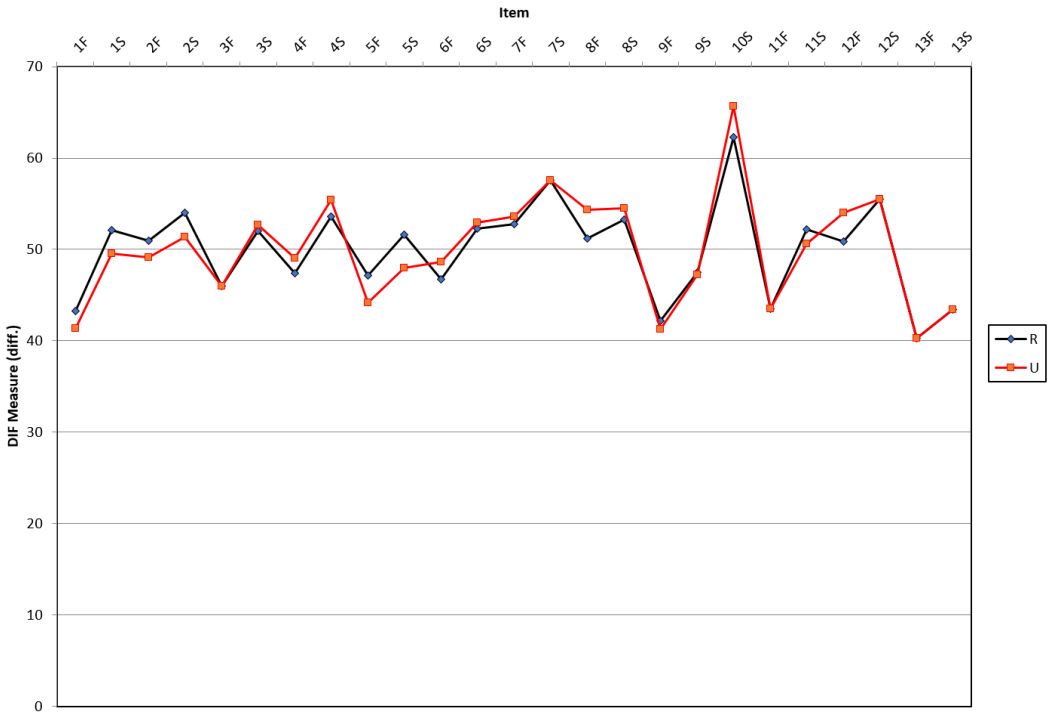


Figure 7.10 DIF (location) measure for each item of VRD-25. The red line (U) represents the group of respondents from the USA and the blue line (R) represents the group of respondents from the ‘rest of the world’.

Table 7.12 DIF (location) contrast and significance values for each item in VRD-25 when comparing the responses of people from the 'rest of the world' and people from the USA. Items in red show DIF.

Item number	Item content	'Rest of the world' DIF measure	USA DIF measure	DIF contrast	Significance (t)
1f	Watching moving traffic etc.	43.2	41.4	1.87	1.11
1s	Watching moving traffic etc.	52.1	49.5	2.57	1.61
2f	Walking alongside a busy road	51.0	49.1	1.87	1.11
2s	Walking alongside a busy road	54.0	51.3	2.67	1.58
3f	Problems moving, OK seated	46.0	46.0	0.00	0.00
3s	Problems moving, OK seated	52.1	52.7	-0.68	-0.43
4f	Moving around the home	47.4	49.0	-1.58	-1.00
4s	Moving around the home	53.6	55.4	-1.79	-1.14
5f	Supermarket aisle	47.2	44.2	3.01	1.85
5s	Supermarket aisle	51.6	48.0	3.68	2.32
6f	Uneven/sloping surfaces	46.8	48.6	-1.85	-1.16
6s	Uneven/sloping surfaces	52.3	53.0	-0.65	-0.42
7f	Walking up or down stairs	52.8	53.6	-0.81	-0.51
7s	Walking up or down stairs	57.6	57.6	0.00	0.00
8f	Onto/off and escalator	51.2	54.3	-3.15	-1.83
8s	Onto/off and escalator	53.2	54.5	-1.29	-0.75
9f	Job/household responsibilities	42.2	41.2	0.94	0.55
9s	Job/household responsibilities	47.4	47.2	0.22	0.14
10s	Hand/eye coordination	62.3	65.7	-3.41	-2.02
11f	Concentration	43.5	43.5	0.00	0.00
11s	Concentration	52.2	50.7	1.52	0.97
12f	Confused/disorientated	50.9	54.0	-3.18	-2.02
12s	Confused/disorientated	55.5	55.5	0.00	0.00
13f	Social activities etc.	40.3	40.3	0.00	0.00
13s	Social activities etc.	43.5	43.5	0.00	0.00

7.5 Re-numbering the instrument

After it was established that the VRD-25 was valid and repeatable, it was decided that the inclusion of the one-part item (10s) in the middle of a collection of two-part items may lead to confusion for the practitioner when calculating a final score since one might wonder if the omission was deliberate or the result of a mistake. The instrument was therefore re-numbered as 1-25 (rather than 1f, 1s, 2f, 2s etc.) so that the single question was presented at the end with the phrase 'thank you for completing this questionnaire' written after it to make it clear that there were no more questions. This resulted the instrument that can be found in Appendix D3. A summary of old and new

numbers together with the subject of each question can be found in table 7.13

Table 7.13 New numbers of the final VRD-25 questionnaire with their previous numbers and a summary of their content. The suffixes ‘f’ and ‘s’ on the old numbers denote a ‘frequency’ and ‘severity’ question respectively

New number	Old number	Content
1	1f	Watching moving traffic or trains and/or crossing roads
2	1s	Watching moving traffic or trains and/or crossing roads
3	2f	Walking alongside a busy road
4	2s	Walking alongside a busy road
5	3f	Moving around (but ok when seated)
6	3s	Moving around (but ok when seated)
7	4f	Moving around the home
8	4s	Moving around the home
9	5f	Walking down a supermarket aisle
10	5s	Walking down a supermarket aisle
11	6f	Difficulty walking on uneven or sloping surfaces
12	6s	Difficulty walking on uneven or sloping surfaces
13	7f	Walking up or down stairs
14	7s	Walking up or down stairs
15	8f	Stepping on or off an escalator
16	8s	Stepping on or off an escalator
17	9f	Interference with job or household responsibilities
18	9s	Interference with job or household responsibilities
19	11f	Difficulty with concentration
20	11s	Difficulty with concentration
21	12f	Feeling of confusion and disorientation
22	12s	Feeling of confusion and disorientation
23	13f	Interference with ability to enjoy social activities
24	13s	Interference with ability to enjoy social activities
25	10s	Problems with hand-eye coordination

7.6 Score converter

The raw scores obtained from the VRD-25 questionnaire needed to be converted to Rasch scores for them to be summed to give a dizziness score. To this end a score converter was created. This is presented in table 7.14. This table should be used when using the full version of VRD-25. The converted scores for each item should be summed to give a vision-related dizziness score with scores ranging from 275 (no dizziness) to 2225 (maximum dizziness). If VRD-12f and VRD-13s are used separately, the conversion tables in table 7.15a and 7.15b should be used for each subscale respectively. When VRD-12f is used separately, the range of scores is 192 to 948. When VRD-13s is used separately, the range of scores is 13 to 1365.

Table 7.14 Score converter for the final version of VRD-25. Item numbers marked with * are frequency items.

Entry \ Item	**0**	**1**	**2**	**3**	**4**
1*	13	21	43	55	70
2	22	30	52	63	79
3*	21	29	51	62	78
4	23	32	43	65	81
5*	17	25	47	58	74
6	23	31	53	65	80
7*	19	27	49	61	76
8	25	33	55	67	81
9*	17	25	47	58	74
10	21	59	51	62	78
11*	18	27	48	60	76
12	23	31	53	65	81
13*	24	32	54	65	81
14	28	36	58	70	85
15*	23	32	53	65	81
16	24	33	54	66	82
17*	13	21	43	54	70
18	18	26	48	60	75
19*	14	22	44	56	72
20	22	30	52	64	79
21*	23	31	53	65	80
22	26	34	56	68	83
23*	11	19	41	53	68
24	14	22	44	56	72
25	32	40	61	73	89

Table 7.15a Score converter for VRD-12f.

Entry / Item	**0**	**1**	**2**	**3**	**4**
1	17	37	47	56	70
3	25	44	54	63	77
5	21	40	51	59	73
7	23	42	53	61	75
9	21	40	50	59	73
11	22	41	52	61	74
13	27	46	57	66	80
15	27	46	57	65	79
17	17	36	47	56	69
19	18	38	48	57	71
21	27	46	57	65	79
23	16	35	46	54	68

Table 7.15b Score converter for VRD13s.

Entry / Item	**0**	**1**	**2**	**3**	**4**
2	12	29	45	65	87
4	15	32	48	68	90
6	14	31	47	68	89
8	17	34	50	71	92
10	11	28	44	64	86
12	14	31	48	68	90
14	21	38	55	75	96
16	16	33	50	70	92
18	7	24	40	61	82
20	29	46	63	83	105
22	13	30	46	66	88
24	18	35	52	72	94
25	1	18	35	55	76

7.7 Limitations

The limitations of the study described in this chapter correspond with those documented in chapter 6 (6.8). Due to the online data collection methods, there

was no way of knowing if the participants had vision-related dizziness either wholly or partially, however, the instrument was designed for use on the general population and the multifactorial nature of dizziness (Colledge et al. 1996; Neuhauser et al. 2008; Tinetti et al. 2000; Ciorba et al.2017) suggests the possibility that dizziness may have a visual element even if the chief cause has been identified as something else. The exclusively online collection of data may have unintentionally excluded those potential participants who didn't use computers.

7.8 Further research

An investigation into whether VRD-25 could discriminate between vision-related dizziness and vestibular-related dizziness would be the next step in development. The instrument would be administered to patients with diagnosed vestibular disease with responses being compared to those of dizzy people who did not have vestibular disease. Potential participants would have to be screened and sorted into a 'vestibular' or 'non-vestibular' category before asking for their participation in such a study. The logical way to proceed would be to collaborate with a hospital vestibular clinic.

7.9 Conclusions

The VRD-25 is the only PROM developed to date to assess vision-related dizziness. It has been developed using Rasch analysis and the two subscales of VRD-12f and VRD-13s provide good psychometric properties, convergent validity and test-retest agreement. VRD-25 could be used to further research into the link between visual impairment, refractive correction and dizziness by providing a PROM for clinical trials of vision and refractive interventions that could reduce dizziness.

Chapter 8.

Summary

This research project set out first to determine if vision had a role in dizziness. A systematic review of the literature (Chapter 2) concluded that self-reported poor vision was linked to dizziness (although likely not when light-headedness is included in the definition of dizziness). It seems likely that this link works via the effects of visual impairment on postural stability (Paulus et al. 1984; Anand et al. 2003a, 2003b; Ray et al. 2008) and the feeling of postural instability leading to symptoms of the disequilibrium subcategory (Drachman and Hart, 1972) of dizziness. This is supported by the reported improvements in dizziness symptoms (assessed using the short form of the DHI) following cataract surgery that were correlated with the improvements in best eye visual acuity (Supuk et al. 2016). Other studies have shown improvements in postural control following cataract surgery (Schwarz et al. 2005, Durmus et al. 2011). Given the shortcomings of the DHI (developed for patients with vestibular disease (Jacobson and Newman 1990) lacks validity (Tesio et al. 1999) possible misinterpretation by patients with visual impairment (sections 4.9 and 5.8) it would be useful to assess dizziness following cataract surgery with the VRD-25. Ideally, postural stability measurements could be taken to allow assessment of associations between vision, postural stability and dizziness changes following surgery. If visual impairment leads to greater dizziness, it would be expected that a low vision population would have higher levels of dizziness than an age-matched group with normal vision and this would be a valuable study. It would also allow determination of which

measurements of vision (visual acuity, contrast sensitivity, visual field, stereopsis) best linked with increased dizziness. Given that contrast sensitivity appears to best link with postural stability (Wood et al. 2009; Lord and Menz 2000), the hypothesis would be that dizziness would also best correlate with contrast sensitivity measures. The role of vision and refractive correction changes in dizziness was then investigated. An exploratory set of case reports (Chapter 3) indicated that both small and large refractive correction changes, fluctuating vision status, spectacle design and possibly ocular dominance might have a role in dizziness. This study led to investigations of refractive correction changes and dizziness both in hospital and private practice settings which in turn highlighted the need for a patient reported outcome measure that specifically assessed vision-related dizziness.

Chapter 4's study investigated whether large refractive correction changes influenced dizziness status and while this study was reluctantly abandoned, the results hinted at dizziness being linked to changes in oblique astigmatism – supporting the work of Supuk et al. (2016). This project was also a very useful learning experience for future research involving NHS ethics procedures.

The study described in chapter 5 was undertaken concurrently with that in chapter 4. It investigated dizziness experienced by people who had small changes in refractive correction by examining the dizziness status of people who were dissatisfied with their new spectacles at three optometric practices. Time restricted the amount of data that could be collected, however the data suggested that oblique cylindrical changes are the most likely to be associated with dizziness with anisometropic changes likely to be linked to dizziness. This

study also highlighted that optometrists don't seem to be aware of the link between dizziness and vision and don't ask about it during routine eye examination.

Finally, the study described in chapters 6 and 7 developed and validated a new questionnaire that is the first to quantify vision-related dizziness since the need for this had been highlighted by the other studies in this thesis.

8.1 Future research

The overall evidence suggests that oblique cylindrical changes (and possibly anisometropic changes) are the spectacle power changes most linked with changes in dizziness status and that dizziness may be reduced by manipulating the refractive correction of a spectacle wearer. Furthermore, optometrists should be made aware of this association and actively enquire about dizziness symptoms when conducting eye examinations.

More research is needed in the area of dizziness, vision and refractive correction changes, especially further study of cylindrical and anisometropic changes to spectacle prescriptions and the VRD-25 will be useful for evaluating patients during these investigations.

A prospective study conducted within private practice would be useful to investigate refractive correction changes further. This setting would provide a large sample with a wide age range who would largely be without the added complications of ocular disease that would be highly prevalent in a hospital population. The VRD-25 would be administered to each patient prior to routine eye examination to provide a baseline measure of vision-related dizziness. Patients who had a change to their refractive correction would be asked to

complete the instrument once again, two to four weeks after collecting their new spectacles to assess any change to dizziness status. These data, along with the recorded spectacle lens changes could then be used to investigate the type and magnitude of spectacle lens change involved in vision-related dizziness.

A parallel study to develop a suitable protocol for assessing and managing patients with vision-related dizziness would involve practitioners following a standard procedure for questioning and prescribing within a set of rules designed with the findings of this thesis in mind. This cohort of patients would also have their dizziness status before and after examination assessed using the VRD-25 and these data would be compared with the patients involved in the first study whose practitioners were not following a specified protocol for dizziness management. It may be that the VRD-25 can be further developed and improved as a result of its use in research investigating vision-related dizziness.

8.2 Future use of VRD-25

The VRD-25 is the first instrument to quantify vision-related dizziness. It is intended that VRD-25 and its subscales will be used for the investigation of vision-related dizziness both in practice and research settings to quantify the impact of interventions. Further research using the VRD-25 may result in determination of the types of refractive correction change that would be most likely to result in visual discomfort and dizziness. This could lead to prescribing advice for optometric practitioners that would reduce the number of spectacle dissatisfaction episodes experienced by patients. The use of VRD-25 in

practice may help practitioners identify individuals susceptible to vision-related dizziness so that they may apply a more cautious approach to prescribing for that patient.

8.3 Recommendations for practitioners

The research carried out in chapter 5 indicated that optometrists are unaware of the link between dizziness and vision and rarely ask specific questions about dizziness during routine eye examination and when conducting a retest. Optometric practitioners should include questions about dizziness in their routine history and symptoms and be aware of the medications that are prescribed for dizziness symptoms and the risk factors (such as polypharmacy, vestibular disease, increasing age etc.) for dizziness.

Optometrists should include questions designed to identify dizziness that might be vision-related such as “Do you feel comfortable with your vision when you are wearing your spectacles?”. More specific questions incorporating the information gathered by patient interviews (6.3.2) might involve questions such as “Do you feel that you have comfortable vision when walking down a supermarket aisle or in a crowd situation?”. Using escalators was also highlighted as a problem for people with vision-related dizziness during patient interviews, however a question asking specifically about the use of escalators might identify those who feel unsteady due to proprioceptive problems as well as patients with vision-related dizziness.

Practitioners should be wary of changing the cylindrical component of spectacle lens power, especially if the cylindrical component is obliquely orientated. In addition, changes in anisometropia should be made cautiously.

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Appendix A: Questionnaires

Appendix A1: The Dizziness Handicap Inventory

DIZZINESS HANDICAP INVENTORY ***(Jacobson and Newman 1990)***
Instructions: Please answer "yes", "no" or "sometimes" to each question. *Answer each question as it pertains to your dizziness or unsteadiness problem only.*

	Item
P1	Does looking up increase your problem?
E2	Because of your problem, do you feel frustrated?
F3	Because of your problem, do you restrict your travel for business or recreation?
P4	Does walking down the aisle of a supermarket increase your problem?
F5	Because of your problem, do you have difficulty getting into or out of bed?
F6	Does your problem significantly restrict your participation in social activities such as going out to dinner, going to movies, dancing, or to parties?
F7	Because of your problem, do you have difficulty reading?
P8	Does performing more ambitious activities like sports, dancing, household chores such as sweeping or putting dishes away increase your problem?
E9	Because of your problem, are you afraid to leave your home without having someone accompany you?
E10	Because of your problem, have you been embarrassed in front of others?
P11	Do quick movements of your head increase your problem?
F12	Because of your problem, do you avoid heights?
P13	Does turning over in bed increase your problem?
F14	Because of your problem, is it difficult for you to do strenuous housework or yardwork?
E15	Because of your problem, are you afraid people might think you are intoxicated?
F16	Because of your problem, is it difficult for you to go for a walk by yourself?
P17	Does walking down a sidewalk increase your problem?
E18	Because of your problem, is it difficult for you to concentrate?
F19	Because of your problem, is it difficult for you to walk around your house in the dark?
E20	Because of your problem, are you afraid to stay home alone?
E21	Because of your problem, do you feel handicapped?
E22	Has your problem places strains on your relationships with members of your family or friends?
E23	Because of your problem, are you depressed?
F25	Does your problem interfere with your job or household responsibilities?
P25	Does bending over increase your problem?

AppendixA2: The Visual Vertigo Analogue Scale

from: J. Vestib Res. 2011;21(3):153-9.

Appendix B: Dissemination of research

Appendix B1: Paper published in *Ophthalmic and Physiological Optics* (2016).

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Is there a link between dizziness and vision? A systematic review

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Keywords: dizziness, systematic review, vision, visual impairment

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Abstract

Purpose: The aim of this study was to systematically review the literature to investigate the link (if any) between vision and dizziness.

Methods: Medline, CINAHL, AMED, Web of Science and The Cochrane Library were searched with keywords chosen to find articles which investigated the causes of dizziness and considered vision as a possible trigger. Citation chaining of all included papers was performed in addition to the hand searching of all reference lists. Unpublished literature was identified using www.opengrey.eu. The review considered studies involving adults which link, measure or attempt to improve any aspect of vision in relation to dizziness.

Results: Nine thousand six hundred and eighty one possible references were found, and the abstracts were screened independently by two reviewers to determine if they should be included in the study. Thirteen papers were found which investigated whether dizziness was linked to an assessment of vision. Visual impairment measures were crude and typically self-report, or Snellen visual acuity with little or no measurement details. Five studies found an independent link between dizziness and vision, five found a weak association (typically finding a link when univariate analyses were used, but not when multivariate analyses were used), and three found no association. Studies finding a strong link were usually cross-sectional with a large study population whereas those finding a weak association had relatively small numbers of participants. Studies which did not find an association used a broad definition of dizziness that included the term light-headedness, an unreliable Rosenbaum near visual acuity chart or an unusual categorisation of visual acuity.

Conclusions: This review suggests that dizziness (although likely not 'light-headedness') is linked with poor vision although further studies using more appropriate measures of vision are recommended.

Introduction

In this systematic review, we aimed to investigate the link (if any) between the assessment of vision and/or refractive correction and dizziness. Traditionally, dizziness has been sub-divided into the four categories suggested by Drachman and Hart[1] These are: vertigo, the feeling that surroundings or self are spinning; pre-syncope, the feeling that one is about to lose consciousness; disequilibrium, the feeling of losing one's balance when standing still and light-headedness, which is often used to describe the feeling associated with postural hypotension. Disequilibrium and vertigo are of particular interest to this study as they both involve movement, the detection of which relies on the visual system. It seems less likely that light-headedness and pre-syncope would be linked to vision. It is difficult to precisely define the term dizziness. Light-headedness, swimming, floating, rocking, spinning, unsteadiness, giddiness, faintness, impending loss of consciousness, unreality, disorientation and imbalance are all used when patients describe their feeling of dizziness. It has been described as a 'non-specific symptom'[2, 3] which has different meanings to

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different individuals, therefore practitioners are advised to ascertain exactly what symptoms their patient has when they use the term dizziness.[4] Warner *et al.*[5] described dizziness as 'an uncomfortable, disturbed state of spatial awareness'. It could be argued that this definition is suitably ambiguous as the term 'dizziness' may be used to describe a variety of often quite vague symptoms, making the condition somewhat difficult to assess and treat.

Dizziness has a prevalence of between 20% and 30% in the elderly population[6–8] and 20–25% in those of working age.[2] Since documentation of dizziness relies on self-report by the patient, these figures may be underestimated due to inaccurate recall (as with falls[9]), differing definitions of dizziness and the exclusion of people with cognitive decline. Dizziness has many different causes. Among these are vestibular disease, which has been found to be a contributing factor in around a third of cases[1,10] and vascular disease, accounting for between 14% and 57% of cases, depending on the population being studied.[11,12] Often, it is not possible to identify a single source for the problem as dizziness is frequently multifactorial[13] and dizziness has been proposed as a geriatric syndrome.[7]

Dizziness can be a debilitating and distressing problem which has emotional and psychological difficulties associated with it as well as functional issues.[14] Dizziness often triggers anxiety[2, 14] and anxiety may lead to dizziness, leaving the patient in a self-perpetuating condition that they feel they may not be able to escape. One of the more serious problems associated with the sensation of imbalance is the increased tendency to fall,[15] especially in the elderly population.[16] When an elderly person falls, it may cause injury and hospitalisation leading to reduced quality of life and loss of independence for the individual.[15] It has been shown that people who have dizziness have a lower perception of their health-related quality of life than non-dizzy people and that dizziness may cause an interruption of normal daily living activities and the tendency to avoid leaving the home. This in turn, presents the sufferer with the economic burden of having to take sick leave, both for themselves and their employer.[10] Dizziness, therefore, can place an economic burden on the community as well as the individual.

There are several possible links between vision, refractive correction and dizziness. First, balance control (or postural stability) is achieved when the visual, vestibular and proprioceptive systems are effectively coordinated.[17] If there is an impairment of one of these systems, the individual relies more heavily on the other two to maintain postural control and minimise disequilibrium and dizziness.[18] The visual element of balance control is influenced by central and peripheral vision as well as eye movements[19] and postural stability has been shown to be reduced in patients with refractive blur, age-related eye disease and eye movement disorders.[20–23]

Second, vision may be associated with dizziness via changes to the vestibulo-ocular reflex (VOR). This reflex ensures the focussed retinal image is stabilized on the retina during head movements by means of equal eye movements in the opposite direction. However, new spectacles change magnification and alter the amount of eye movement gain that is needed to match head movement: myopes tend to have lower VOR gains and hyperopes higher VOR gains[24] For example, a myopic change in refractive correction in new spectacles minifies the visual world so that a head movement of, say, 20° leads to a much larger eye movement than is now needed (the patient should use a lower VOR gain) and the visual world will move or, as described by patients, it will 'swim' and this could cause dizziness. The adaptation with astigmatic changes is complicated further as different amounts of magnification occur in different meridians. Similarly, adaptation to progressive addition lenses is complicated by variation in magnification across the lens requiring variable VOR gain across the visual field.[25]

Third and finally, some patients are diagnosed with Visual Vertigo typically due to unilateral vestibular problems in patients suffering from anxiety.[26] Their dizziness is triggered by an increased sensitivity to rapid changes in their visual surroundings,[27] likely due to altered visual-vestibular integration, leading to greater visual reliance for postural control.[18, 26]

Objectives

If the role of vision and refractive correction in patients with dizziness can be identified and quantified, it may be possible to manipulate vision and the refractive correction to reduce the symptoms of these patients, thus improving the quality of life of those individuals.

In this systematic review we aimed to:

- Investigate the link (if any) between vision and refractive correction and dizziness.
- Determine the methods of measurement of dizziness and vision in research settings and how the link between dizziness and vision may be affected by these methods.
- Determine whether further investigations are needed in this field.

Methods

Inclusion criteria

This review considered all studies involving adults over the age of 18 years where vision was deemed to be among the factors contributing towards dizziness. Studies

which linked or measured any aspect of vision and/or refractive correction in relation to dizziness were considered. The primary outcome of interest was the link between dizziness and vision. Secondary outcomes were the measurement methods used to quantify both dizziness and vision. There were no restrictions on the publication year or status of papers. Case reports were excluded from the review as the evidence offered by them is of the lowest quality.[28] Only papers published in English were included in the review as no translation facilities were available.

Search strategy

Databases searched were Medline (1944–2015), CINAHL (1932–2015), AMED (1980–2015), Web of Science (1950–2015) and the Cochrane Library. Reference lists from papers included in the review were hand searched and citation chains of all included papers were also hand searched for further papers using Google Scholar.[29] Unpublished sources were searched for using www.opengrey.eu, to reduce publication bias.[29]

Subject librarians at the University of Bradford library were consulted about methods for deciding upon the search terms to be used. The search terms were (dizz* or vertigo or 'postural imbalance' or 'postural balance' or 'postural stability' or disequilibrium or oscillopsia or 'light-headed' or disorient*) AND (vision or visual or sight or 'dynamic visual acuity' or ocular or 'depth perception' or stereopsis or 'contrast sensitivity' or spectacles or 'refractive error' or multifocal or bifocal or magnification or optometrist or optometry or 'field of vision' or 'stereo acuity' or AMD or glaucoma or diabet* or cataract or macular or 'eye disease') The combination of search terms is presented in *Table 1*.

Search protocol

Two reviewers, DA and EC, independently searched the databases using the defined strategy. Titles and abstracts of papers identified by the search were reviewed by each reviewer to determine eligibility for inclusion. The two lists of relevant abstracts were then compared and any abstract identified by only one reviewer was read by a third researcher (AA) who made the final decision on inclusion.

Both DA and EC independently read the full documents of the remaining papers and made decisions on eligibility. The final list of papers from each reviewer was then compared, and again, any papers identified by only one reviewer were read by AA to determine eligibility. DA and EC manually screened the reference lists and citation chains of each included paper to identify any further studies which should be included. All included papers were stored on an Endnote library and a PRISMA[30] flow diagram was used to document study selection (*Figure 1*).

Table 1. Table showing how the search terms were combined during the initial database searching for the systematic review

Search terms			
Dizz*	Vision	"Refractive error"	Glaucoma
Vertigo	Visual	Multifocal	Diabet*
"Postural imbalance"	Sight	Bifocal	Cataract
"Postural balance"	AND "Dynamic visual acuity"	Magnification	Macular
"Postural stability"	Ocular	Optometrist	"Eye disease"
Disequilibrium	"Depth perception"	Optometry	Spectacles
Ocillopsia	Stereopsis	"Field of vision"	AMD
"Light headed"	"Contrast sensitivity"	"Stereo acuity"	
Disorient*			

*denotes a search for any word that begins with these letters.

Quality assessment and data extraction

Review specific data extraction forms were created using the Critical Appraisal Skills Programme (CASP) quality assessment tool guidelines[31] The data extraction forms were piloted before the full data search by DA and EC who independently completed data extraction forms for two studies and discussed the results with AA in order to produce the optimum document.

Four screening questions were included in the data extraction sheet, and studies which failed these questions were excluded from the review. Data extraction forms were completed by both DA and EC for each study included in the review. Disagreements between reviewers were discussed and resolved with the assistance of AA.

The Strengthening of the Reporting of Observational Studies in Epidemiology (STROBE)[32] guidelines were used to indicate the quality of included studies. Four researchers independently assessed each paper according to these guidelines. Their findings were then discussed and an agreement was reached about the STROBE score to be given to each paper. The included papers were initially grouped according to the methods used to measure visual function and dizziness. Studies were then assessed to determine what association (if any) was found between vision and dizziness.

Results

Initial database searching identified 9681 papers, with 85 of these being removed as duplicates and title and abstract

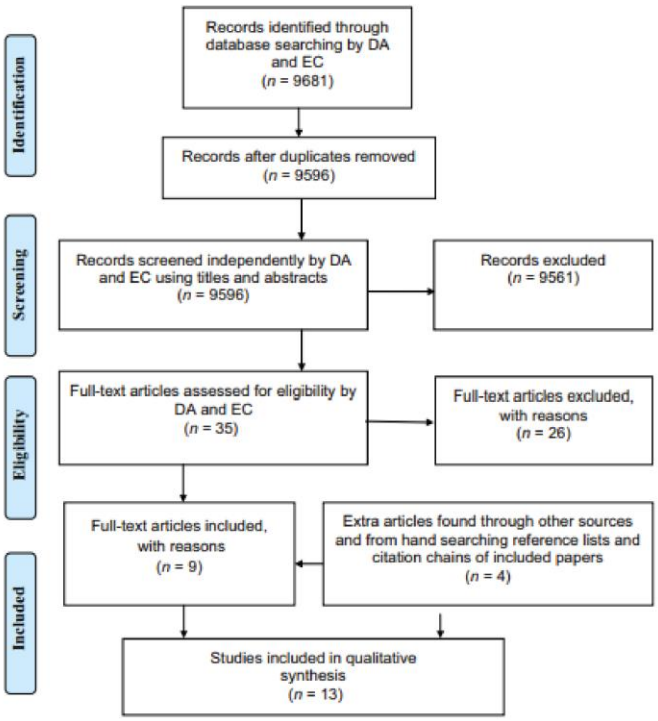

Figure 1. PRISMA flowchart showing the number of papers at each stage of the systematic review process.

screening determined that 35 should be read in full. After the screening process was complete, 13 papers were found which attempted to determine whether there was an association between dizziness and vision.[7, 8, 11, 33–42] Reasons for rejection are presented in *Table 2*. Eight of the included studies were cross-sectional, four were cohort studies, and one was a case control study. Six papers studied a population of 65 years and above, five investigated people of 60 years and above and one study's population was 72 years and above, with the remaining study examining a population of 73–92 years. Of the included studies, five were conducted in the USA, three in the Netherlands, two in the UK, and one in each of Colombia, Sweden and Australia. Both genders were included in all studies.

The 13 papers that have attempted to determine whether there is a link between dizziness and vision are presented in *Tables 3, 4* and *5*. All thirteen papers were reviewed independently by the four authors and the strength of the association between vision and dizziness was estimated. If vision was found to be an independent risk factor we classed it as a strong association and if an association was found in univariate analysis but not in multivariate this was classed as weak association. Any disagreements were discussed subsequently and a final decision agreed upon. Each table includes information about dizziness and vision assessment along with study design, quality assessment and population. *Table 3* presents information from three studies that found no association, *Table 4* presents information from five studies that found a weak association and *Table 5* presents information from five studies that found a strong association.

Discussion

Studies that found no association between vision and dizziness (Table 3)

These three studies, (all with good quality reporting levels) included the term 'light-headedness' in their dizziness definition. This term has links with postural hypotension and feeling faint, which may cause dizziness but has little or no association with vision. Participants (who were largely made up of the older, elderly population – 72+ years) were asked to self-report their dizziness over a long period of time (12+ years[40]) and a lifetime[41] This has implications

Table 2. Reasons for rejection of papers which were read in full

Reason for rejection of paper	Number of papers rejected
Doesn't attempt to link dizziness with vision	7
Discussion article – information based on clinical experience rather than evidence	6
Balance, not dizziness investigated	6
Case report	3
Weak statistics (vision grouped with spectacles or sensory impairment; percentages of patients with risk factors given with no significance values)	3
Same data used as other included study	1

for recall bias and means that a vision measurement made at the time of the examination was compared to a report of dizziness over a long time span. It is impossible to know the participants' vision status at the time that they were dizzy and many of them are likely to have had cataract surgery[43,44] and/or new spectacles within this time frame. These studies used differing methods of vision assessment with none of them providing details of visual acuity measurement such as the distance at which the measurement was taken, luminance levels, whether the measurements were taken monocularly or binocularly or with or without spectacle correction, the type of chart used (assumed to be Snellen), the number of clinicians used to take the measurements (inter-clinician measurements have been shown to have a low levels of repeatability[45]) or whether a termination rule of visual acuity measurement was followed.[46] Tinetti *et al*[7] used the Rosenbaum near vision card which has been shown to be unreliable.[47] Only Aggarwal *et al*[41] specified that spectacles were worn at the time of the test.

Studies that found a weak association between vision and dizziness (Table 4)

Five studies found a weak association between vision and dizziness. These studies largely had small populations (hundreds rather than thousands of participants) and the association was found using univariate analyses meaning that vision may not have had an independent association with dizziness. In four of the papers, no attempt was made to quantify dizziness, with its presence being determined by asking the participant a single question about their dizziness status. Snellen (or unspecified) visual acuity was used to describe vision in three of the studies,[8,37,38] and this method of measurement has been shown to be a poorly reliable method of assessment[48,49] Again, no details about visual acuity measurement were offered, as was the case in the studies which did not find

Table 3. Methods of vision and dizziness assessment for studies that found no association between dizziness and vision

Paper	Design and population	Dizziness assessment	Vision assessment	Association OR (95% CI) or Prevalence (%)	Participant number (N)	STROBE quality/22	Comments
1. Aggarwal[41] *J Gerontol*, 2000	Cross-sectional 65+ USA	"Have you ever been dizzy or light-headed?"	Snellen VA with specs (type not specified, assumed distance)	No association in MV analyses (no data shown)	672	18	Broader definition of dizziness, includes light-headedness. Odd categorisation of VA (6/12 or better; 3/30–6/60 or 6/120+)
2. Menant[40] *JAGS* 2013	Cohort, prospective, secondary analysis 73–92 Australia	"Since the age of 60 years, have you suffered from dizziness or vertigo and light-headedness when standing"	Edge contrast sensitivity	Vision impairment 35% dizzy vs 30% non-dizzy; NS CS 21.2 dB ±1.9 dizzy vs 21.3 ± 2.0; NS	Dizzy 217 Non-dizzy 299	17	No link with vision. Broader definition of dizziness, includes light-headedness
3. Tinetti[65] *Ann Int Med* 2000	Cross-sectional 72+ USA	"During past 2 months have you had episodes of feeling dizzy, unsteady or like you were spinning or moving, light-headed or faint?"	50% visual impairment calculated from near VA with Rosenbaum card	Visual impairment > 50 % 36% dizzy vs 36 % not dizzy; $p > 0.2$	1087	20	No link with near visual acuity. Broad definition of dizziness as includes light-headedness & feeling faint

MV, multivariate; NS, not significant; CS, contrast sensitivity; VA, visual acuity; OR, odds ratio; CI, confidence interval.

Table 5. Methods of vision and dizziness assessment for studies that found vision had a strong association with dizziness

Paper	Design and population	Dizziness assessment	Vision assessment	Association OR (95% CI) or prevalence (%)	Participant number (N)	STROBE quality/22	Comments
9. Gomez[33] *J Nutr, health & ageing*, 2011	Cross-sectional 60+ Colombia	"Have you ever been bothered by dizziness in the past month"	"Trouble with vision?" Y/N	UV: 1.83 (1.33–2.52); $p < 0.001$ MV: 1.48 (1.05–2.08); $p < 0.02$	1692	17	Dizziness independently linked with self-reported "trouble with vision"
10. Maarsingh[34] *BMC Geriat*, 2014	Cohort, prospective 60+ Netherlands	"Are you dizzy regularly?" Y/N	"Can you see well enough?" Y/N	7 years UV:2.3 (1.5–3.6); $p < 0.001$ 7 years MV: 1.8 (1.1–3.0); $p = 0.016$	1379	18	Visual impairment an independent predictor of future dizziness at 7 years
11. Sloane[35] *JAGS*, 1989	Cross-sectional 60+ USA	"Have you ever been bothered by dizziness?"	"Blurry vision" or "poor eyesight" or "blindness" Y/N	UV: Risk ratio 2.58, $p < 0.001$ MV: OR 3.7 (2.7–4.9); $p < 0.001$ for 'neurosensory impairment' (10 variables including 'blurry vision', 'poor eyesight & 'blindness' Y/N)	1622	15	Strong association between dizziness and various aspects of poor vision
12. Stevens[36] *Age & Ageing*, 2008	Cross-sectional 65+ England	"How often do you have problems with dizziness when you are walking on a level surface?"	Rate sight (very good, good, fair, poor)	MV: 1.7 (1.2–2.4)	2925	11.5	Self-reported poor vision an independent predictor of dizziness
13. Supuk[42] *OPO* 2015	Cohort, prospective & retrospective 65+ England	Dizziness Handicap Inventory (short form) questionnaire	Distance VA (logMAR) pre & post operation	Change in best eye VA MV: OR 17.71, $p = 0.003$	287	19	Dizziness improved by cataract surgery and linked with best eye VA change. Oblique astigmatism may increase dizziness

UV, univariate; MV, multivariate; Y/N, yes or no answer; VA, visual acuity; OR, odds ratio; CI, confidence interval.

a link between vision and dizziness (see the above discussion). The term 'impaired vision' is not defined in any of these studies. The cut off, for what is termed 'impaired vision' varied between studies and the categories (where stated) did not divide the data equally. For example, Kao's paper has a cut off of 'VA worse than 6/18' which would mean the majority of participants would be in the 'good vision' category, placing the remaining participants in the 'poor vision' category. This leaves sample sizes in the intermediate (where categorised) and poor vision categories with much reduced numbers when compared with numbers in the good vision category.

Studies that found a strong association between vision and dizziness (Table 5)

Five studies[33–36,42] found an independent association between dizziness and vision. Four of these reports had large study populations of over 1000 participants. Multivariate analyses were used, indicating that an independent association of vision with dizziness was found. Studies asked patients mainly about recent dizziness with Supuk *et al.*[50] quantifying the amount of dizziness experienced using the short form of the Dizziness Handicap Inventory, which has been Rasch analysed and shown to have good validity. Four studies[33–36] did not measure visual acuity, preferring to use self-report of vision as an indicator of visual status.[33–36] This suggests that dizziness may be more highly linked to an individual's perception of their vision, rather than to their measured vision. Anxiety can have a negative effect on self-perceived health[51] and several studies have shown anxiety to be a risk factor for dizziness[2, 52, 53] with patients who suffer from anxiety disorders tending to feel more handicapped by their dizziness when conducting their daily tasks than those who are not anxious.[54] Although Gomez[33] and Stevens[36] did not investigate anxiety, Maarsingh[34] and Sloane[35] included 'anxiety', or 'perception of self as a nervous person' in their multivariate analyses[34, 35] and yet those analyses suggested that self-reported poor vision was an independent risk factor for dizziness even after adjusting for anxiety measures. This suggests that poor vision may well be an independent risk factor for dizziness. Maarsingh's[34] paper also concluded that visual impairment is an independent predictor for future dizziness at seven years indicating that the association between vision and dizziness may well be strong.

Limitations

There may have been search terms which were overlooked when deciding upon the search strategy. This would result in papers which should have been included in the study being omitted, however hand searching the reference lists and citation chaining all the included papers would safeguard against missing any significant papers. The exclusion of papers not written in English may have resulted in significant papers being overlooked from this review. The assessment of the extent of the association between dizziness and vision was independently made by several researchers and then agreed upon, but as all were clinical vision scientists (two of which were authors on a recent study included in this review[42]) there may have been a bias towards finding an association rather than the reverse.

Recommendations

Standardisation of methods of vision and dizziness assessment would aid comparison of findings. The use of a validated questionnaire, such as the Dizziness Handicap Inventory[55] or its short form[50] to quantify dizziness would help to determine the severity and character of the problem. The nature of visual impairment is very much dependent upon what has caused the difficulty, thus, a simple measure of visual acuity using Snellen charts may not accurately quantify the visual impairment of someone with visual field or contract sensitivity loss. Snellen visual acuity measurements have been shown to have poor repeatability due to practitioner and observer variability,[45] and poor chart design[48] highlighting the need for a more accurate assessment of visual acuity. In addition, a more comprehensive assessment of visual function to include aspects of vision such as contrast sensitivity, visual field and stereoacuity is required to accurately assess vision status. Future studies should be undertaken using more appropriate measures (and cut off values) of vision and dizziness (which should be measured at the same time) to quantify the association between the two, as to date, studies have not done this reliably. Investigations into links between dizziness and vision in the working age population would help to ascertain whether this is a concern for all patients who suffer from dizziness, or whether the problem is limited to the elderly population.

Conclusion

This review has identified an area where little research has been published to date. The inconsistency of measurement methods for dizziness and vision made accurate comparison of studies difficult. Studies finding no link between vision and dizziness all included the term 'lightheadedness' in their definition of dizziness, used participants from the older, elderly population (72+ years) and asked patients to recall dizziness over a long period of time. Those finding a weak association between vision and dizziness had relatively small numbers of participants and did not attempt to quantify dizziness or define what

was meant by 'impaired vision'. The five studies finding an independent association between vision and dizziness were typically cross-sectional with large study populations who were mainly asked about their recent dizziness and self-perceived vision status. The overall evidence therefore suggests that dizziness (although likely not when lightheadedness is included in the definition of dizziness) is linked with poor vision.

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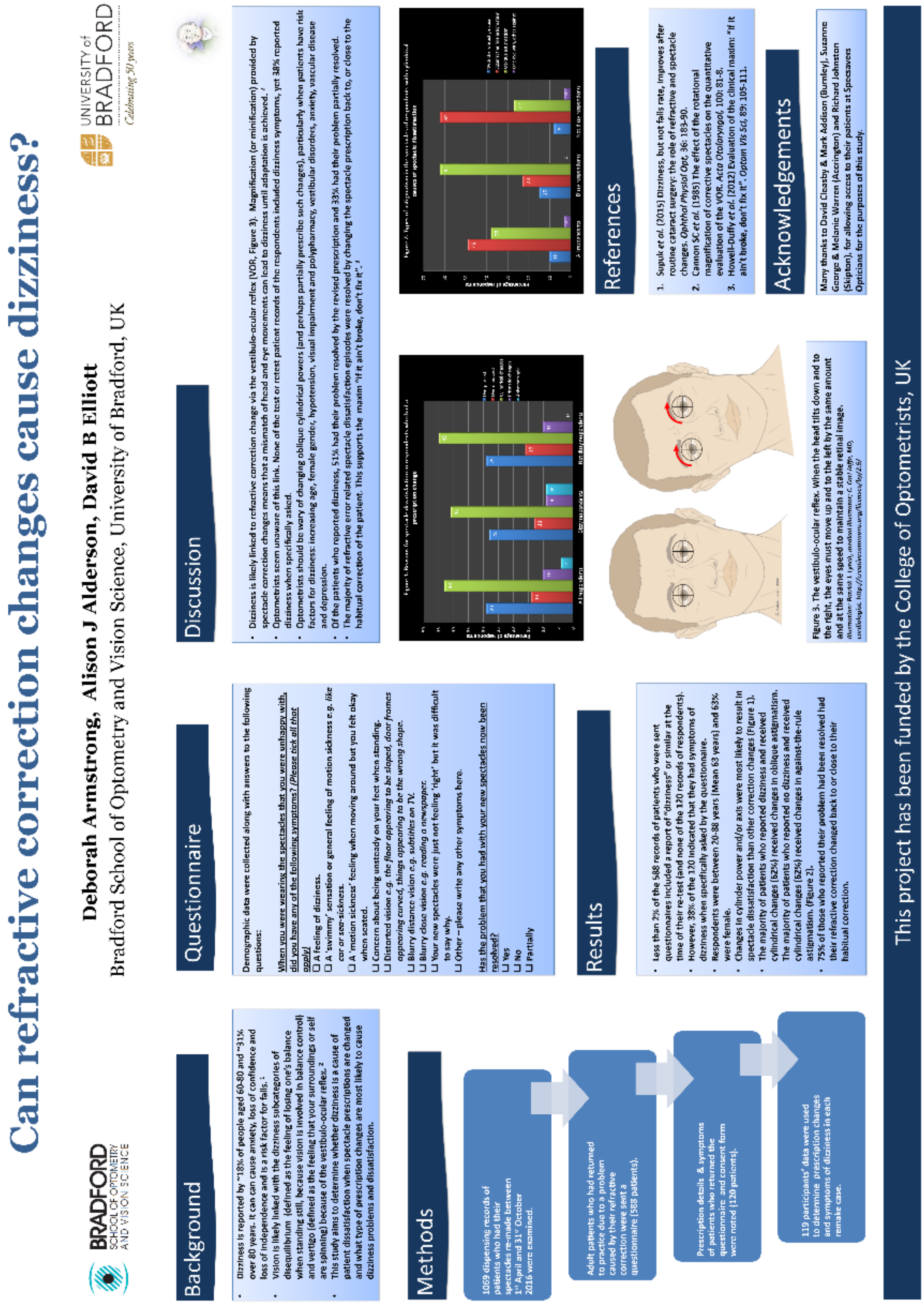
Appendix B2: Poster presented at *Optometry Tomorrow*, The College of Optometrists' annual conference and trade exhibition. Birmingham, UK on 13th and 14th March 2016.

Appendix B3: Poster presented at *Optometry Tomorrow*, The College of Optometrists' annual conference and trade exhibition. Birmingham, UK on 19th and 20th March 2017.



Appendix B4: Paper published in *Frontiers in Neurology* (2018)**.**

frontiers in Neurology

ORIGINAL RESEARCH
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Development and Validation of the Vision-Related Dizziness Questionnaire

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Purpose: To develop and validate the first patient-reported outcome measure (PROM) to quantify vision-related dizziness. Dizziness is a common, multifactorial syndrome that causes reductions in quality of life and is a major risk factor for falls, but the role of vision is not well understood.

Methods: Potential domains and items were identified by literature review and discussions with experts and patients to form a pilot PROM, which was completed by 335 patients with dizziness. Rasch analysis was used to determine the items with good psychometric properties to include in a final PROM, to check undimensionality, differential item functioning, and to convert ordinal questionnaire data into continuous interval data. Validation of the final 25-item instrument was determined by its convergent validity, patient, and item-separation reliability and unidimensionality using data from 223 patients plus test–retest repeatability from 79 patients.

Results: 120 items were originally identified, then subsequently reduced to 46 to form a pilot PROM. Rasch analysis was used to reduce the number of items to 25 to produce the vision-related dizziness or VRD-25. Two subscales of VRD-12-frequency and VRD-13-severity were shown to be unidimensional, with good psychometric properties. Convergent validity was shown by moderately good correlations with the Dizziness Handicap Inventory ($r = 0.75$) and good test–retest repeatability with intra-class correlation coefficients of 0.88.

Conclusion: VRD-25 is the only PROM developed to date to assess vision-related dizziness. It has been developed using Rasch analysis and provides a PROM for this under-researched area and for clinical trials of interventions to reduce vision-related dizziness.

Keywords: vision-related dizziness, dizziness, patient-reported outcome measure, questionnaire, Rasch analysis

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INTRODUCTION

Dizziness is common in older people (~30% in patients over 65 years of age) (1), can have significant negative effects on quality of life (2, 3), and is a major risk factor for falls (4). Although vestibular disease and central vascular disease are the most commonly reported diagnoses in secondary/tertiary care (1, 5) and primary care (1), respectively, the prevalence of specific causes of dizziness varies hugely (1, 6) and dizziness is a multifactorial geriatric syndrome (1–3, 6) like falls. Causes

include vestibular disease, psychiatric disorders, vascular disease including hypotension, polypharmacy, medication side effects, Parkinson's disease, and visual impairment. There are several subcategories (7) of dizziness: disequilibrium, light-headedness, pre-syncope, and vertigo and each may be related to different diagnoses. Visual impairment (1) and changes in refractive correction (8) likely have a role in the dizziness subcategories of vertigo (the feeling that either the individual or their surroundings are spinning) *via* the vestibulo-ocular reflex and disequilibrium (the feeling that an individual cannot keep their balance when they are standing still) *via* the influence of visual function on postural stability (9).

Although the literature investigating the link between vision and dizziness is relatively small, the authors of a systematic review concluded that large-sample, well-designed epidemiological studies found that self-reported visual impairment was a significant independent predictor of dizziness (10). In addition, a recent cohort study found that dizziness reduced following first-eye cataract surgery by an amount linked to the improvement in best eye visual acuity, but was increased by changes in oblique astigmatic refractive correction (11). Finally, patients with Visual Vertigo report dizziness that is triggered by visual motion such as when walking in supermarket aisles, driving, and watching moving scenes. This condition is thought to be due to overreliance on visual control after vestibular disease or other insult (12, 13).

There are currently no patient-reported outcome measures (PROMs) that assess vision-related dizziness (3). The Visual Vertigo Analog Scale (14) is a nine-item visual analog scale to assess the intensity of symptoms for patients with Visual Vertigo which was developed using classical test theory. It is restricted to assessment of the one condition of Visual Vertigo. Most of the commonly used dizziness PROMs, such as the current standard, the Dizziness Handicap Inventory (DHI), were developed for patients with vestibular disease (15). In addition, the great majority of PROMs that target dizziness used traditional classical test theory questionnaire development methods (3, 15) and a systematic review concluded that there were no validated PROMs for the study of age-related vestibular loss in clinical trials (15).

Preferred for the development of PROMs are the psychometric methods of item response theory that includes Rasch analysis (16–20). These have many advantages over classical test theory such as the conversion of ordinal data from questionnaire responses into continuous interval data, allowing linear measurement and determining dimensionality (16, 18). Indeed, traditionally developed PROMs have been re-engineered and scored using Rasch analysis when assessing vision-related quality of life (19, 20). Rasch analysis has been used to develop a short-form (13 items) of the 25-item DHI (21) and we have used this PROM in a study of dizziness before and after cataract surgery (11). However, it was developed to assess patients with vestibular disease, with 6 of 13 items being directed at symptoms from such patients (items relate to dizziness when getting in and out of bed, turning over in bed, bending over, quick head movements, looking up, and walking in the dark) with just three items being related to vision in some way (dizziness when reading, walking down the aisle of a supermarket, and walking on the sidewalk, the latter two being well-known triggers for Visual Vertigo) and is limited in its assessment of vision-related dizziness.

The aim of this study was to develop and validate using Rasch analysis the first PROM to quantify vision-related dizziness. This would provide a PROM for clinical research in the under-researched area of vision-related dizziness and for clinical trials of vision and refractive interventions aimed to reduce dizziness.

MATERIALS AND METHODS

PROM Development

Patient-reported outcome measure development and validation generally followed the recommendations by Pesudovs et al. (16). This study was carried out in accordance with the recommendations of the Research Ethics Committees of both the University of Bradford and the UK National Health Service (UK EC1843 and IRAS 180272). The protocol was approved by these committees. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

Domain and Item identification

Patient-reported outcome measures relating (separately) to visual disability, vision-related quality of life, and dizziness were identified from a comprehensive search of the literature and were examined to identify domains and items that could be related to vision-related dizziness. The structure of the Rasch-developed visual symptom PROM, Quality of Vision (22), with its three subscales of the "frequency," "severity," and "bothersomeness" of symptoms, was incorporated into the item identification process. We previously found that a "frequency" based questionnaire developed to assess spectacle adaptation symptoms (which included dizziness), appeared to be limited by a lack of assessment of the severity/bothersomeness of symptoms (23). Response categories of "so severe/bothersome I have reduced doing this" and "so severe/bothersome I have stopped doing this" provided assessment of the activity limitation aspects of dizziness. The domains and items identified by the literature search and further identification of other domains and items were discussed with nine experienced clinicians and structured interviews with patients who self-reported problems due to dizziness. The clinicians included two consultant geriatricians (in the UK, a consultant physician typically has at least 10 years post registration experience and is similar to a US attending physician) and a specialist physiotherapist with 10+years of experience, a consultant ophthalmologist, two optometrists (authors David B. Elliott and Alison J. Alderson, with 20+years of clinical experience), two ENT consultants, and a hospital specialist audiologist with 20+years of experience. The nine patients were recruited from the staff of the University *via* an email request and patients from local vision and falls clinics and included patients with self-reported vision-related dizziness linked to age-related cataract (two) multifocal spectacle lens use (two), large spectacle power changes (one), one patient with Visual Vertigo and three patients with vestibular disease who helped differentiate between dizziness linked to vestibular disease and vision-related issues. Patients were recruited and

interviewed until saturation of themes had been reached. They were asked about the important quality of life issues that were affected by their dizziness.

Item Reduction

Items deemed to be irrelevant, duplicate, or unhelpful were then discarded by a three-step process. First, by separate consultation with the clinicians described above. Second, by a focus group of six of those clinicians. Third, by a focus group of four patients (age range 35–79 years, two females) who were recruited *via* an email request from the staff of the University and patients at the University Eye Clinic and reported vision-related dizziness (two diagnosed with Visual Vertigo, two with a history of dizziness due to multifocal spectacles).

Cognitive Interviews

After item reduction, the patient focus group provided cognitive interview information by discussing the readability and ease of comprehension of the items and response categories. This resulted in appropriate wording changes to some questions and the addition of clarification of what was meant by each response category. For example, the category of "Very Often" could mean different frequencies to different people, so the focus group suggested that adding "(e.g., 2–6 times per week)" would make it easier for participants to understand what was meant.

Pilot Questionnaire

As the diagnosis of dizziness is multifactorial and challenging and many patients are unaware of whether vision is part of the etiology of their dizziness (1), the inclusion criteria for completion of the pilot questionnaire included any patient with self-reported dizziness who was over 18 years and had suffered from dizziness in the past month. An electronic version of the questionnaire was created using Wufoo (http://www.wufoo.com) and indicated that a questionnaire was being developed to quantify vision-related dizziness. Patients gave their consent by submitting a completed online questionnaire. The research was publicized *via* e-newsletters and social media to international dizziness-related support groups (e.g., the Vestibular Disorders Association, Vertigo & Meniere's disease support group), national support centers for older people (e.g., Women's Institute of the UK and Canada; Age UK), and a wide range of regional UK older peoples' forums and support groups. Paper copies of the pilot instrument were made available to patients with dizziness in regional Falls, Vestibular Diseases and Audiology Clinics, and informed consent was gained from patients who completed the paper version of the questionnaire. The pilot questionnaire was available for completion on the Wufoo site between April 4, 2016 and June 21, 2016. The minimum target sample size was 250 (24). Additional information collected included respondent age, sex, cause of dizziness, and whether they had fallen in the last 6 months.

Data Analysis of Pilot Questionnaire

Rasch analysis (Winsteps version 3.91.0; Winsteps, Chicago, IL, USA) using an Andrich rating scale model assessed the response categories and individual person data. Individual items from the pilot data were examined in terms of their fit to the Rasch model of Infit and Outfit [values outside the range of 0.60–1.40; this is slightly more lenient than the 0.70–1.30 suggested by Pesudovs et al. (16) and follows Wright and Linacre] (25), normality of the distribution including ceiling and floor effects, proportion of missing data (>33%) (26), and the distance of the item mean response to the mean participant response (16). Poorly fitting items were removed iteratively with the model being reanalyzed after each item elimination. If the fit of the model was negatively affected by the removal of an item, that item was re-introduced. The process was repeated until all items fitted well and the content of the final instrument, the vision-related dizziness (VRD-25) PROM, was determined. Unidimensionality of VRD-25 was checked with principal components analysis. Any subscales identified by the principal components analysis were then reanalyzed using Rasch analysis to ensure robust psychometric properties. Dimensionality of VRD-25 was assessed using principal components analysis to test for unidimensionality and differential item functioning (DIF) was used to assess whether different groups (such as younger vs. older participants, males vs. females) answered the questions differently. A significant difference was taken as the Rasch–Welch DIF contrast being >0.5 logits and the t value being $\geq \pm 2$ (27).

Assessment of VRD Performance

Electronic versions of the VRD-25 and the DHI, were created using Wufoo (http://www.wufoo.com) and publicized *via* the same e-newsletters and social media used previously. Respondents were asked to complete both questionnaires and they were available on the Wufoo site between November 1, 2016 and February 22, 2017. Performance of the VRD-25 was assessed using convergent validity, person, and item-separation reliability, test–retest agreement, dimensionality using principal components analysis, and DIF using Rasch analysis.

Convergent validity was assessed by the amount of correlation with a related measure, the most commonly used dizziness PROM, the DHI (15). Acceptable performance would be a correlation coefficient between VRD and DHI between 0.30 and 0.90 (16). This is the first step in evaluating validity of VRD and future studies may assess other aspects of validity.

Discriminative ability was assessed using Rasch person and item-separation reliabilities. These measure how well the items of the instrument differentiate between people with different levels of dizziness. Good separation indices indicate that the instrument can discriminate between people with different levels of dizziness. For example, a person-separation index of >2.0 indicates that the instrument can discriminate between people with high and low symptom levels and good performance would be reliability coefficients ≥0.80 (16).

Test–retest reliability of VRD was determined by re-administering VRD (and DHI for comparison) after 2–4 weeks to those participants who had consented. Good performance would be a test–retest intra-class correlation coefficient ≥0.80 (16). Correlation analyses were performed using SPSS statistics for Windows (version 23.0; IBM Corp., Armonk, NY, USA).

RESULTS

The development process is summarized in **Figure 1**.

Domain and Item Identification

One hundred twenty items under three domains of symptoms, activity limitation, and psychosocial issues were identified. Items included the frequency and severity of dizziness related to reading, walking alongside a busy road, down the aisle of a supermarket, on sloping surfaces, up or down stairs, moving around the home, stepping onto an escalator, watching moving scenes on TV, watching a scrolling computer screen, when driving a car, and looking from a height; plus psychosocial issues due to dizziness of difficulties concentrating, feeling confused, anxious or upset, people thinking you are intoxicated and being afraid to leave the home.

Item Reduction

Questions that related to "light-headedness" (most often used to describe symptoms associated with postural hypotension) were removed from the list of possible items, as the results of a systematic review of the link between vision and dizziness suggested these were not relevant to vision-related dizziness (10). Initially, items included three versions relating to the frequency, severity, and bothersomeness of symptoms (22). However, the clinicians and patient focus group felt that if a patient found their dizziness to be "bothersome," they would rate it as "severe" and they thought the latter term was more understandable so that "bothersome" response categories were removed. In addition, the original Quality of Vision instrument reported the lowest person-separation reliability and construct validity for the bothersomeness scale (22). A five-point Likert-type response scale for responses was used to minimize respondent burden while maximizing measurement of the construct (28). The resulting 46-item instrument, including three domains of symptoms (17 items), activity limitation (17 items), and psychosocial issues (12 items), formed the pilot questionnaire.

Pilot Study Questionnaire

The pilot instrument was completed by 351 participants with a mean age of 57 ± 14, range 20–94 years; 79% were female; 95% completed online; 75% were from North America, 21% from Europe, and 4% other; the most common self-reported causes of participants' dizziness were Vestibular (including Ménière's Disease, Vertigo, and Labyrinthitis) 58%, unknown 26%, visual 5%, and other 11%; 38% had fallen in the last 6 months.

Each item and person's responses were examined and 16 sets of individual respondent data were discarded as they were incomplete [>33% missing responses (26)] or reported not being dizzy in the previous month. All items provided less than 33% missing responses, and all were included in the analyses. Category probability curves were generated from the remaining sample of 335 and suggested no redundancy of response categories and only minor differences between response categories *3 and 4 which were not alleviated by* collapsing the two categories so that they were retained. The Rasch person-item map is shown in **Figure 2**. It shows the average positions of items on the right as numbers from Q1 to Q23 for both F (frequency) and S (Severity) items, with the items at the top being more rarely endorsed as they were only responded to positively by people who had high levels of dizziness. The respondents are on the left of the map with a # representing two respondents. Respondents at the top have more frequent and severe symptoms than those at the bottom.

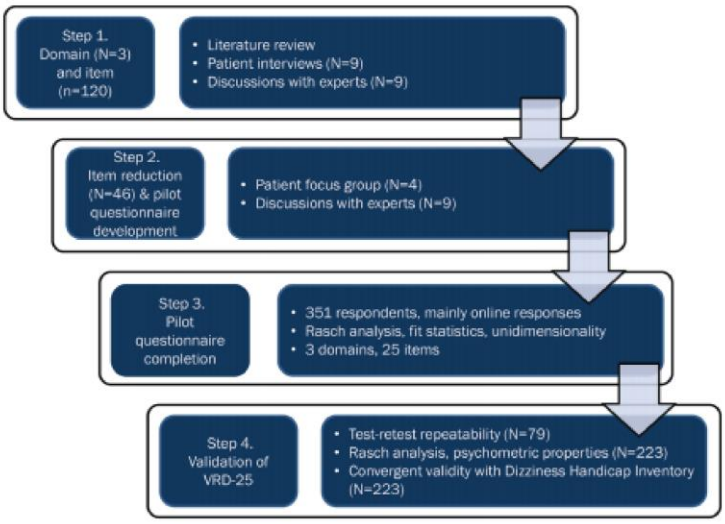

FIGURE 1 | A flowchart showing the development and validation process for the 25-item vision-related dizziness (VRD-25) patient-reported outcome measure.

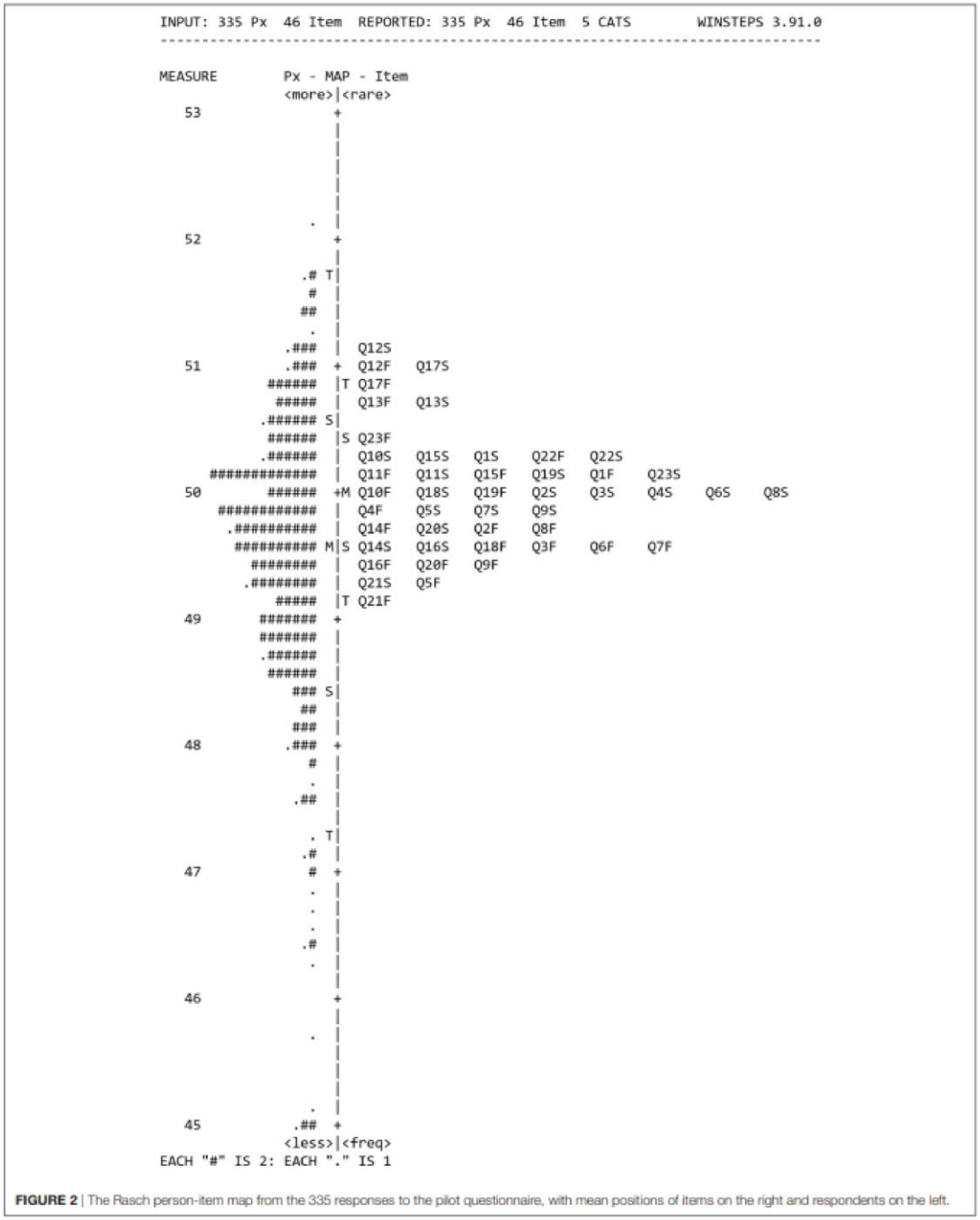

FIGURE 2 | The Rasch person-item map from the 335 responses to the pilot questionnaire, with mean positions of items on the right and respondents on the left.

The person-separation and item-separation reliabilities were 0.94 and 0.98, respectively. Using the procedure described in the methods, twenty-one (46%) poorly fitting items were iteratively removed, to leave VRD consisting of 25 items. VRD-25 is shown in Presentation S1 in Supplementary Material.

VRD-25 Validation

Differential item functioning (a test of item bias) showed no significant differences for age (above and below the median age of 57). Slight DIF differences were found between male and female respondents for three unconnected items and were not deemed sufficiently important to remove the item. The VRD-25 provided an excellent person-separation reliability of 0.94 and item-separation reliability of 0.98, which are well above the level required for good performance of ≥0.80 (16).

Principal components analysis indicated that the data were not unidimensional, with 57% of the raw variance explained by the measure and the eigenvalue of the first contrast being 3.2 and above the cutoff value of 2.0 (27). Two components were indicated by principal components analysis and these clearly split into the items that related to the "severity" of the dizziness and its "frequency." These two subscales were then assessed using Rasch analysis and principal components analysis. Both subscales of "frequency" (termed VRD-12f) and "severity" (VRD-13s) items were found to be unidimensional (VRD-12f 58%, VRD-13s 59% raw variance explained, all eigenvalues below 1.95). Rasch indices remained very good for all items (infit and outfit values within 0.60–1.40), person-separation reliabilities (VRD-12f: 0.88; VRD-13s: 0.90), and item-separation reliabilities (VRD-12f: 0.96; VRD-13s: 0.98).

VRD-25 and DHI were completed by a further 223 participants (mean age 48, SD 12 years; 83% female; 100% completed online; 56% from North America, 29% from Europe including 26% UK, 7% Oceania, and 8% other). VRD-12f and VRD-13s data were normally distributed (Kolmogorov–Smirnov, $p > 0.10$) but DHI data were not ($p = 0.021$). Rasch analysis indicated the following person-separation reliabilities (VRD-12f: 0.88; VRD-13s: 0.90) and item-separation reliabilities (VRD-12f: 0.97; VRD-13s: 0.96), with other psychometric properties similar to the pilot instrument data. Scatterplots of VRD-13s and VRD-12f vs. DHI are shown in **Figure 3**, showing Spearman correlation coefficients between the two of 0.75 (VRD-12f vs. DHI) and 0.76 (VRD-13s vs. DHI).

VRD-25 and DHI repeatability data was obtained from 82 participants (mean age 51, SD 11 years; 90% female; 100% completed online; 54% from North America, 27% from Europe including 21% UK, 11% Oceania, and 8% other) and data from 3 participants were discarded as they showed major changes in dizziness score (>33 on the 0–100 scales). The Bland–Altman 95% repeatability values were ±13 (DHI), ±19 logits (VRD-12f), and ±14 logits (VRD-13s) (**Figure 4**). To allow comparison with earlier reports, intra-class correlation coefficients between test and retest data were calculated and found to be 0.92 (DHI), 0.88 (VRD-12f), and 0.88 (VRD-13s). The mean time taken to complete the PROM was 6 (range 3–10) minutes.

DISCUSSION

As expected, the VRD-25-item instrument was found to be multidimensional with two clear subscales, one containing items related to the frequency of vision-related dizziness issues and the other related to their severity. These two subscales were found to be unidimensional, which is a prerequisite before item responses can be summed to provide a total score (17, 28). Our previous experience (23) and that of others (22) is that the assessment of symptoms appears to need an assessment of both their frequency and severity/bothersomeness. The VRD-25 subscales of frequency (VRD-12f) and severity (VRD-13s) were individually shown to have excellent person-separation reliability (>0.87) and item-separation reliability (>0.89) by Rasch analysis and well above the recommended level for good performance of 0.80 (16). Convergent validity was determined by the association with the DHI and was found to be within the acceptable performance band of between 0.30 and 0.90 (16) (VRD-12f, $r = 0.70$; VRD-13s, $r = 0.73$). Test–retest repeatability of the VRD-25 was well above the good performance level of test–retest intra-class correlation coefficients (0.80) at 0.88 and 95% confidence limits of agreement were ±14 (VRD-13s) and ±19 logits (VRD-12f) and similar to the repeatability of the DHI ($r = 0.92$, ±13, respectively). The DHI repeatability data are similar to that reported by the developers of the instrument with morning–afternoon test–retest data (from which you might expect reduced variability compared to a 2-week test–retest period) from 14 participants of ±18 limits of agreement and a test–retest correlation coefficient of 0.97.

A limitation of the study is that the participants who completed the pilot and final PROMs may not be representative of patients with vision-related dizziness. Indeed, 58% reported that the principal cause of their dizziness was Vestibular disease (including Ménière's Disease, Vertigo, and Labyrinthitis) and only

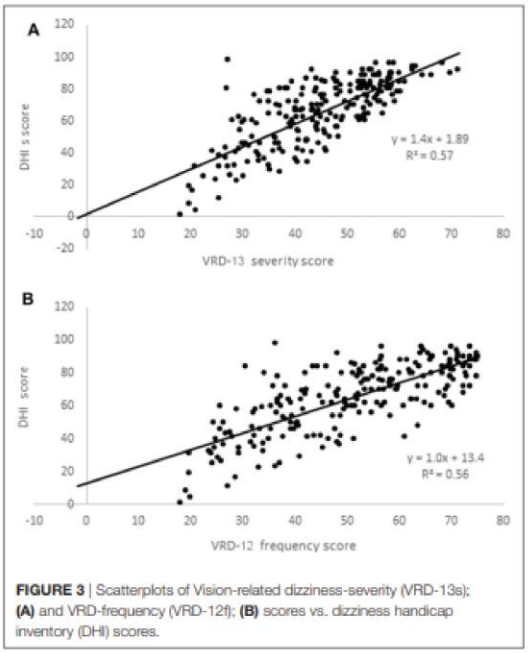

FIGURE 3 | Scatterplots of Vision-related dizziness-severity (VRD-13s); **(A)** and VRD-frequency (VRD-12f); **(B)** scores vs. dizziness handicap inventory (DHI) scores.

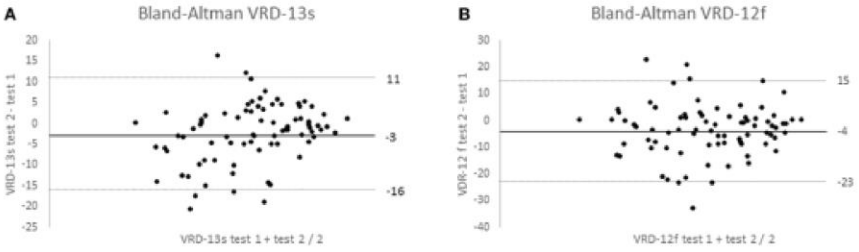

FIGURE 4 | Bland–Altman plots of Vision-related dizziness-severity (VRD-13s); **(A)** and VRD-frequency (VRD-12f); **(B)** showing mean test–retest differences and 95% confidence limits for 70 participants.

5% reported their dizziness was mainly due to a vision problem. However, dizziness is multifactorial (1–3, 6) and vision plays a greater role in controlling balance when the vestibular system is impaired (29), so that any impairment in vision in patients with vestibular disease is likely to lead to increased dizziness. This is highlighted by the condition "Visual Vertigo" which is thought to be due to overreliance on visual control after vestibular disease or other insult (12, 13). In addition, the prevalence of vision-related dizziness may be underestimated (for example, patients may believe that their dizziness is due to a vestibular problem yet have Visual Vertigo) and there is little high quality epidemiological data investigating the link between visual impairment and dizziness (10). It may be that once more is known about the visual contribution to dizziness, an improved vision-related dizziness PROM can be developed. The high percentage of respondents being female (79%) may be because dizziness is more common in women and particularly older women (2), who constituted the majority of our respondents. It may be that women are also more likely to be members of support groups such as those we targeted like the VDA, Pensioner forums, and of course, the Women's Institute.

In summary, VRD-25 is the only PROM developed to date to assess vision-related dizziness. It has been developed using Rasch analysis and the two subscales of VRD-12 (frequency) and VRD-13 (severity) provided good psychometric properties, convergent validity, and test–retest agreement. VRD-25 can be used to develop research into the link between dizziness and visual impairment and refractive correction and provides a PROM for clinical trials of vision and refractive interventions that could reduce dizziness.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the Research Ethics Committees of both the University of Bradford and the UK National Health Service (UK EC1843 and IRAS 180272). The protocol was approved by these committees. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

AUTHOR CONTRIBUTIONS

DA: study design, data collection, data analysis, and manuscript preparation. AA: study design and manuscript preparation. CD: data analysis, data interpretation, and manuscript preparation. DE: study design, data interpretation, and manuscript preparation.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at https://www.frontiersin.org/articles/10.3389/fneur.2018.00379/full#supplementary-material.

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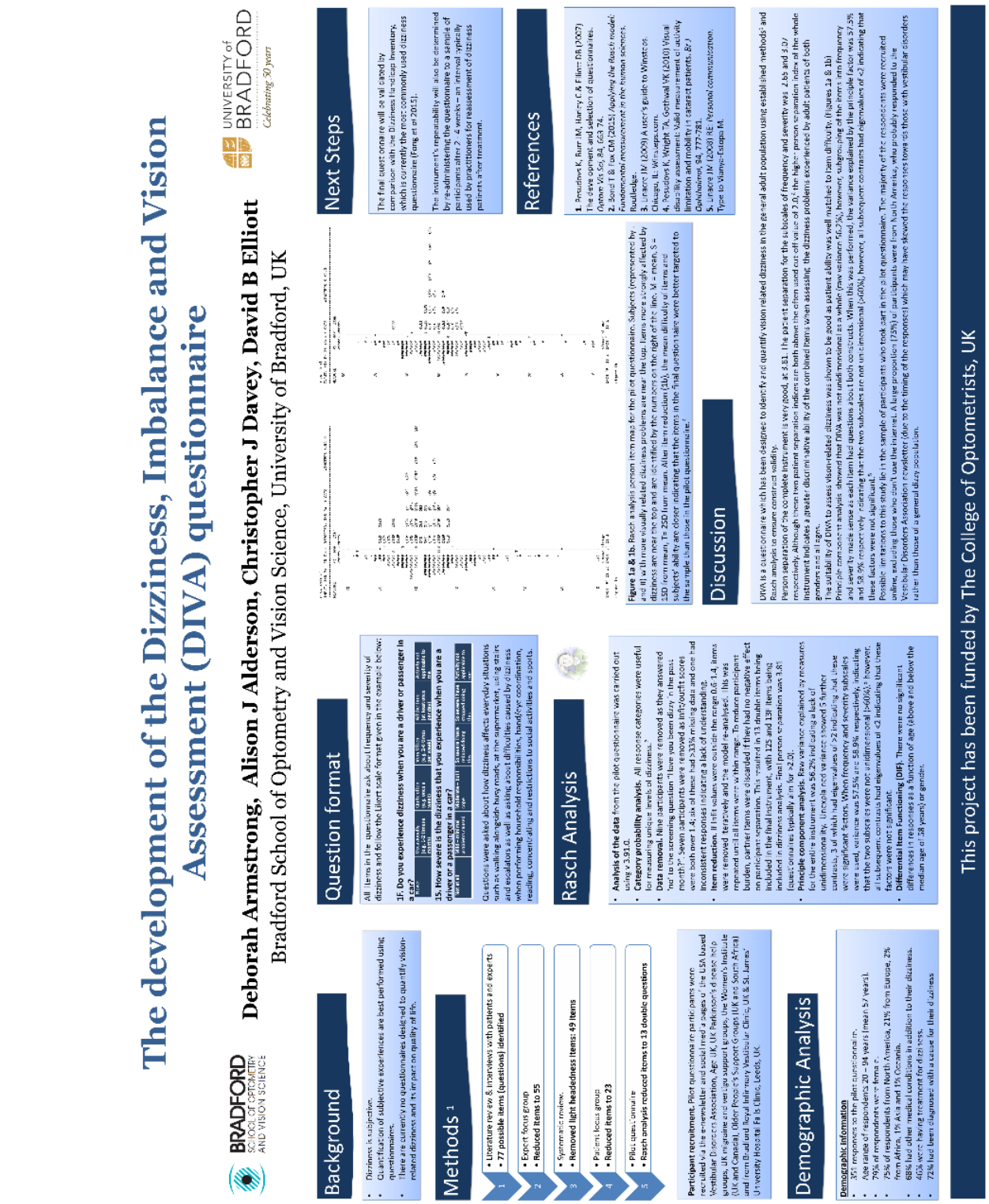
Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer JC and handling Editor declared their shared affiliation.

Appendix B5: Poster presented at *Academy 16.* American Academy of Optometry Conference. Anaheim, USA 10th and 11th November 2016.



Appendix C: Data extraction sheet

DATA EXTRACTION SHEET – Is there a link between vision and refractive correction and dizziness?
Title/journal/date of publication:

Date of data extraction:	Reviewer:
Study design	Cohort Case-control Cross-sectional Prospective Retrospective Epidemiological
Is the population studied suffering from dizziness?	YES NO
Is at least 1 of the risk factors vision related (poor vision, change in glasses, field of vision, binocular vision etc.)?	YES NO
Is the paper written in English?	YES NO
Is the population studied over 18 years of age?	YES NO

If the answer to all the questions above is yes continue, if not the study can be excluded.

Are there any other reports of this study? YES NO

Section A: Participant details

No. invited to participate	
Method of recruitment	
No. enrolled in study	
No. included in analysis	
Age of participants	
Gender of participants	
Country where study was conducted	
Setting	Community Institution Hospital Other
Inclusion criteria	Age Mobility Cognitive ability Other
Exclusion criteria	Age Mobility Cognitive ability Other

Section B: Measurement of symptoms

Risk factors examined	Age Gender Meds GH Mobility Mental ability Anxiety vestibular probs vision other
How is vision measured?	
What visual function is measured?	Distance vision/VA Near vision/VA CS Depth perception Visual fields self-report other
Duration of dizziness	
What definition of dizziness is used? If any.	No definition specified
How is dizziness measured?	Questionnaire Which one? Self-report
Is a vision-related problem identified as a risk factor for dizziness?	YES NO
Potential for bias	
When in study was vision measured?	Beginning End Other
Information re. whether any change in glasses/cataract surgery/other occurred during study period	YES NO
Prevalence of dizziness in population studied	
When is dizziness present?	With Rx Without Rx Both
Information on type of correction worn	YES NO

Section C: Outcome measures

Type of outcome	
Length of follow up	
Results of analysis	
Type of analysis used	

Section D: Miscellaneous

Does this study attempt to improve vision?	YES NO Details.
Does this study attempt to reduce dizziness symptoms?	YES NO Details
Conclusions of study authors	
Comments from review authors	
New references found	

Appendix D: Development and validation questionnaires

Appendix D1: 46 item pilot questionnaire used in the development of VRD-25

Dizziness, Imbalance and Vision Assessment (DIVA) Questionnaire

Version 11 created 09/01/16

PILOT QUESTIONNAIRE

The results of this study will be presented anonymously. Please do not give your name.

Please enter your age to the nearest year

	years
	Prefer not to say

Please select your gender

Female	
Male	
Prefer not to say	

Instructions

Please complete the following questions, using a tick as in the example below.

Example: Do you experience dizziness when you are a driver or a passenger in a car?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week) ✓	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

Example: How severe is the dizziness that you experience when you are a driver or a passenger in a car

Not at all	Mild – minimal problems caused ✓	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

When thinking about any dizziness you have had over the past month……..

1. **Do you experience dizziness when you are a driver or passenger in a car?**

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are a driver or passenger in a car?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

2. **Does your dizziness cause you to have difficulty watching moving traffic or trains and / or crossing roads?** (*please answer for whichever activity causes the most dizziness*)

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are watching moving traffic or trains and / or crossing roads?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

3. **Does your dizziness cause you to have difficulty watching moving scenes on TV or watching a scrolling computer screen?** (*please answer for whichever activity causes the most dizziness*)

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when watching moving scenes on TV or watching a scrolling computer screen?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

4. Do you have problems walking alongside a busy road because of your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are walking alongside a busy road?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

5. Do you have problems when moving around because of your dizziness but are okay when seated?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are moving around?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

6. How often is moving around your home difficult due to your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are moving around your home?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

7. Does walking down the aisle of the supermarket increase your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are walking down the aisle of the supermarket?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

8. How often is it difficult for you to walk around obstacles? (*e.g. in a crowd)*

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are walking around obstacles?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

9. Does your dizziness make it difficult for you to walk on uneven or sloping surfaces?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are walking on uneven or sloping surfaces?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

10. Is it difficult for you to walk up or down stairs because of your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are walking up or down stairs?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

11. Do you have difficulty stepping on to or off an escalator because of your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are using an escalator?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

12. Does your dizziness lead to you having difficulties using a lift?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are using a lift?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

13. Does your dizziness make it difficult for you to stand in a wide open space?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are standing in a wide open space?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

14. Do you avoid heights or looking from a height because of your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you look from a height?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

15. Do you have difficulties reading due to your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are reading?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

16. **Does your dizziness interfere with your job or household responsibilities?**

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are doing your job or household responsibilities?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

17. Does your dizziness cause difficulties with hand/eye coordination? *E.g. problems when reaching for a door knob.*

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are attempting hand/eye coordination?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

18. Is it difficult for you to concentrate because of your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you have difficulty concentrating?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

19. Does your dizziness cause you to feel confused or disorientated?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that causes you to feel confused or disorientated?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

20. Do you feel anxious or upset due to your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that causes you to feel anxious or upset?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

21. Does your dizziness interfere with your ability to enjoy or participate in social activities, sports or pastimes?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that interferes with your ability to enjoy or participate in social activities, sports or pastimes?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

22. Are you afraid people may think you are intoxicated because of your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are afraid people may think you are intoxicated?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

23. Does your dizziness make you afraid to leave your home on your own?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are afraid to leave home on your own?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

Thank you for completing this questionnaire

APPENDIX D3: The version of the VRD-25 that was used in the validation and repeatability study

Vision Related Dizziness questionnaire (VRD-25)

Version 1 created 17/10/16

The results of this study will be presented anonymously. Please do not give your name.

Please enter your age to the nearest year

	years
	Prefer not to say

Please select your gender

Female	
Male	
Prefer not to say	

What type of vision correction do you wear for distance tasks, (e.g. driving, walking about, TV, theatre) and how often do you wear it?

(tick all that apply, ***if no vision correction is needed, please leave blank***)

	All of the time		Some of the time	
	Spectacles	Contact lenses	Spectacles	Contact lenses
Distance vision correction				
Bifocal correction				
Varifocal / Multifocal correction				

Please give your date of birth in the forma dd/mm/yyyy followed by your full initials (this will be used to pair up questionnaires during reliability evaluation)

Have you suffered from dizziness during the past month?

By 'dizziness' we mean a sensation that you or your surroundings are moving when you know that there is no movement. This is NOT referring to the light-headedness that is sometimes felt when rising suddenly from a chair.

Yes	
No	

Please write today's date here:

Day	Month	Year

Instructions

Please complete the following questions, using a tick as in the example below.

1. **Example: Does your dizziness cause you to have difficulty watching moving traffic or trains and / or crossing roads?** (*please answer for whichever activity causes the most dizziness*)

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week) ✓	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

Example: How severe is the dizziness that you experience when you are watching moving traffic or trains and / or crossing roads?

Not at all	Mild – minimal problems caused ✓	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

……

When thinking about any dizziness you have had <u>over the past month</u>……..

1. Does your dizziness cause you to have difficulty watching moving traffic or trains and / or crossing roads? (*please answer for whichever activity causes the most dizziness*)

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are watching moving traffic or trains and / or crossing roads?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

2. Do you have problems walking alongside a busy road because of your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are walking alongside a busy road?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

3. Do you have problems when moving around because of your dizziness but are okay when seated?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are moving around?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

4. How often is moving around your home difficult due to your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are moving around your home?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

5. Does walking down the aisle of the supermarket increase your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are walking down the aisle of the supermarket?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

6. Does your dizziness make it difficult for you to walk on uneven or sloping surfaces?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are walking on uneven or sloping surfaces?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

7. Is it difficult for you to walk up or down stairs because of your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are walking up or down stairs?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

8. Do you have difficulty stepping on to or off an escalator because of your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are using an escalator?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

9. Does your dizziness interfere with your job or household responsibilities?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are doing your job or household responsibilities?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

10. Does your dizziness cause difficulties with hand/eye coordination? *E.g. problems when reaching for a door knob.*

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you are attempting hand/eye coordination?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

11. Is it difficult for you to concentrate because of your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that you experience when you have difficulty concentrating?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

12. Does your dizziness cause you to feel confused or disorientated?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that causes you to feel confused or disorientated?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

13. **Does your dizziness interfere with your ability to enjoy or participate in social activities, sports or pastimes?**

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

How severe is the dizziness that interferes with your ability to enjoy or participate in social activities, sports or pastimes?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

Now we need to compare this new questionnaire with an established one. Please choose one option per question.

The Dizziness Handicap Inventory

	Yes	No	Sometimes
Does looking up increase your dizziness?			
Because of your dizziness, do you feel frustrated?			
Because of your dizziness, do you restrict your travel for business or recreation?			
Does walking down the aisle of a supermarket increase your dizziness?			
Because of your dizziness, do you have difficulty getting into or out of bed?			
Does your dizziness significantly restrict your participation in social activities, such as going out to dinner, going to the movies, dancing, or going to parties?			
Because of your dizziness, do you have difficulty reading?			
Does performing more ambitious activities such as sports, dancing, household chores (sweeping or putting dishes away) increase your dizziness?			
Because of your dizziness, are you afraid to leave your home without having someone accompany you?			
Because of your dizziness, have you been embarrassed in front of others?			
Do quick movements of your head increase your dizziness?			
Because of your dizziness, do you avoid heights?			
Does turning over in bed increase your dizziness?			
Because of your dizziness, is it difficult for you to do strenuous housework or gardening/yardwork?			
Because of your dizziness, are you afraid people might think you are intoxicated?			
Because of your dizziness, is it difficult for you to go for a walk by yourself?			
Does walking down a pavement/sidewalk increase your problem?			
Because of your dizziness, is it difficult for you to concentrate?			
Because of your dizziness, is it difficult for you to walk around your house in the dark?			
Because of your dizziness, are you afraid to stay home alone?			
Because of your dizziness, do you feel handicapped?			
Has your dizziness placed stress on your relationships with members of your family or friends?			
Because of your dizziness, are you depressed?			
Does your dizziness interfere with your job or household responsibilities?			
Does bending over increase your dizziness?			

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE.

IF YOU WOULD LIKE TO HELP WITH TESTING THE RELIABILITY OF THE QUESTIONNAIRE, PLEASE COMPLETE IT AGAIN IN 2-4 WEEKS' TIME USING THE SAME DATE OF BIRTH AND INTIALS ID CODE.

APPENDIX D3: The final VRD-25.

Vision Related Dizziness questionnaire (VRD-25)

Please enter your age to the nearest year

	years
	Prefer not to say

Please select your gender

Female	
Male	
Prefer not to say	

Instructions

Please complete the following questions, using a tick as in the example below.

Example: Does your dizziness cause you to have difficulty watching moving traffic or trains and / or crossing roads? (*please answer for whichever activity causes the most dizziness*)

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week) ✓	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

Example: How severe is the dizziness that you experience when you are watching moving traffic or trains and / or crossing roads?

Not at all	Mild – minimal problems caused ✓	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

When thinking about any dizziness you have had <u>over the past month</u>……..

1. Does your dizziness cause you to have difficulty watching moving traffic or trains and / or crossing roads? (*please answer for whichever activity causes the most dizziness*)

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

2. How severe is the dizziness that you experience when you are watching moving traffic or trains and / or crossing roads?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

3. Do you have problems walking alongside a busy road because of your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

4. How severe is the dizziness that you experience when you are walking alongside a busy road?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

5. Do you have problems when moving around because of your dizziness but are okay when seated?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

6. How severe is the dizziness that you experience when you are moving around?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

7. How often is moving around your home difficult due to your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

8. How severe is the dizziness that you experience when you are moving around your home?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

9. Does walking down the aisle of the supermarket increase your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

10. How severe is the dizziness that you experience when you are walking down the aisle of the supermarket?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

11. Does your dizziness make it difficult for you to walk on uneven or sloping surfaces?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

12. How severe is the dizziness that you experience when you are walking on uneven or sloping surfaces?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

13. Is it difficult for you to walk up or down stairs because of your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

14. How severe is the dizziness that you experience when you are walking up or down stairs?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

15. Do you have difficulty stepping on to or off an escalator because of your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

16. How severe is the dizziness that you experience when you are using an escalator?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

17. Does your dizziness interfere with your job or household responsibilities?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

18. How severe is the dizziness that you experience when you are doing your job or household responsibilities?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

19. Is it difficult for you to concentrate because of your dizziness?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

20. How severe is the dizziness that you experience when you have difficulty concentrating?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

21. Does your dizziness cause you to feel confused or disorientated?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

22. How severe is the dizziness that causes you to feel confused or disorientated?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

23. Does your dizziness interfere with your ability to enjoy or participate in social activities, sports or pastimes?

Never	Occasionally (e.g. 1-2 times a month)	Quite often (e.g. once a week)	Very Often (e.g. 2-6 times per week)	All the time (at least once per day)	Activity not applicable to me

24. How severe is the dizziness that interferes with your ability to enjoy or participate in social activities, sports or pastimes?

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

25. How severe is the dizziness that you experience when you are attempting hand/eye coordination? *E.g. problems when reaching for a door knob.*

Not at all	Mild – minimal problems caused	Moderate – but I cope	So severe I have reduced doing this	So severe I have stopped doing this	Activity not applicable to me

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE