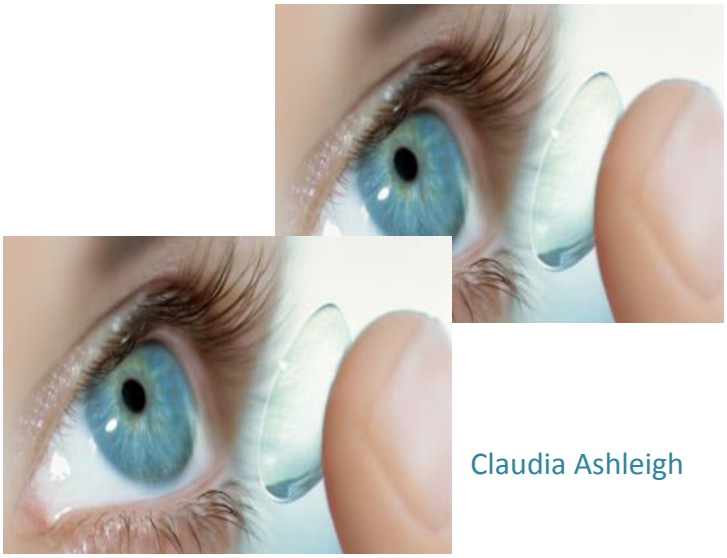
A Double Masked Randomised Crossover Trial of two Silicone Hydrogel Multifocal Contact Lenses



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A thesis submitted in partial fulfilment of the requirements of London South Bank University for the degree of Professional Doctorate in Optometry

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Abstract

Purpose:

To compare visual performance and acceptance of two different designs of monthly disposable silicone hydrogel multifocal contact lenses, the Air Optix Aqua Multifocal and the Biofinity Multifocal.

Methods:

A double masked randomised crossover trial of 62 presbyopic participants (between 41 and 60 years of age) was conducted. Participants were randomised first into either the Air Optix Aqua Multifocal or the Biofinity Multifocal lens to be worn for four weeks for each modality. There was a washout period of one week before wearing the second option. Measurements included binocular photopic distance visual acuity (VA), binocular photopic near VA, stereoacuity at distance and near and contrast sensitivity in photopic, mesopic and scotopic lighting conditions. Subjective participant experience for quality of vision was collected using the VF-14 visual function questionnaire and a specially designed daily diary.

Results:

Fifty-seven participants completed both periods of this crossover study (mean age 52.9, 43 females, 14 males). The difference for binocular photopic distance and near VAs between the Air Optix Aqua and Biofinity Multifocal were marginal (distance: $p>0.13$, near: $p>0.24$). Differences for stereoacuity at distance and near between the Air Optix Aqua and Biofinity Multifocal were not statistically significant (distance: $p=0.33$, near: $p=0.36$) and measurements for contrast sensitivity in mesopic and scotopic lighting conditions showed no statistically significant difference between the lens types (mesopic: $p>0.18$ and scotopic: $p>0.31$). Photopic contrast sensitivity

showed statistically significant results and was marginally better with the Air Optix Aqua Multifocal than Biofinity Multifocal (p=0.013 by paired t-test and p=0.018 Wilcoxon Signed Ranks test). This was judged unlikely to be of clinical significance and most likely a chance finding. Marginal but not statistically significant preferences were found for the data of the VF-14 visual function questionnaire and the daily diary with participants preferring the Air Optix Aqua Multifocal for distance vision (distance vision scores: Wilcoxon Signed Ranks test: 79-76%) and reporting more satisfaction with intermediate and near vision with the Biofinity Multifocal lens design (intermediate vision scores: 66-60% and near vision scores: 74-72%). Comfort scores were equally high for both lens designs (comfort scores: 78-82%). 43 participants (75%) felt soft multifocal contact lenses were a good alternative to spectacles and 33 participants (58%) were continuing to use one of the two designs one year after the trial ended. Of these, 17 wearers (51%) were wearing the Air Optix Aqua and 16 (49%) the Biofinity Multifocal lens.

Conclusions:

There were no consistent differences in visual performance between the Air Optix Aqua Multifocal and the Biofinity Multifocal lens design. The Air Optix Aqua multifocal was found to be marginally superior in participants' subjective scores for binocular distance vision and the Biofinity Multifocal for binocular intermediate and near vision. Based on feedback at follow up, presbyopic participants in this research rated soft silicone hydrogel multifocal contact lenses a good alternative to spectacle wear.

Key Words:

Presbyopia, multifocal, silicone hydrogel, contact lens, double masked crossover, comparison study, visual function questionnaire, daily diary

Acknowledgement

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'Success is no accident. It is hard work, perseverance, learning, studying, sacrifice and most of all LOVE of what you are doing!'
(Pélé)

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5.1.4.1 Binocular photopic distance VA

Table 13: Paired t-test Analysis for Binocular Photopic Distance VA Lens A and Lens B

5.1.4.2 Binocular photopic near VA

Abbreviations

VA	visual acuity
D	dioptre
DK	oxygen permeability
GP	gas permeable
SiH	silicone hydrogel
PMMA	poly methyl methacrylate
MMA	methyl methacrylate
SA	stereoacuity
FDA	Food and Drugs Agency
CS	contrast sensitivity
CSF	contrast sensitivity function
MTF	modular transfer function
BDVA	binocular distance visual acuity
ASA	American Standards Association

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Chapter 1

Introduction

This thesis is a comparison study of two different designs of monthly disposable silicone hydrogel multifocal contact lenses. The purpose of this introductory chapter is to give an insight into the anatomy of the human eye and its properties. It will explain the basic refractive errors and how these can be assessed and corrected using modern optometric measures like contact lenses. The final part of this chapter concentrates on the history of contact lenses, the evolution of contact lens materials and techniques used to correct a person's ageing eye with contact lenses to give a basic understanding of the evolution of contact lenses and their possibilities.

1.0 Overview of the eye

1.1 The optical properties of the eye

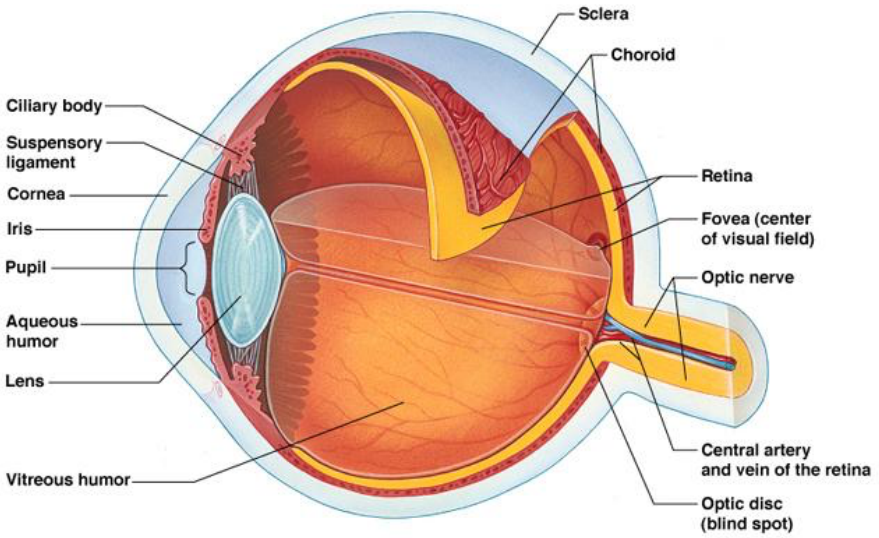


Figure 1: A schematic view of the eye (Chader and Taylor, 2013)

The eye is a complex organ consisting of many structural elements and layers: together they convert light entering its sphere into an image on the retina, which is then delivered to the human brain for its interpretation. For basic purposes of analysis the eye can be divided into five major components:

1) The front of the eye through which light enters, consisting of the cornea, the anterior chamber and the aqueous humour.
2) The accommodative apparatus, where light is focussed to make its path through the varying media to eventually form a clear image at the back of the eye. This part of the eye consists of the iris, the suspensory ligaments, the ciliary body and the crystalline lens, positioned towards the anterior aspect of the eye.
3) The support section at the medial aspect of the eye, which gives stability to the structure as a whole, consisting of the vitreous humour.
4) The posterior surface where the image is formed and which connects the eye to the brain, consisting of the retina, the choroid, the fovea and the optic nerve.
5) The surrounding shell protecting the structure, consisting of the sclera.

To create an image on the retina, light passes through many different media and surfaces with different refractive properties on its way from the anterior surface to the posterior pole of the eye. Refractive qualities have been investigated by past researchers and to simplify calculation, resulted in a universally accepted model of the standard eye and its refractive qualities.

1.1.1 The "Standard Eye"

In the early part of the 20th century Helmholtz and other researchers demonstrated the refractive qualities of the eye (von Helmholtz, 1924). On the basis of these findings, Gullstrand developed a sophisticated version of the "Standard Eye"(Katz & Kruger, 2006), which allows a set of standardised calculations to be used, simplifying the complex refractive qualities of all the surfaces and media necessary to create a sharp image on the retina. Gullstrand's universally accepted version of the eye has an overall refractive power of 58.64 dioptres (D) and an axial length of 24.4mm.

1.2 Refractive errors

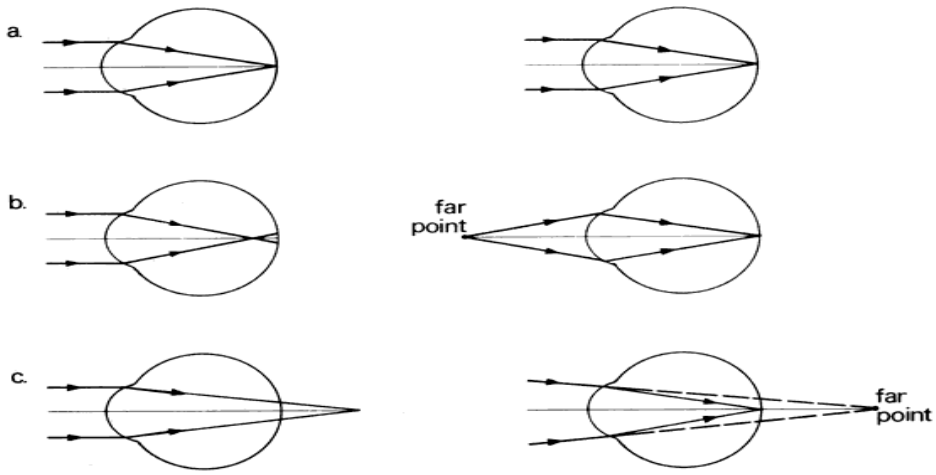


Figure 2: The human eye as an optical system (Katz & Kruger, 2006), a: schematics of an emmetropic eye, b: schematics of a myopic refractive error and its correction without showing a corrective lens, c: schematics of a hyperopic refractive error and its correction without showing a corrective lens

1.2.1 Emmetropia

This describes the condition when the focussing of the visual system works in such a way that all rays of light get projected directly onto the retina at the back of the eye. This results in a near-perfect sharp image, as seen in Figure 2a. Using the simple parameters of

Gullstrand's "Standard Eye" mentioned above a sharp image will form on the retina of an emmetropic eye.

1.2.2 Ametropia

This describes any refractive error of the eye, which is a focussing error in relation to distance objects when the eye is not accommodating. The main types of refractive errors are myopia, hypermetropia (hyperopia) and astigmatism.

1.2.3 Myopia

In this refractive condition the eye has grown too long or the refractive power of the eye is too great. A sharp image does not form on the retina, but in front of it, therefore creating an out-of-focus magnified image on the actual retina (Figure 2b). Appropriately powered spectacles or contact lenses will optically reposition the resultant image onto the retina.

1.2.4 Hypermetropia

Here, the eye has not reached perfect length or the refractive power of the eye is reduced such that a diminished, blurred image forms on the retina. The sharp image is projected past the retina to a virtual, far point beyond the eye, as seen in Figure 2c. The focussed eye, spectacles or contact lenses will bring the image forward, re-positioning it onto the retina.

1.2.5 Astigmatism

This term describes the condition of any part of the eye where its anatomical shape does not allow the formation of a perfect image on the retina creating an optical system without spherical symmetry.

The result is that all focal points fail to come together in one perfect place, creating two axes that focus at different locations. A distorted and out-of-focus image occurs on the retina. In astigmatism, typically the shape of the cornea consists of differing vertical and horizontal radii. Astigmatic refractive errors can occur in different locations along the eye's axis, caused by the irregular surface of the cornea, the crystalline lens or a combination of both. Two terms describe its features, regular astigmatism and irregular astigmatism. In regular astigmatism, the horizontal and vertical principal radii are separated by 90°, whereas those in irregular astigmatism are not. The majority of refractive errors that include astigmatism are regular astigmatism.

A schematic, simple view can be seen in Figure 3. Spectacles or contact lenses can correct astigmatism with surface parameters that converge the two different foci to a common single point of focus on the retina. Two components that comprise of a spherical and cylindrical value together with a corresponding axis indicating the direction of the astigmatism, describe the corrective parameters for a given corneal or ocular astigmatism. The term for a spectacle lens or contact lens that corrects astigmatism is 'toric' lens.

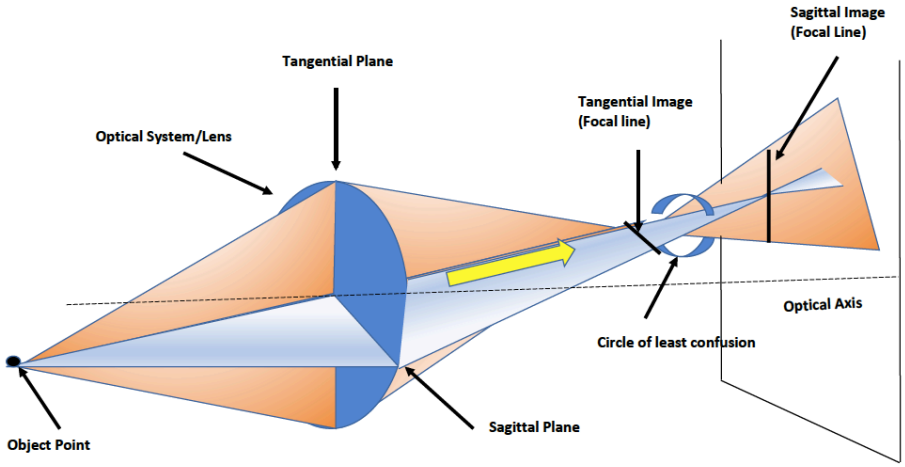


Figure 3: Simplified schematic view of astigmatism (by the author C. Ashleigh)

1.2.6 Presbyopia

In this ocular condition, a reduced ability to focus on near objects is caused by the loss of elasticity of the crystalline lens, usually near the age of forty five (Holden et al., 2008). The crystalline lens is a biconvex structure, which sits directly behind the iris and in front of the vitreous humour. It is held in place on either pole by the suspensory ligaments.

The lens comprises of four layers:

- The lens capsule
- The sub-capsular (anterior) epithelium
- The lens cortex and
- The nucleus in its centre.

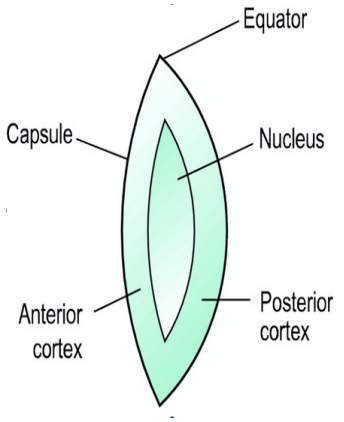


Figure 4: The crystalline lens (Millodot, 2008)

The crystalline lens grows throughout life, constantly adding new lens fibres to its cortex and therefore getting more substantial in thickness with age while at the same time reducing in flexibility. As a person ages, nearing their mid-forties, focussing at different distances becomes more arduous and will take longer. This presbyopic process ultimately leads to visual blur for near vision tasks. A person will often need different optical correction for seeing in the distance, for intermediate and for their near focus. Spectacles, incorporating multifocal lenses, such as bifocals, trifocals and progressive power lenses, as well as separate pairs of spectacles for distance, intermediate and near can all correct this condition. In recent years, similar contact lens options have also become available

to correct presbyopia and these are described in further detail below.

1.2.7 Assessment of visual acuity

Distance visual acuity can be measured using a variety of letter charts. The most commonly used, are the **Snellen acuity chart** and the **Bailey-Lovie LogMAR acuity chart** seen in Figure 5, both used in common optometric practice. The Snellen chart, which was developed in 1862 by the Dutch ophthalmologist Herman Snellen, employs optotypes of equal thickness defined in minutes of arc. Visual acuity is defined by a fraction of test distance/letter size where a decimal acuity with 1.0 represents 20/20 vision, if the chart is used at 20 feet or 6/6 when the chart is used at a distance of 6 metres. The chart commonly used and accepted in most clinical research today, is the Bailey-Lovie LogMAR chart developed by the National Vision Research of Australia in 1976 (Bailey and Lovie, 1976). Here, visual acuity is measured employing a logarithmic progression with five letters of Sloan font in each line. Each of these letters has a logarithmic value of 0.02 log units, negative LogMar scores representing good VA (Thomson, 2005). The spacing between each letter varies logarithmically, making it possible to record visual acuity letter by letter much more accurately compared to the older Snellen letter chart version. This enables non-standard viewing distances to be used and to score visual acuity more accurately.

Figure 5: The Bailey-Lovie letter chart presented using the Thomson Test Chart 2000 Pro program (Thomson Software Solutions, 2006)

1.3 Contact Lenses

1.3.1 The early history of contact lenses

While some historic researchers credit the concept of contact lenses to Leonardo Da Vinci (Ferrero, 1952), others would argue that only the work by René Desçartes (1637) bears a remote resemblance to the contact lens (Enoch, 1956). It is reported that these pioneers merely theorised about different media and the notion of immersing the cornea in water, causing optical neutralisation of the cornea. Sir John Herschel, an English mathematician and astronomer, then linked these early theories with the beginning of clinical contact lens work in 1845 (Herschel, 1845).

Some years later in 1886, the Franco-Polish ophthalmologist, Xavier Galezowsky put forward the idea of applying a gelatine disc to the cornea directly after cataract extraction, which was impregnated with cocaine and sublimate of mercury, for corneal anaesthesia (Mann, 1938), making this the first mention of a hydrophilic contact appliance used as a therapeutic device directly on the eye. August Müller in Wiesbaden (1889) used the term ‘corneal lens’ for the first time, when he published his inaugural thesis for his degree of the

Doctorate in Medicine at the University of Kiel (Müller, 1889). He used blown glass lenses with a white scleral zone and was interested in treating myopia with such a device. Adolph Fick (1888) and Eugene Kalt in Paris researched the correction of keratoconus, a progressive deformation of the cornea, with corneal lens forms as orthopaedic appliances. Fick's paper is credited with "*astonishingly accurate observations*" (Fick, 1888). He suggested the use of these devices for aphakia (the absence of a crystalline lens most commonly due to cataract extraction), prosthesis/cosmetic lenses and the use as a pinhole contact lens. Fick also described the problem with corneal epithelial clouding, now known as Sattler's veil or Fick's phenomenon (Lamb and Sabell, 1989).

No headway was made in achieving good vision or acceptable tolerance by a wearer of such devices for extended periods of time until much later in the 1930's. The first corneal fitting sets were mentioned in publications by Fick, then by Dr W. Stock for Zeiss and Professor Leopold Heine (Heine, 1929). The latter's fitting sets were afocal and were very costly for ophthalmologists to acquire, which again caused hindrance in such developments and research in moving forward. Theodore Obrig, an optical technician from New York noted corneal clouding and limbal pressure (Obrig, 1938a) and he considered the moulded lens the optimum for a successful fit. His great contributions to corneal lens advancement were his famous table of average corneal dimensions and the discovery of the use of blue light, in conjunction with fluorescein dye, to assess the fit of a corneal lens in situ (Obrig, 1938b). Fluorescein proved to be essential in assessing the fit of rigid contact lenses and is still used for this purpose today. Fluorescein is also extremely useful for assessing corneal health and integrity (Gasson and Morris, 2010).

In the 1930s and 1940s there were further developments in understanding the topography and physiology of the cornea, which helped to improve comfort and wearing time of contact lenses. Practitioners experimented with different size corneal contact lenses and with different solutions to aid lens cleaning and disinfection. Dallos' investigations of corneal clearance paved the way for better tolerance and longer wearing times by wearers of such appliances. Dallos and Bier described the first fenestrated scleral contact lenses, which led to much wider use of these appliances (Dallos, 1946, Bier, 1945, Bier, 1948). They showed that by fenestrating contact lenses the cornea would be better oxygenated and lenses more comfortable to wear for longer periods.

In the 1950s and '60s, Istvan Györrfy in Budapest re-introduced Poly-Methyl Meth-Acrylate (PMMA) for the manufacture of scleral and corneal lenses (Györrfy, 1950, Györrfy, 1968). Lenses manufactured from this material allowed a wearing period of a full day for the first time due to their reduced size and multi-curve designs and more wearers were fitted successfully. Improvements were being made with development of more gas permeable rigid lens materials, which improved oxygen supply to the cornea of lens wearers. On 18th January 1962, the first 'hydrocolloid' material for soft contact lens production was announced in the New Scientist, developed by Wichterle and Lim in Prague. They claimed that eight hours wear could be achieved with this new hydrophilic soft lens material (Wichterle, 1961). At the time, this announcement did not raise much enthusiasm in the UK, as the bi-curve and multi-curve hard corneal lens designs already in use were by now allowing up to 75% of wearers a daily wearing time of 12-16 hours. However, the Czech material did pave the way for a more mass-produced commodity by the 1970s which, over time, led to the 'soft disposable' contact lens, as we know it today (Lamb and Sabell, 1989).

1.3.2 Soft contact lens materials

The 1960s and '70s saw significant developments in soft contact lens material design, material composition and their manufacture, which could be used alongside the already established hard and gas permeable lens designs. Wichterle's hydrocolloid material led to the Geltakt and SPOFA-lenses. These were manufactured by Protetika in Prague around 1964 and were made from a spun-cast gel. Corneal oedema, resulting from reduced corneal oxygenation (hypoxia) in varying thickness of the contact lenses, restricted wearing times to less than eight hours per day and practitioners voiced concern about bacterial contamination of such lenses (Larke and Sabell, 1971).

Numerous American optometrists and investors were involved in moving developments forward in the 1970s, leading to the Bionite material, a copolymer made from HEMA hydrogel and a pyrrolidone hydrophilic ring. This material had the advantage of higher water content within its structure, resulting in better comfort and oxygen permeability for the wearer in a soft contact lens. However, this also made them less robust and lead to easy breakage. Lenses made from the same polymer HEMA/PV were still available at the end of the last century.

In the 1970s, the UK as well as the USA saw developments of a different material containing a copolymer of methyl methacrylate (MMA) and a pyrrolidone ring (Morris, 1980). This led to a high-water-content contact lens for extended wear. Different techniques of spin casting, moulding and lathe-cutting were further developed and perfected in the 1970s by the American group Bausch & Lomb with their Soflens and Hydron Lenses Ltd in the UK. Towards the beginning of the 1980s, the soft lens designs became much more successful, as many of the early developmental setbacks were

overcome. Numerous companies started soft contact lens production and water contents of lenses varied according to design. These values ranged between low (38%), medium (50-65%) and high (68-80%), using either spin casting, moulding or lathe-cutting techniques for their manufacture. Spin casting was later used for easier mass production, whereas the lathe-cutting technique could produce toric, prism-ballasted and lenticular designs, to correct more complex prescriptions.

In 1982, the first contact lens marketed as a disposable lens was a Danish product called the Danalens. Design and ownership was later sold to Johnson & Johnson, who are one of the leading contact lens manufacturers to this day. This disposable lens was designed to be worn constantly for one week and then discarded until Vistakon, a subsidiary of Johnson & Johnson introduced the first daily disposable version of a soft contact lens in 1995, the 'One-Day-Acuvue' (Lamb and Sabell, 1989). Nowadays, there are many different makes of frequent replacement soft contact lenses, with frequencies of replacement varying from three monthly to daily. Sophisticated tints to change the wearer's iris colour and coatings, such as those that provide ocular UV protection are often incorporated in the lens designs today.

Since the 1990s, contact lens materials have further improved, with the arrival of silicone hydrogels. This material was developed to address earlier hypoxic problems in contact lens wear and to provide more oxygen to the cornea. It has become possible to correct nearly all refractive errors either with a gas permeable or a soft contact lens modality. Perhaps most interestingly, it is now possible to combine different powers in a contact lens successfully, so that the ageing, presbyopic population can also be more suitably fitted with contact lenses that provide better for their visual needs.

1.4 The optical correction of presbyopia with contact lenses

Presbyopia is present in approximately 1.8 billion people, one quarter of the world's population (Holden et al., 2008). As life expectancy rises and the world's population lives longer, this represents an opportunity for contact lens manufacturers and potential contact lens wearers. Even those not yet affected by presbyopia will most likely benefit from progress that is being made in contact lens design and improved materials. In 1998, Woodley wrote that only 3% of presbyopes wear some form of presbyopic contact lens correction (Woodley, 1998). Eleven years later, Morgan and Efron suggest that fewer than 40% of all symptomatic presbyopes are prescribed a presbyopic prescription in their contact lens correction (Morgan and Efron, 2009). Bennett observed in his abstract that "*the contact lens wearing presbyopic population is underserved worldwide*" (Bennett, 2008). Optometrists who wish to correct presbyopia with contact lenses commonly use four different modes of correction:

1) Single vision distance contact lenses combined with reading spectacles.
2) Monovision contact lenses, "*where one eye is focused for distance vision and the other for near*" (Evans, 2007).
3) Bifocal contact lenses, "*in which separate corrections for distance and near vision are provided in each eye*"(Bennett, 2008).
4) Multifocal contact lenses - those in which correction for more than two foci is incorporated in the contact lenses.

1.4.1 Single vision distance contact lenses, combined with reading spectacles

This represents the most rudimentary version of presbyopic contact lens correction, where a single vision distance contact lens is fitted to both eyes. This is then supplemented with a pair of near vision spectacles to correct a person's near focus.

1.4.2 Monovision contact lenses

Here, the fact that most people have two eyes for lens correction has been cleverly exploited to help combine both distance and near correction. The concept of ocular dominance, which will be described in more detail further on in this thesis, is used to fit the wearer's dominant eye with their distance prescription, while the non-dominant eye receives the near vision correction in most cases. Monovision carries a success rate between 59% and 67% with wearers and is popular with contact lens practitioners due to a relatively easy fitting procedure (Back et al., 1989, Erickson and Erickson, 2000). As either eye is used in turn, depending on the viewing distance, the wearer must learn to suppress the blur from the eye that is not in focus. Consequently, the binocular function is often greatly diminished in this fitting technique with monovision lenses.

1.4.3 Bifocal contact lenses

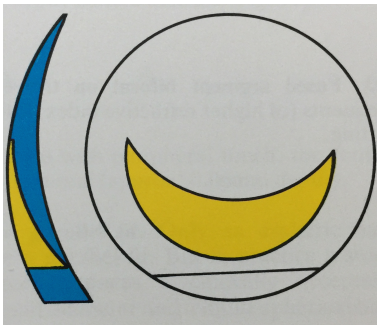
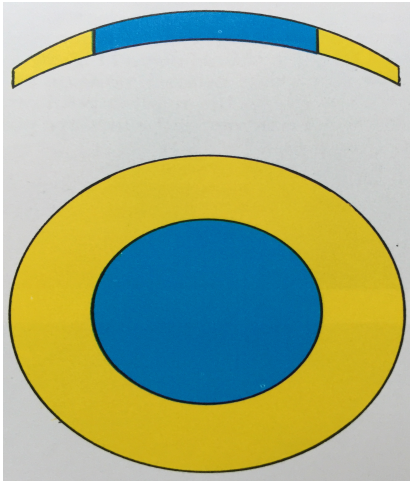


Figure 6: A bifocal contact lens with separate segments in the optic zone, also known as a translating or alternating vision bifocal, blue distance zone with yellow near vision segment (Ruben, 1982)

The concept of a contact lens incorporating both a distance and a near focus can be traced to William Feinbloom. He first described bifocal and trifocal segments in the optical zone of a scleral contact lens made from PMMA in 1938 (Mann, 1938). This design is also known as a translating or alternating vision bifocal lens (see Figure 6). This type of lens provides alternating vision for the contact lens wearer moving the different optic zones of the contact lens into position, depending on the focal length required. One of the challenges of this design is the stability of the near segment on the eye in the wearer's optimum position. In 1950 Williamson-Nobel, a British ophthalmologist described his design of a concentric bifocal lens with the near zone being in the centre of the scleral lens and the distance vision in an annulus in the periphery of the lens (Williamson-Noble, 1951). In this design, also called a simultaneous vision or bi-vision bifocal (see Figure 7), the light enters both the distance and near zone at the same time, creating one sharp and one superimposed blurry image simultaneously. This design creates an image that is less sharp than that formed with the translating lens design, but this technique overcomes the stability issue. It was and is challenged by any change in the wearer's change in pupil diameter, since light and focussing ability vary.



Essentially, these two designs have survived and have been perfected in various versions and different materials to this day. Progress has been made with prism ballasted rigid and gas permeable bifocal designs, which are heavier inferiorly, so that the reading segment stays in a more

Figure 7: Diagram of a concentric bifocal design also called a simultaneous vision or bi-vision bifocal, blue central distance zone with surrounding yellow peripheral near zone (Ruben, 1982)

permanent position on the wearer's cornea, hence giving the near vision focus more stability (Ruben, 1982). Numerous designs have followed to try to overcome the challenges posed by varying pupil size and reading distances of different wearers. The concept of a concentrically designed contact lens has been improved upon using soft lens designs and has led to the more sophisticated multifocal designs, using concentrically radiating rings.

1.4.4 Multifocal contact lenses

The first wearable multifocal lens is traced to Newton Wesley in 1972 (Wesley, 1972). Wesley made a back surface concentric bifocal that was fused with a front surface concentric bifocal. A trifocal resulted, by making the distance zone of the back surface smaller than that on the front. A similar idea had been discussed as early as 1958, but was never a wearable option at the time due to manufacture technique restrictions. Söhnges developed the concept of concentric rings of gradually increasing power, and then blending the zones in 1962/63. The magnification that this lens generated gradually increased towards the edge, but side effects resulting from the blended zones caused overlapping images, making these lenses unsuccessful for wearers.

Manufacturers, throughout the 1970s/80s and 1990s worked to minimise distortion and blur from overlapping optical zones, aberrations from light entering the blended part of the lenses and the problem with pupil size variation and position of gaze when reading. Different materials were put to the task and gas permeable as well as soft multifocal contact lenses were becoming more successful towards the turn of the century. In 2009, Ciba Vision produced a centre near design multifocal contact lens. CooperVision followed by the end of 2011: their lens design combined a centre

near with a simultaneously worn centre distance lens for the other eye. Here the central zone of one lens contained the near vision prescription, whereas the lens for the fellow eye contained the wearer's distance prescription, thus making use of the monovision concept in the design. The principle resulted in the construction of a multifocal contact lens consisting of varying powers in the concentric rings surrounding both the right and left central zones. Highly sophisticated manufacturing processes have led to improvement in the zone stability and better blending techniques especially for soft multifocal lens designs. These lenses were used for this contact lens trial.

Two longitudinal studies examining contact lens trends in the UK and other countries suggest that the arrival of new lens designs and materials are changing the way practitioners fit their patients (Morgan and Efron, 2006, Efron et al., 2010). Prediction was made that the contact lens market would grow in the next twenty years (Pujol et al., 2003), with the presbyopic contact lens market still expanding the fastest. It is thought that presbyopes will become the single largest group of potential contact lens wearers by 2018, with a stake of 28% of the entire contact lens market or approximately 13.5 million people (Studebaker, 2009). Research into multifocal designs and comparisons between different presbyopic lens modalities is still rare and the purpose of the next chapter is to investigate research to date.

1.4.5 Silicone hydrogels

One major factor that changed the market for presbyopic contact lens wearers was the arrival of silicone hydrogels. Silicone hydrogel (SiH), as a contact lens material was introduced to the UK in 1999. The first silicone hydrogel multifocal design became available in July

2006, being introduced by Bausch & Lomb (Morgan et al., 2010, Gupta et al., 2009). Janakiraman and Rappon observed that 40% of all new contact lens fittings in the USA in 2005 were silicone hydrogel lenses compared to 17% for the same period in 2004 (Janakiraman et al., 2006). Three out of the four leading contact lens manufacturers in the UK now offer a monthly multifocal silicone hydrogel lens. These are CooperVision, Alcon and Bausch & Lomb (see Table 1 below).

Table 1: Silicone Hydrogel Monthly Disposable Multifocal Contact Lenses Currently Available in the UK

Company	**Name of contact lens**	**Wearing schedule**	**Type of SiH**
CooperVision	Biofinity Multifocal	Monthly disposable	Comfilcon A
CooperVision	Clariti Multifocal	Monthly or daily disposable	Filicon II 3
Alcon	Air Optix Aqua Multifocal	Monthly disposable	Lotrafilcon B
Bausch&Lomb	Purevision 2 Multifocal	Monthly disposable	Balafilcon A

1.5 Summary

This chapter gave an overview of the structures of the eye and refractive errors. It explained the concept of presbyopia and how visual acuity is assessed with modern optometric test charts in community optometric practice. The latter part of Chapter 1 gave an overview of the history of contact lenses and the evolution of materials used for manufacture of such devices to help with a better understanding of the underlying complexities that are the foundation of monthly disposable silicone hydrogel multifocal contact lenses, which are the subject of this thesis. The next chapter

will give insight into previous literature and review evidence of previous trials of this nature.

Chapter 2

2.0 Literature review of contact lens correction for presbyopia relevant to this thesis

This chapter will give insight into recent research of presbyopic correction with multifocal contact lens designs together with previous comparison studies. The literature review specifically includes studies of similar study design and purpose, showing comparison between two or more lens designs using the concept of multifocal lens correction. It includes the time period from the arrival of silicone hydrogels in the UK in 1999, since both the lens designs compared in this study are made from silicone hydrogel.

2.1 Methods for the literature search

For the purpose of this search, a review of the contemporary English and German language literature on presbyopia and multifocal contact lenses was undertaken. Numerous documents about the early history of contact lenses were published in Germany and as German is the author's first language the advantage was exploited to fully understand those original publications. Searches for publications on different correction modalities for presbyopia were made of PubMed, Contact Lens Spectrum USA, Contact Lens & Anterior Eye and the online British Journal of Ophthalmology. Relevant articles were identified and other publications identified from the bibliographies of these papers. Hard copy journals, books, papers from conferences and any form of relevant references were recognised. For the electronic online searches, the following terms were entered: 'Presbyopia', 'Monovision', 'Bifocal Contact Lens', 'Multifocal Contact Lens', 'Translating Vision Contact Lens', 'Alternating Vision Contact Lens', 'Simultaneous Vision Contact Lens',

'Silicone Hydrogel'. Specific subject headings used for electronic online searches were: 'Comparison studies of presbyopic contact lens modalities' and 'Comparison studies of multifocal contact lens modalities'. For the purpose of this thesis a number of comparative studies were included. These show the variety of corrective contact lens options for presbyopia. Progressive research, including comparison studies highlights the gaps in the research that exist in respect of silicone hydrogel multifocal contact lens comparison trials. The last online search was conducted on 11th August 2016.

Amidst an increasing market for correcting presbyopia with contact lenses, research comparing different multifocal contact lenses of this kind is needed. Comparison studies observing different options for presbyopic contact lens correction have been conducted. These often compare multifocal contact lens designs to monovision lens wear and examine the visual performance of different contact lens modalities (Gupta et al., 2009, Rajagopalan et al., 2006, Sivardeen, 2016). Some have concentrated on multifocal designs in particular life situations, including night time driving (Chu et al., 2010), flying (Timmis and Elliot, 2010) or include novel collection methods for data, such as BlackBerry hand held devices (Woods et al., 2009). However, comparison studies examining and comparing multifocal contact lens designs are still extremely limited. These comparisons have been mostly conducted in the United States and are sometimes conducted by contact lens manufacturers (Woods et al., 2009, Janakiraman et al., 2006). Recently, a pilot study comparing two silicone hydrogel multifocal lenses with a new hybrid multifocal contact lens evaluated visual performance (Pinēro, 2015).

2.2 Ocular dominance

Numerous studies relating to monovision in comparison with other presbyopic correction modalities preceded the end of the 1990s. A comprehensive review by Evans (2007) concentrated on ocular dominance in monovision and the effect of monovision on stereopsis and binocularity (Evans, 2007). The mode of monovision contact lens wear is often used as a comparison with other presbyopic contact lens options in existing studies. A factor influencing the decision to fit monovision contact lenses is ocular dominance. Most individuals have one eye that is stronger and quicker in conducting an ocular response than their fellow eye. The stronger is referred to as the individual's 'dominant eye'. This phenomenon can be compared to a person being right or left-handed, although the dominant eye of a right-handed individual is not necessarily their right eye. Evans (2007) documented the different techniques in determining a subject's dominant eye in detail, retracing first methods to 1949 (Charnwood, 1949). Over the years, a large number of these techniques in this field have been described, some even quoting 25 different tests to determine ocular dominance (Walls, 1951).

Some multifocal soft contact lens designs employ a technique in which one eye is partly favoured for distance and the fellow eye for near, such as the Biofinity lens used in this trial. It is commonly accepted amongst practitioners to prescribe the distance lens to the sighting dominant eye and the near vision lens in the less dominant eye (McGill and Erickson, 1991, Wright, Guemes et al. 1999, Westin, Wick et al. 2000).

2.3 Review of evidence: Relevant comparison studies within the identified period

2.3.1 Studies comparing monovision, bifocal and multifocal contact lenses made from conventional hydrogel as well as silicone hydrogel materials

Kirschen et al. (1999) compared monovision with Johnson & Johnson's Acuvue bifocal soft contact lenses, which had recently been introduced to the market. In this small independent study, nineteen presbyopic participants, with an average age of 52.5 years were selected randomly from a private patient base. All were "*happy*" monovision wearers. With their monovision corrections in situ, these wearers were tested for visual acuity (VA), stereoacuity (SA) and suppression at both distance and near. The process was then repeated with participants wearing the Acuvue bifocal soft lenses. Johnson and Johnson's official fitting guide was used to obtain best distance and near VAs. Both monovision and bifocal lenses were worn for one week only, before relevant tests were performed. It was not made clear in the paper if participants wore the lenses in their capacity as extended wear, one weekly replacement lenses or, indeed, as the recommended two weekly replacement lenses. Extended wear would mean that wearers slept in the contact lenses, wearing them continuously for one week, day and night, without removal from the eye. This relatively small study aimed to relate inter-ocular acuity differences to stereopsis, achieved with either monovision or the bifocal option and attempted to quantify degrees of binocular function with each modality. It predicted that bifocal contact lens wear would show smaller intra-ocular differences than monovision wear and thus outperform monovision in certain binocular functions. This was justified with a statistically relevant result in the test outcomes of a four line VA difference for the monovision option, compared to only

one line VA difference with bifocal contact lens wear. The study also showed that not all participants wearing a bifocal contact lens would achieve good stereopsis, since it was found that monovision stereoacuity threshold levels at near increased with higher reading power.

A U.S. study by Martin and Roorda (2003) conducted experiments on sixteen pre-presbyopes between the ages of 23 and 34 years, predicting and assessing the visual performance of multi-zone bifocal contact lenses (Martin and Roorda, 2003). Three different concentric-ring bifocal contact lenses were used in this study: the Acuvue Bifocal, the LL Bifocal and the SimulVue38, all made by different manufacturers, but all of simultaneous vision designs. Compared with not wearing a contact lens, it was predicted that wearers would have a decrease in distance vision performance and an increase for the near vision performance. Presbyopia was simulated using 1% Cyclopentolate hydrochloride eye drops in randomly selected participants wearing a bifocal contact lens. The contrast sensitivity function (CSF) and modulation transfer function (MTF) were calculated. Their predicted visual quality and monochromatic aberrations were also noted. The bifocal benefit was defined as a relative measure based on the difference of CSF and the MTF for each subject not wearing the contact lens. Participants, whose bifocal benefit was found smaller than one, encountered decreased visual quality with the bifocal contact lens. Participants, whose bifocal benefit was larger than one found visual improvement wearing the bifocal. Predicted visual quality was defined as either increased depth of focus or a bifocal response. The result of this relatively small study highlights that wearing a bifocal contact lens does not necessarily guarantee bifocal vision, where both eyes participate equally at distance and near. Some contact lens wearers simply experience increased depth of focus due to the aberrations of

the eye. Martin and Roorda's study (2003) gave statistically significant results showing that it is possible to predict a patient's visual quality wearing a bifocal contact lens, based on visual aberrations, produced as a result of a patient's ocular correction. All participants reported an improvement of visual quality at near. It was interesting that non-presbyopes were used in this study. In 2011, Gispets et al. in Terrassa (Spain) evaluated visual satisfaction and wearing success, comparing the Acuvue Bifocal with the Proclear Multifocal. In this longitudinal, double-masked crossover study, 22 presbyopic university staff were fitted with the two different designs for 14 days each, with a washout period of 48 hours in between. A number of questionnaires were employed to evaluate lens satisfaction at different stages in this study, evaluating participant's satisfaction with habitual visual tasks at home or at work at distance, intermediate and near distance. Six months after completion of the trial, success rate was determined by how many participants still wore the lenses. This study's main outcome was that insufficient visual quality was the reason why participants did not continue wearing these multifocal lens designs (Gispets, 2011).

Two interesting American comparison studies were published in 2006. Richdale et al. (2006) conducted a crossover study on 38 presbyopes, comparing monovision with multifocal contact lenses. None of the participants had any previous experience wearing a presbyopic contact lens design. Participants were randomly fitted with either a Bausch & Lomb Soflens 59 single vision monovision contact lens or with the Soflens multifocal design made by the same company. Subjects wore one set of contact lenses for one month after which the second set was crossed over with no 'washout' period in between. For all participants, their dominant eye was established and visual performance measured in a high and low contrast environment. Visual acuities were measured for distance and near, as well as near stereoacuity. A patient satisfaction

questionnaire was used to collect qualitative data and their final subjective lens of choice documented. The study concluded that both modalities gave better VAs than 20/20 in a high contrast environment for distance and for near. In examining the near vision results, however, the multifocal lens design performed worse in low contrast conditions. The authors cite the fact that success of wear of a multifocal contact lens design is more dependent on the patient's pupil size than that with monovision. Richdale et al. (2006) observed that previous studies conducted in the 1990s also mention pupil size as a factor influencing the success of multifocal lens fitting. No significant findings were found when glare was examined and compared. The researchers identified a limit of the study, which was that due to the specific lens design used, a crossover was not really possible. This was because the patient's dominant eye was always the one fitted with the distance correction. A positive finding of this study however was noted in how subject's stereoacuity was recorded and compared. Two measurements were obtained, one wearing a multifocal contact lens and one being re-measured with the subject's habitual correction. It was argued that this gave more information about the lens performance in the "*real world*".

Rajagopalan *et al*. (2006) examined visual performance of participants wearing four different presbyopic lens modalities: a gas-permeable (GP) multifocal, a soft bifocal, GP monovision and spectacle correction. The researchers in this US study mention several previous papers examining similar modalities in the 1990s. The contact lens modalities used in the study were chosen as a close representation of what can be used to correct the presbyopic contact lens population. 32 presbyopic participants between 42 and 65 years of age were recruited and split into four groups of eight participants. Binocular high and low contrast sensitivity (CS) acuities were recorded at small intervals of cycles of degree. Monocular glare

sensitivity was measured at three luminance settings. Finally, binocular near vision task performance was examined. This study placed particular emphasis on the findings of the four different modalities at low light levels. It was argued that due to increased pupil size in low luminance levels, increased problems with glare might result. The researchers concluded that presbyopic contact lens wearers in need of good vision in low lighting conditions would benefit from a GP lens design. These lenses were found to induce the lowest amount of monocular disability glare, in which the wearer experienced visual disturbance from glare. The monovision option was found to give the worst visual acuity and stereoacuity performance. Results showed that all options examined produced good binocular CS and increased sensitivity to glare. Interestingly, spectacle and GP multifocal contact lens wearers scored low errors on binocular near vision task performance, with bifocal and monovision wearers making more mistakes on visual task performance. In this study, soft bifocal lens wearers fared worst, which differed to a previous study from the late 1980s, in which the monovision group performed worst on binocular near vision performance (Sheedy et al., 1988). Rajagopalan et al. (2006) identified this as one of the findings of the study, which could neither be explained nor fully understood.

Sanders et al. (2008), were also interested in visual acuity and "*balanced progressive*" simultaneous vision multifocal contact lenses. This study's objective was to examine the relationship between visual acuity and increased addition power worn in a CooperVision Proclear multifocal soft contact lens design. Controversially, 25 normally sighted non-presbyopes were recruited for this study, for reasons not clearly identified. Participants were fitted with a centre distance lens in their dominant eye. This lens transitions through an aspheric intermediate to the outer near zone.

The non-dominant eye received a centre near contact lens, which transitions through an aspheric intermediate to the spherical peripheral distance zone, as per the company's Proclear fitting parameters (Bennett, 2008). Distance visual acuity with four increasing near addition powers, ranging from +1.00 to +2.50 were used in the trial. Measurements were obtained for VAs at distance for all four different addition powers, at low and high light levels. High and low CS was also measured. Distance VA was constant for all addition powers, with no statistically significant difference evident in the test results for high luminance. At low contrast level conditions, however, a small but statistically significant decrease in VA was noted, worsening in vision with the increase in addition power. Pupil size adjustment with respect to changing addition powers averaged the same across different light levels.

Gupta et al. (2009) conducted a British study, comparing visual function in Bausch & Lomb PureVision multifocal contact lenses to PureVision single vision monovision. Twenty presbyopic participants were fitted with one of these two silicone hydrogel options. After a one-month trial, distance intermediate and near VAs were measured, as well as distance and near CSF. All twenty participants were then crossed over and refitted with the second option. A near range of clear vision was established and the stereoacuity measured. The authors of this study stated in their discussion that the PureVision multifocal silicone hydrogel contact lens used in this study has one of the "*latest additions to the growing market of contact lens designs aimed at providing spectacle-free vision correction for the presbyopic patient*", which served as motivation for the study. It was found that distance and near VA was significantly better in high-contrast conditions wearing this multifocal design than the monovision option. It was argued, with reference to a previous paper (Schor et al., 1987), that inter ocular

suppression in monovision allows the clearer eye to dominate perception, which then leads to better acuity. However, when using a multifocal design, the creation of simultaneous retinal images reduces the retinal image contrast and quality in both eyes, therefore preventing similar compensation (Borish and Soni, 1982).

Gupta et al. (2009) identified that these findings did not consolidate those documented by Richdale et al. (2006). Here, monovision and multifocal designs performed similarly for VAs. The authors observed that differences in participant selection used in each study might have contributed to these differences – it being noted that in Richdale's cohort, some 87% were female participants. Gupta et al. (2009) argue that this might not be a true representation of the presbyopic contact lens market. Differences in the manner of which the multifocal contact lenses were fitted might have been another reason for differences in the outcomes. The authors identified that Richdale et al. (2006) employed a "*modified multifocal fitting option*" in some cases, which might have artificially resembled a monovision fitting. This study argues that for true comparison between the two different fitting modes, a true monovision fitting and a true multifocal fitting would be essential. CSF with simultaneous vision contact lenses was found not to be substantially different to that of monovision correction. Although similar findings were documented in a previous study (Collins et al., 1989), the CSF measurement was smaller than expected, since it was suggested that the PureVision lenses employ a combination of spherical and aspherical surfaces.

Gupta et al. (2009) predicted that CSF would have shown more difference had a concentric bifocal contact lens design been used. The authors suggested that more defined retinal images would be produced, which interfere with retinal image contrast to a greater extent. McGill et al. (1987) observed similar findings. Multifocal

contact lenses outperformed the monovision mode on both the range of near vision correction and stereoacuity performance. As in previous studies, this was expected. Gupta et al. (2009) concluded that both monovision and multifocal contact lenses should be offered to potentially correct the vision of presbyopic participants. With a choice of two modes of contact lens correction, wearers would be able to decide which visual functions would mostly satisfy their individual needs, should they wish to be spectacle-free.

A Canadian study by Woods et al. (2009) and sponsored by Ciba Vision, examined early presbyopes and asked: "*what correction modality works best*". A low-addition silicone hydrogel multifocal soft lens, the Air Optix Aqua multifocal, was compared with monovision. It was also compared to the subject's habitual correction and their optimized distance correction, after an eye examination. All lenses used were made from the same silicone hydrogel material and all were Ciba Vision contact lenses. The study was conducted as a prospective double blind, randomised crossover trial, consisting of four one-week phases and each participant trialled all four fitting modes. Tests were conducted with each modality in situ, examining CSF in high and low light levels, stereopsis and critical print size. The authors of this study employed a number of novel data collection methods, which formed a large part of their outcome approach. As well as controlled laboratory conditions, they collected qualitative data with a BlackBerry communication device. After performing tasks such as reading, using computers, watching television and driving, subjective results were recorded. Woods et al. (2009) concluded that the low-addition multifocal silicone hydrogel contact lens provided a successful correction mode for early presbyopes. Pointing to qualitative ratings of subject responses, the authors suggested that in the decision-making process practitioners

should employ a range of "*real-world*" conditions as well as testing room results.

Another published study using this modality was a Spanish crossover study, conducted on 20 presbyopes between 50-60 years of age who had no previous experience in presbyopic wear (Ferrer-Blasco and Madrid Costa, 2010). It compares the monthly disposable Ciba Vision Focus Progressive with the Bausch & Lomb PureVision multifocal for their stereoacuity performance. Both lenses were worn for the full four weeks, with no washout period in between. Interestingly, the participants in this study were more mature, established presbyopes and only high addition power lenses were used. Several different tests for stereoacuity were conducted on both pairs of lenses and the study found that both lenses did not show a difference in stereoacuity at distance, but did for near vision stereoacuity (Ferrer-Blasco and Madrid-Costa, 2010). The most recent publication is a randomised crossover trial of silicone hydrogel presbyopic contact lenses by Sivardeen et al. from 2016. Here 35 presbyopes between 42 and 65 years of age were fitted randomly with one of four different silicone hydrogel presbyopic contact lens designs: Air Optix Aqua multifocal, PureVision 2 for presbyopia, Acuvue Oasys for presbyopia, Biofinity multifocal and also monovision with Biofinity single vision lenses. After 4 weeks of wear, the participants returned to be fitted with another one of the four contact lens types. While the participants remained masked, the contact lens fitter in this study was unmasked at all times and no wash-out period between lenses was mentioned. Distance and near VAs were established in photopic and mesopic lighting conditions. Stereoacuity and reading speed evaluated with a tablet hosting the Radner Test mobile app in this study. (Stifter et al., 2004a, Stifter et al., 2004b) and a defocus curve measured over a range of +1.50D – 5.00D. This study also employed the standardised NAVQ near vision questionnaire

previously used by Gupta et al. in 2007 as well as a diary which documented viewing distance, as well as light scatter and hours worn completed on four days in the month. Finally, optical aberrations were measured using a wavefront analyser. The authors regarded some of the outcomes of this trial as "*disappointing*", as no significant differences were recorded for most variables.

2.3.2 Studies comparing different single vision contact lens designs made from silicone hydrogel material

Two papers are of note. All trials exclusively examined the performance of silicone hydrogel contact lenses. Respected contact lens manufacturers in the USA conducted this research. All three papers compared the contact lenses in single vision lens fitting modalities, not in their facility as a presbyopic monovision option. The studies are included here, because it is relevant to consider whether different silicone hydrogel materials influence lens performance.

In 2006, a large study was conducted for Ciba Vision, comparing the Ciba Vision O_2Optix to the Vistakon Acuvue Advance (Janakiraman, 2006). The objective of this study was the performance of two silicone hydrogel lenses worn for two weeks of daily wear. 81 participants completed the study, all wearing the lenses for a minimum of six hours per day over a period of two weeks. After two weeks, participants were asked to complete questionnaires on comfort, dryness, vision and handling on a 1 to 10 scale. Satisfaction was graded using a five–point scale. At two weeks, a higher percentage of participants reported dissatisfaction with the Acuvue Advance lenses. The authors concluded that their Ciba Vision lens outperformed the Acuvue Advance lens on comfort and dryness, scoring equally good results on vision and handling. Brennan et al. (2007) conducted a smaller study sponsored by Cooper Vision,

comparing different silicone hydrogel contact lenses on 33 participants. Two groups of participants were each fitted with a Comfilcon A contact lens in one eye. The first group was fitted with a Lotrafilcon A in the fellow eye and the second group with a Balafilcon A respectively. The Comfilcon A contact lens was perceived to be superior by both groups. This lens scored higher on overall comfort, comfort during the day and end-of-day comfort and was preferred overall. The first group also preferred Comfilcon A on quality of vision.

2.4 Summary

The first chapter provides an insight into various refractive errors that can affect the eyes of an individual during the course of their life. The development of contact lenses leading to the sophisticated silicone hydrogel multifocal soft disposable contact lens design was discussed. The present chapter has provided an insight into previous research of presbyopic contact lens wear and comparison studies. It is clear that previous research that solely compares soft disposable multifocal contact lens designs is still extremely limited, partly due to the fact that this type of contact lens design has not been available to the optical market for very long. This thesis is the first double blind comparison study using a large sample size, comparing two disposable silicone hydrogel multifocal contact lenses. The next two chapters describe in detail the experimental design of this particular study and explain the reasons for the clinical decisions made at the design stage, in order to create a robust piece of research improving its design and moving forward compared to previously conducted studies. An overview of all relevant papers referenced in this thesis covering the relevant period 1999-2016 can be seen in Table 2 below.

Table 2: Comparison Studies of Presbyopic Soft Contact Lens Modalities 1999 – 2016

Author	Year	Contact Lens Modalities	Size of the Study	Objectives/ Results
Kirschen et al. (Fullerton USA)	1999	Monovision / Acuvue bifocal	19 presbyopes	Bifocal contact lenses outperform monovision in certain binocular functions
Martin/ Roorda (Houston, USA)	2003	3 concentric Bifocal designs Acuvue Bifocal, LL bifocal, Simulvue 38	16 pre-presbyopes	Decreased DV, Improved NV, Bifocal does not guarantee Bifocal response
Richdale et al. (Columbus, USA)	2006	Monovision Bausch & Lomb Soflens 59 / Soflens multifocal	38 presbyopes, no experience with presbyopic design	Monovision perform better in low light levels due to pupil size variation
Rajagopalan et al. (St Louis, USA)	2006	GP multifocal, soft bifocal, GP single vision monovision, spectacles	32 presbyopes	GP lenses best in low light levels
Saunders et al. (Fort Lauderdale, USA)	2008	CooperVision Proclear multifocal	25 normal sighted participants	The effects on increased addition power on VA
Gupta et al. (Birmingham, UK)	2009	Bausch & Lomb silicone hydrogel PureVision multifocal/ monovision	20 presbyopes	Comparison of the visual function with single vision monovision and multifocals
Woods et al. (Ontario, Canada)	2009	Ciba Air Optix Aqua multifocal/ monovision single lens/ habitual/ optimised single lens	Early symptomatic presbyopes (Number not known)	Which modality works best/ study uses real life situation for evaluation
Ferrer-Blasto & Madrid-Costa (Valencia, Spain)	2010	Ciba Focus Progressive/ PureVision Multifocal	20 presbyopes	Comparison of stereoacuity with both lens modalities
Gispets et al. (Terrassa, Spain)	2011	Proclear Multifocal/ Acuvue Bifocal	22 presbyopes	Task orientated visual satisfaction and wearing success employing a number of questionnaires
Fernandes et al. (Braga, Portugal)	2013	Biofinity Multifocal / Biofinity Single Vision Monovision	20 presbyopes	Comparison of High/low contrast VA, CSF and Stereoacuity
Vasudevan et al. (Glendale, USA)	2014	Acuvue Oasys/Air Optix Aqua Multifocal/Biofinity Multifocal	10 pre-presbyopes and early presbyopes	Objective and subjective visual evaluation within the same visit using a variety of test methods
Pinēro et al. (Alicante, Spain)	2015	No 7 Duette Multifocal hybrid/ Air Optix Aqua Multifocal/ Biofinity Multifocal	8 presbyopes	Comparison of photopic contrast sensitivity and aberrometry with both lens modalities

Woods et al. (Ontario, Canada)	2015	Air Optix Multifocal/ Monovsion	50 presbyopes	Comparison of photopic VA and stereopsis
Sivardeen et al. (Birmingham, UK)	2016	Air Optix Aqua Multifocal/ PureVision 2 for presbyopia/ Acuvue Oasys for presbyopia/ Biofinity Multifocal/ Biofinity monovision single lens	35 presbyopes	Assessment of visual performance using a variety of modern computerised test methods. Results not clinically different for most variables

Chapter 3 outlines the hypotheses as well as the research question at the centre of this comparison study. It describes the experimental design, ethical background and outlines the aims of this multifocal contact lens trial. Inclusion and exclusion criteria for participant recruitment are listed and this then leads to the description of the methods used in Chapter 4.

Chapter 3

3.0 Hypotheses and experimental design

3.1 The research question

Are there any significant differences in the clinical performance and patient acceptance of two different soft silicone hydrogel multifocal contact lens designs?

3.2 Hypotheses

Null Hypothesis: The visual performance and acceptance of Lens A and Lens B will ***not*** be significantly different.

Alternative Hypothesis: The visual performance and acceptance of Lens A and Lens B ***will be*** significantly different.

3.3 Experimental design

This experimental trial was designed as an independent, randomised, double blind crossover study. Two soft monthly silicone hydrogel multifocal contact lens designs, produced by two different manufacturers and available in community optometric practice in the UK, were compared in clinical and normal use.

3.4 The aim of the study

The aim of the study was firstly to compare the performance and acceptance of two brands of modern monthly disposable silicone hydrogel multifocal contact lenses that use different designs. Several measures of visual function and acceptance were assessed, with the

key variable being binocular photopic distance visual acuity. Secondly, the study set out to find the success rate of wearing such multifocal contact lenses and if this success was perceived as a viable alternative mode of correction to a person's spectacles.

3.5 Ethics

Ethical approval for this study was obtained from the London South Bank University (LSBU) and the Institute of Optometry Research Ethics Committees in October 2012 (see Appendix 9). As this study only recruited private participants, NHS ethical approval was not considered to be relevant (see Appendix 10).

3.5.1 Inclusion and exclusion criteria

Table 3: Inclusion and Exclusion Criteria of the Study

Inclusion Criteria	**Exclusion Criteria**
Participants between 41 and 60 years of age	Participants using hot compresses, wipes and/or artificial tears for Meibomian gland dysfunction and/or dry eye
Participants that understand the spoken and written information that they were given	Astigmatism over +/-1.00D
Participants with reported problems reading while using their distance spectacles or contact lens prescription, therefore being diagnosed as presbyopic.	Amblyopia (Inter-ocular VA difference of more than two lines on LogMar chart, stereoacuity worse than 60'' of arc)
Participants with a clinically significant degree of presbyopia (at least +1.00D near correction was necessary in this trial)	Participants using medically prescribed eye drops for ocular conditions (e.g.: for glaucoma)
Neophytes as well as existing contact lens wearers (for true representation of a realistic cross-section of contact lens wearers in common optometric practice)	Any other ocular surface condition (e.g.: keratoconus)

Chapter 4

4.0 Methods

4.1 Sample size calculation

At the design phase of this trial, a sample size calculation was performed, based on a parallel group design. It was decided to use the conservative assumption that a significant number of participants might drop out before completing the second period or before the second period altogether, in which case the study would need adequate statistical power for a parallel group design. In a paper by Wellek & Blettner (Wellek & Blettner, 2012) there is a recommendation to check data for carry-over effects and if there are any, then to analyse just the first period only using a parallel study design. It is argued that if the researcher chooses a sample size based on a parallel group design and then later analyses it as a full crossover study, the results would have greater power to detect small differences.

For this study, the calculation and outcome were based on the key variable distance visual acuity (VA) measured as the Logarithm of Minimum Angle of Resolution (LogMAR), since this was considered to be the most important variable and most widely used to quantify visual performance in published trials (Richdale et al., 2006, Gupta et al., 2009). Calculation confirmed that the required sample size was 28 participants in each group, bringing the total number of participants needed for this study to 56.

It was hoped that most participants would conclude Period 1 and Period 2 of the study, therefore making it appropriate to treat this research trial as a crossover study.

The details for the sample size calculation are outlined below with n being the number of participants required:

$$n > 2\left\{\frac{(z_{2\alpha}+z_{2\beta})\sigma}{\delta_0}\right\}^2$$

Where: $\alpha = 0.05$ and β=0.80

$\delta_0 = 0.06$ (Difference between Lens A and Lens B)

And: $\sigma = 0.08$ (Standard deviation, see both below)

δ_0 = represents the difference between the two periods that the researchers judged would be a clinically significant difference. The main alternative to multifocal contact lenses for the correction of presbyopia is monovision. Gupta and Naroo (2009) compared monovision with multifocal contact lenses and found that distance visual acuity was 0.06 logMAR better with monovision than with multifocal contact lenses. This acuity deficit is often considered clinically acceptable because of other advantages of multifocal contact lenses compared with monovision (e.g., stereoacuity, better focus at intermediate distances). It seems reasonable to argue that if in the present research one multifocal lens type is associated with the acuity advantage of monovision then this would become the multifocal contact lens of choice. This reasoning would indicate that a clinically important difference is 0.06 LogMAR and this value was used for $\delta_{0.}$

σ is the standard deviation of VA. In previous research with multifocal contact lenses the SD of VA varied from 0.07 to 0.10 LogMAR with a typical value of 0.08 LogMAR (Richdale et al., 2006, Gupta and Naroo, 2009, Ferrer- Blasco et al., 2010). Therefore 0.08 was used for σ in the present study.

4.2 The two contact lens designs used in this trial

4.2.1 Air Optix Aqua Multifocal by Alcon

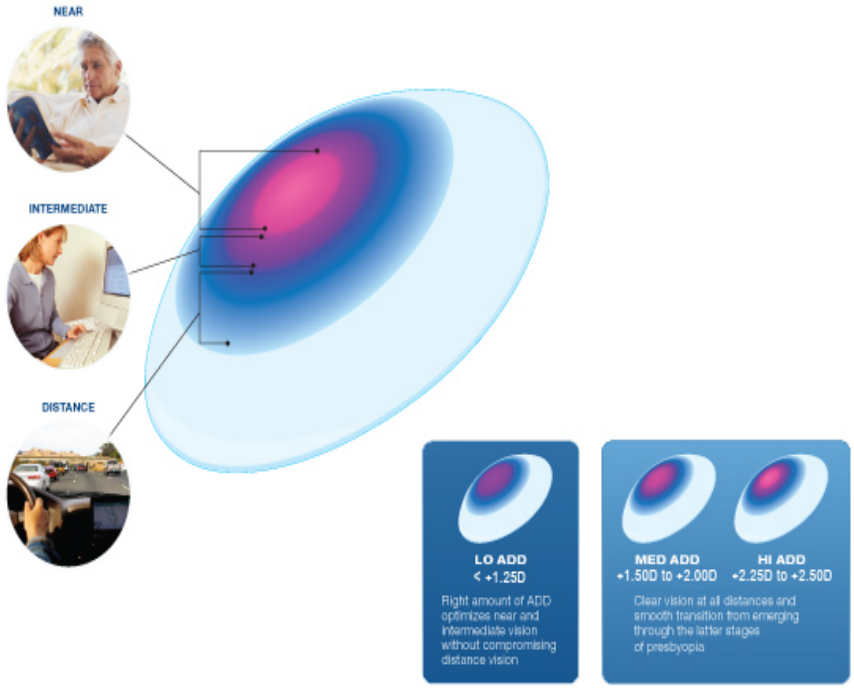


Figure 8: Design of the Alcon Air Optix Aqua Multifocal

Ciba Vision launched the initial Air Optix Aqua Multifocal contact lens late in 2009 before it became part of Alcon and it is a monthly disposable soft contact lens. 33% of the lens is water and the other 67% is lotrafilcon B, a fluoro-silicone-containing hydrogel. The lens is surface treated with an 'aqua moisture system', which is said to contain a lubricating agent that binds with the lens surface to make the lens comfortable on contact with the eyelid. This patented material is said to minimise the rate of lens dehydration and to have good deposit resistance. This lens uses a centre-near design for each eye, and is said to have a relatively low contact angle of 37% for increased wettability. The Air Optix Aqua multifocal caters for emerging presbyopes, as well as for established presbyopes. It is available in powers between +6.00 to -10.00 dioptres (D) altering in

0.25D steps and has three addition powers (low, medium and high) from which to choose, depending on the wearer's ocular correction and age. The lenses have a light blue visibility tint to aid lens handling.

4.2.2 Biofinity Multifocal by Cooper Vision

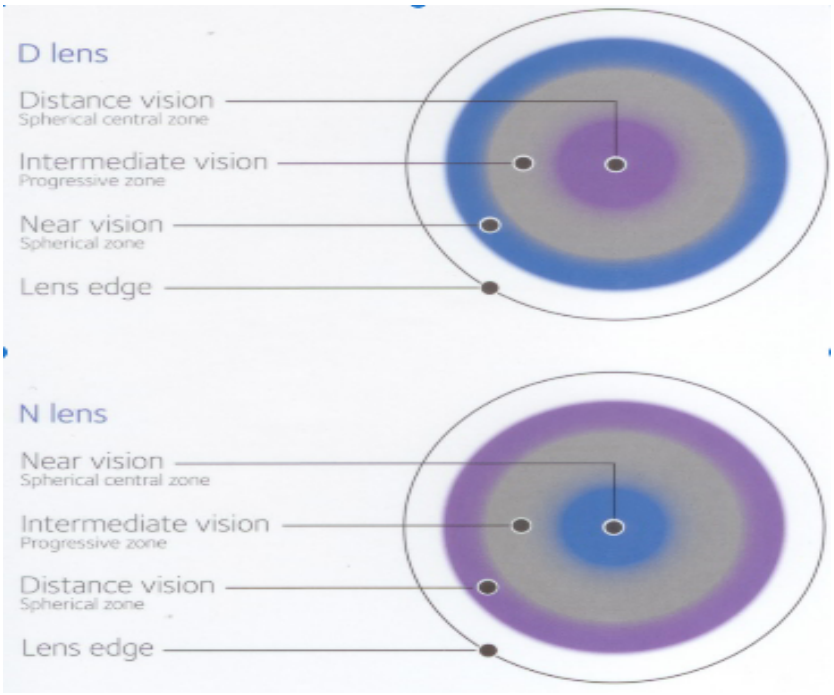


Figure 9: Design of the CooperVision Biofinity Multifocal

The Biofinity Multifocal was launched late in 2011 and is also a monthly disposable soft contact lens. This lens contains 48% water and 52% comfilcon A, which is a silicone-containing hydrogel. The FDA approved the patent (080011) for this material on 19th November 2008. This lens material includes what CooperVision call 'Aquaform Comfort Science'. Manufacturers claim that this creates a naturally hydrophilic lens, locking water within the lens matrix to minimise dehydration. It is said to do so by using longer siloxane chains, resulting in less silicone content within the lens material and so, retaining water. According to the manufacturers, this treatment makes the lens more flexible and its highly wet surface resists

deposits and stays moist without the need of a wetting agent. The Biofinity Multifocal employs a combination design with the suggested fitting of a centre distance lens worn in one eye and a centre near lens being worn in the fellow eye. These varying optical zones are claimed to enhance the vision for distance, intermediate and near and give a large choice of fittings depending on age and prescription power for the contact lens practitioners. These lenses are available in powers between +6.00D and -10.00D with four addition powers +1.00D, +1.50D, +2.00D and +2.50D, depending on patient's prescription and age. The lenses have a soft blue visibility tint to aid handling.

Although slightly different in design, the two lenses look identical and have no markings other than the blue handling tints. Due to their identical appearance, it was possible to maintain the double blind masking, while the contact lenses were fitted, worn and examined by the practitioner. This was an advantage of these two lens types for this trial. The lens designs and properties are summarised in Table 4 below.

Table 4: Characteristics of the Two Multifocal Contact Lenses Used in the Trial

Lens A/B	**Air Optix Multifocal**	**Biofinity Multifocal**
Launch	Late 2009	Late in 2011
Manufacturer	Alcon	CooperVision
Sphere powers	+6.00 to -10.00D, 0.25 steps	+6.00 to -8.00D, 0.25 steps, -8.50 to -10.00D, 0.50 steps
Addition powers	Low, medium and high	+1.00, +1.50, +2.00, +2.50
Lens design	Centre Near R+L	Centre Distance, Centre Near
Surface treatment	Aqua Moisture System	Aquaform Comfort Science
Material	Lotrafilcon B	Comfilcon A
Water content	33%	48%
Base Curve	8.60	8.60
Diameter	14.20mm	14.00mm
DK	110	128
Handling tint	Blue	Blue
Recommended replacement schedule	Monthly	Monthly
Approved wearing schedule	Daily or up to 6 nights extended, worn only during the day over four week period in this trial	Daily or up to 29 nights continuous wear in Europe, Canada, Australia and New Zealand, worn only during the day over four week period in this trial

4.3 Recruitment and fitting procedures

4.3.1 Recruitment

62 participants were recruited from a private patient base of three private optometric practices in Hampshire, UK. Potential participants were sent a recruitment letter, then given an information leaflet and consent form by the researcher at a recruitment interview (Appendices 1, 2 and 5). The leaflets and consent forms were designed prior to the beginning of the trial. The researcher advised participants that they had the right to leave the trial at any time. At the recruitment interview, participants were encouraged to discuss the project and to have questions answered. After a week's consideration time the participant's signature was required on a consent form in order to allow them to join the trial (Appendix 5). After signing the consent form, the fitting for the first lens was arranged.

4.3.2 Contact lens fitting procedure

The contact lenses were fitted free of charge to the participants and fitted according to the manufacturer's instructions as published in their fitting guides. All contact lenses and lens care products were given to participants without cost to them. In community optometric practice, manufacturers make trial lenses available to practitioners for the initial fitting, without charge. These trial lenses were used in this research. No contact lens manufacturer was involved in the research or financing of this entirely independent trial. The NHS in community optometric practice does not fund contact lenses or time for contact lens fittings and therefore all contact lens work with multifocal contact lenses is non-NHS dependant.

Prior to fitting any contact lenses, a full eye examination was performed. Visual acuities were established. Where more than two lines of difference in VA between the two eyes on the logMAR chart were recorded or a lack of stereoacuity of more than 60 seconds of arc was evident using the Titmus fly stereoacuity test, the participant was disqualified from this trial. This is described more in detail later in this chapter. An initial contact lens assessment was carried out to ensure that each participant was suitable for contact lens wear. To establish this baseline, accepted clinical procedures were followed in initial pre-fitting anterior eye assessment (Gasson and Morris, 2010). The participant's corneas, eyelids and ocular tear film were examined under magnification using a slit lamp bio-microscope. Fluorescein dye was instilled in order to better visualise any potential corneal or tear abnormalities. If any pathology was detected, the participant was considered ineligible for the research and was counselled and referred following local referral criteria and pathways and in accordance with the guidelines of the College of Optometrists. Similarly, if any complications or pathologies became apparent during the trial, the contact lens wear was ceased and appropriate action taken, following local referral criteria and pathways, as well as in accordance with the guidelines of the College of Optometrists.

The fit of all trial contact lenses was checked after settling for at least 15 minutes. The study protocol was to abandon the fitting if the fit of the lenses was inadequate to the extent that it would compromise corneal health. An inadequate fit was defined as a lens that did not show movement on blinks and eye movements or that gave limbal baring (e.g., because the total diameter was too small or the lens was positioned too eccentrically, giving the participant discomfort).

At the first fitting, the lens for the first period was fitted by the practitioner. Manufacturer's guidelines were followed, achieving the best possible vision for distance and near for the participant at this time with Lens 1. A specially trained optical advisor randomly allocated participants to be fitted with the first or the second contact lens product, Lens A, or Lens B. These were then removed from the original packaging and given to the practitioner marked with Lens 1 or Lens 2. Lens fit and centration were recorded. The practitioner ensured that the participants were happy with comfort and visual acuity while wearing these contact lenses, before explaining in detail, how to fill in the daily diary and complete the monthly questionnaire. Further details about these two secondary variables will be explored later in this chapter.

The participants received instructions about the cleaning, care and management of their contact lenses and the researcher ensured that participants knew how to look after and handle the contact lenses throughout the month. Participants were given two leaflets, one about driving in the contact lenses and the other about how to detect an eye infection (see Appendix 3 and 4). These leaflets had also been prepared before the start of the trial.

4.3.3 Washout period

Participants wore Lens 1 during the day for four weeks, after which they then had a 'washout' period of one week, where no trial contact lenses could be worn. In this interim period participants were instructed to revert back to wearing their own previously worn optical correction (e.g.: their own spectacles or their own single vision distance contact lenses.) It was important in the design of this crossover trial, to introduce a washout period. A paper by Wellek and Blettner warns in detail of carry-over effects (Wellek and

Blettner, 2012). The purpose of this washout period was to avoid such effects.

It was decided that one week was a suitable time for the washout period for two reasons. From a physiological perspective, a paper by Rho et al. (Rho et al., 2014), which investigated corneal swelling in soft contact lens wear, documented the same length of washout period. From an optical standpoint, two relatively recent trials of multifocal contact lenses mention a washout period. Gispets et al. (2011), employed a break of 48 hours in between 14 days of lens wear whereas Pinēro et al. (Pinēro, 2015), describe a seven day break after two weeks of contact lens wear. Therefore, it was felt that the design with a one-week washout period was adequate and would produce a scientifically robust study design. Thereafter, the second product Lens 2 was fitted and dispensed to participants, again to be worn for four weeks during the day to complete the crossover.

4.3.4 Contact lens wearing time

Since both products used in this trial were monthly disposable contact lenses, a wearing time of one month at a time was appropriate. It was felt that it was important to see each lens perform throughout its full wearing cycle, as intended by the manufacturers. Previous studies also stipulated the same wearing time schedule (Richdale et al., 2006, Gupta et al., 2009).

As is usual in clinical practice, participants were instructed to immediately remove the contact lenses if they experienced any symptoms suggesting an adverse reaction (e.g., discomfort). All participants used the same contact lens care system designed for silicone hydrogel contact lenses, manufactured by a third

independent manufacturer. The system used was Synergi, a multipurpose cleaning solution originally manufactured by Sauflon Pharmaceuticals.

4.3.5 Calibrations and test room conditions

Test conditions were set up identically each time in the three different practice locations prior to seeing the participants, with lighting and test charts carefully calibrated to maintain uniformity. The calibrations were carried out with a Rank Electra luminance meter, following instructions for internally illuminated charts by Smith (Rabbetts, 1982). He showed that the luminance (L) could be estimated with a photographic exposure meter or camera metering system. With the meter set for a given ASA film speed rating, F (Frames)/no and exposure (t in seconds) for the correct exposure were noted and adjusted so that all three test charts were used at an identical background luminance setting.

The luminance was then found using the following formula:

$$Luminance = \frac{13.1 \times \left(\frac{F}{no.}\right)^2}{exposure(s) \times ASA\ setting} cd/m^2$$

Room length in each setting was already set at 6m from the participant's eye position to the test chart, which is the normal test room length used in community optometric practice in the UK.

4.4 The double blind masking

The practitioner examined the contact lenses with the help of a previously determined coded system and the help of a previously trained optical assistant. This ensured that the lens practitioner

could not identify the lens type, nor did the participant know which lens they received. Lenses were removed from manufacturer's packaging by the optical assistant and placed in cases identified only by Lens 1 and Lens 2 and R and L for the right and left eye. Participants were only provided with one pair of lenses at a time and the first pair was taken from each participant before the second pair was issued after the washout period. The optical assistant marked the lenses separately for statistical analysis as Lens A and Lens B on a separate card.

The researcher carried out all the results analysis whilst maintaining the "blinding", only identifying the lenses as lens type A or B. The code was only revealed once the Results section of the thesis was complete and work had commenced on the Discussion.

4.5 Key outcome variables

The four main outcome variables investigated in this trial were:

1) Photopic binocular distance visual acuity
2) Photopic binocular near visual acuity
3) Stereo-acuity at distance and near
4) Photopic, mesopic and scotopic binocular contrast sensitivity at distance

The conditions were photopic (day) for the visual acuities and photopic (day), mesopic (twilight) and scotopic (night) for visual acuity on the contrast sensitivity chart. A pupil adaptation time of one minute was allowed each time for it to change size when the light levels were altered. The depth perception (stereoacuity) was measured at three metres room distance and at 40cm for near.

The two secondary variables investigated in this trial were:

1) The patient's subjective assessment of the contact lens comfort and the satisfaction with the vision assessed with a daily diary
2) Overall satisfaction with visual performance of the contact lenses, assessed with a monthly questionnaire

4.5.1 Photopic binocular distance visual acuity

Visual acuity was measured using the illuminated Bailey-Lovie Thomson Test Chart 2000 Pro seen in Figure 3 at high luminance with all lights on in the test room. This widely used test chart allows repeated randomisation of standardised test letters (Holladay, 2004, Williams et al., 2008) and has been used frequently in previous optometric research. The participant was seated at a 6-metre distance from the chart, which is the standard test room length in community optometric practice in the UK. The participant was asked to read the rows of letters and any individual extra letter was counted and the results scored as standardised LogMAR units to single letter accuracy.

4.5.2 Photopic binocular near visual acuity

Figure 10: The Institute of Optometry Near Test Card (Evans and Wilkins, 2001)

The same procedure was repeated for near vision photopic visual acuity, with the participant holding the Institute of Optometry Near Test Card at a reading distance of 40cm. This near test card employs the same LogMAR approach as the Thomson distance unit and it was chosen for that reason (Evans and

Wilkins, 2001). The participant was asked to read as far as possible and all words read were counted, converted into a standardised LogMAR value and then recorded on the initial examination sheet (Evans and Wilkins, 2001).

4.5.3 Stereopsis or stereoacuity

Stereopsis, also known as stereoacuity is defined as direct awareness of depth due to retinal disparity (Millodot, 1990). Stereoacuity only functions when binocularity exists. Different levels of stereopsis can be measured with a variety of tests. Stereoacuity is commonly assessed during optometric examinations from a very young age, as it forms an important part of the diagnosis of amblyopia and squints. Numerous stereoacuity tests have been examined and compared in research for years, with an array of studies (Simons, 1981, Hall, 1982, Fawcett and Birch, 2003, Fu et al., 2006, Kriegbaum-Stehberger et al., 2008). For this study, stereopsis formed a key variable, as this is a major advantage of the multifocal lens variety over another common mode of presbyopic contact lens correction (i.e., monovision), especially when driving. This study set out to examine if there was a statistically significant difference in stereoacuity between the two multifocal contact lenses.

4.5.3.1 Photopic distance stereoacuity

The Thomson 2000 Pro distance stereoacuity test chart was used for these measurements as specified in the test instruction manual by Thomson Software Solutions (Thomson Software Solutions, 2006). Participants were asked to look at random dot stereogram letters simultaneously with both eyes. Red and green non-prescription filters, provided with the stereoacuity chart were worn over the contact lenses as instructed in the manual and participants were

asked to identify a letter in each pixelated chart. The dynamic stereograms allow the disparity of the letters to be adjusted to provide an accurate assessment of the participant's stereoacuity. Font size of the optotype letter was set at 1.0 LogMar, number of dots in stereograms at 7000 with disparity of background pixels at 5, as is suggested in the manual. In this test, one eye sees the green dots and the fellow eye the red dots, while the brain attempts to fuse both. Separation of these dots in part of the images is interpreted as disparity and measured. Distance stereopsis was measured at normal room illumination as used for assessment of binocular distance VA while the participant was sitting at a distance of 3 metres from the Thomson test chart for best results after consultation with the test designer (Professor David Thomson, personal communication). The smallest degree of disparity was identified, recorded on the examination sheet in seconds of arc and copied to the Excel spread sheet.

4.5.3.2 Photopic near stereoacuity

Figure 11: The Titmus Fly Near Stereoacuity Chart (Stereo Optical Co., 1988)

Near stereoacuity was measured using the Titmus-fly stereoacuity test. Participants wore polarised filters to perform this test as specified in the manual. The test was performed at a near vision distance of 40cm measured from the front of the frame holding the filters (Stereo Optical Co., 1988). The Titmus-fly test is a clinically

valued near stereoacuity test regularly used in everyday optometric practice. It is popular in community optometric practice, as it is easy to use and quick to score. The Titmus-fly test has been used to establish near stereopsis in numerous research papers, including the recent paper by Ferrer-Blasco and Madrid-Costa (2011), which investigated stereopsis with different techniques in simultaneous vision multifocal contact lenses. When using this test, four rings, as seen in Figure 11 are seen simultaneously in a square. Only one of the circles has a degree of crossed disparity, which varies with each square. The Titmus-fly test has disparity ranging from 800 to 40 seconds of arc and the measurement for the smallest size rings identified was recorded on the examination sheet.

4.5.4 Contrast sensitivity

Contrast sensitivity is an important variable in relation to multifocal contact lens trials. The measurement of contrast sensitivity in the eye is a more complete assessment of vision than standard visual acuity assessment. It provides an evaluation of the detection of objects of varying spatial frequencies and of varying contrast. (Millodot, 1990) Contrast sensitivity testing does not usually form part of the regular community optometric eye examination, but varies a great deal within individuals. It is a very important measure, especially in situations such as day, twilight and night driving, when light levels are not constant. Even if an individual has excellent visual acuity, they can suffer from health conditions that may diminish their contrast sensitivity such as glaucoma, cataracts or diabetic retinopathy. Several relevant studies preceding this thesis have measured contrast sensitivity with contact lenses in situ (Richdale et al., 2006, Janakiraman P, 2006). According to the Thomson contrast sensitivity chart guide, contrast sensitivity is usually measured with large letters to provide an assessment at the low spatial frequency

end of the contrast sensitivity function. On this chart contrast sensitivity is either displayed in percentages (varying from 100%-0%) or Log contrast sensitivity units (varying between 2 and 0).

4.5.4.1 Pupil diameter and size

Contrast sensitivity reduces in situations such as low light, fog or glare, even if the eye is perfectly healthy. One of the reasons for this Is a person's varying pupil size, shape or diameter. In bright light, the pupil will constrict to protect the eye from light, whereas in low lighting and darkness, it will expand in diameter to let more light into the eye. The varying pupil size is especially relevant when wearing a

Figure 12: Pupil function in different lighting conditions, right: pupil dilated in low light, left: pupil constricted in bright light (Photographs of a right eye taken by the author C. Ashleigh, 2017)

simultaneous vision concentric multifocal contact lens design, since the size of the pupil influences the lens zone that is relevant and hence the optical performance of the lens. These changes can lead to blur or softer focus when wearing either lens design in this trial.

In this trial, the pupil diameter for each participant was measured using a pre-fabricated pupil gauge (Chaglasian et al., 2006), which displays the different pupil diameters across its edge, giving a diameter measurement in millimetres. The right and left pupil size was measured individually, since it is not uncommon for individuals to have different size pupil diameters - a condition called anisocoria.

All pupil measurements were first taken in photopic lighting in a fully illuminated optometric consulting room. The participant was instructed to focus into the distance, not concentrating on a specific target, to avoid pupillary miosis (constriction) associated with near vision. When testing for mesopic contrast sensitivity, the pupils were measured with the participant wearing neutral density filters. Finally contrast sensitivity in scotopic lighting was measured in the dark test room with all lights off, other than the background illumination from the Thomson contrast sensitivity chart. One minute of adaptation time was given each time when lighting conditions were changed.

4.5.4.2 Photopic distance contrast sensitivity

Figure 13: The Thomson Contrast Sensitivity Chart (Thomson Software Solutions, 2006)

To obtain these measurements, the computerised version of the Thomson contrast sensitivity chart (see Figure 13 above) was used at distance, this test chart having been used in previous optometric clinical trials. Thayaparan et al. (2007) compared this chart, used for near contrast sensitivity in clinical practice when it was first introduced to the optometric market, with the Mars and Pelli-Robson contrast sensitivity charts, both of which had already been accepted and used for this purpose in clinical trials. Since then other publications have reported on this computerised test for contrast sensitivity successfully (Smolarek-Kasprzak et al., 2014).

Using the Thomson contrast sensitivity chart for photopic distance, the participant was wearing the contact lenses in the fully illuminated test room, sitting at a distance of 6 metres away from the test chart. All letters seen on the chart are exactly the same size and three letters are seen in each of three rows on each presentation. With each row, the letters reduce in contrast. The participants were asked to read the letters binocularly and the lowest letter that could just be identified was recorded on the examination sheet in contrast sensitivity Log units.

4.5.4.3 Mesopic distance contrast sensitivity

It was felt important for the contrast sensitivity experiment in this trial, to measure contrast sensitivity in mesopic conditions. This was set up to resemble twilight when driving, as this particular situation causes a gradual change in pupil size, as the pupil slowly adjusts to the change in lighting. The participants wore a pair of grey grade 3.0 medium neutral density filters to simulate mesopic lighting conditions. These were mounted in a trial frame over the contact lens correction in an illuminated test room, sitting 6 metres away from the test chart. No adjustment time for the change in pupil size was given to the participants in this lighting condition. The lowest letter that could just be identified while wearing the filters was recorded on the examination sheet converted into Log contrast sensitivity units.

4.5.4.4 Scotopic distance contrast sensitivity

To simulate night time driving and viewing conditions in dim lighting, participants viewed the chart from 6 metres away, just wearing their contact lenses. This time, all lighting in the test room was turned off and participants were given a light adaptation time of one minute,

before reading the letters. The lowest letter that could just be detected was recorded in converted Log contrast sensitivity units.

4.6 The participant's subjective analysis of the two lens modalities

Only two previous trials employed the use of a tool to document the participants' subjective experience when wearing different contact lens modalities. These two relevant studies employed a self-designed questionnaire or an instrument modified for the purpose of supporting their particular study objectives (Richdale et al., 2006, Gupta et al., 2009). At the design stage for the present research, it was felt important to quantify the visual performance with the contact lenses, but also to include an opinion of the quality of vision given by the participants themselves while wearing these multifocal contact lenses. This was done with two separate tools, using a pre-designed daily diary and a monthly questionnaire (see Appendices 6 and 7).

4.6.1 A daily diary

A short simple daily diary was designed. Participants were asked to complete this at lunchtimes and in the evening every day. Previous research on multifocal contact lenses was examined, but no suitable diary that had been used before or described in published literature was found. A diary was therefore developed, which was printed in the form of a booklet, with the first page as instructions and then a page for each day with sections to be completed at lunchtime and in the evenings. This diary was designed to be very simple and rapid to complete, taking less than one minute each time an entry was made. A copy can be seen in Appendix 7.

The diary investigated:

1) The participant's experience of lens use from morning to lunchtime and lunchtime to evening to establish a subjective assessment of patient satisfaction and comfort while wearing the contact lenses.
2) Perceived clarity of vision for distance, intermediate and near to break down the multiple aspect of the contact lens design and investigate this part of their efficiency (see Appendix 7).

4.6.2 A monthly questionnaire

A comprehensive monthly questionnaire was given to every participant at the end of each trial phase. This questionnaire was based on an existing questionnaire (Mackenzie et al., 2002) and required participants to score their opinion on visual quality related to distance, intermediate and near vision with the contact lenses.

The assessment of visual function in presbyopia and vision-related quality of life are issues that are not unique to multifocal contact lenses, so the task was set to find a suitable tool to use in the current research. This revealed substantial literature and from the available questionnaires, one was chosen as being particularly appropriate for the present research.

The VF-14 visual function questionnaire (see Appendix 6) was chosen as an ideal tool for the present research - a 14 item standardised questionnaire, used in nearly 200 studies. This instrument was modified from its usual format in two ways. First, the most common format for this questionnaire starts with: "*Check the box that best describes how much difficulty you have, even with glasses*" and this has been changed to: "*Tick the box that best describes how much*

difficulty you have when wearing the multifocal contact lenses." Other, similar modifications have been used, for example by researchers investigating the effects of intraocular lens implants. (Cuthbertson et al., 2009, Gothwal et al., 2010, Hadid et al., 2008)

A second modification was made at the end of the questionnaire. An additional section with a blank space prefaced by: "*Please, add any additional comments that you may have about your experience with the contact lenses, which you have been wearing for the last 3-4 weeks. We are particularly interested in any comments that may not have been covered by the options given in your daily diaries or this questionnaire. If necessary, please continue overleaf*." was added as a separate box underneath the existing questionnaire. Each participant was asked to fill in a questionnaire at the end of both four-week periods to document his or her subjective experience with either contact lens. Results were entered in an Excel spreadsheet.

4.6.3 Final participant preference

After data collection for both contact lenses had ended, a final set of three questions were put to each participant to finish the trial. The answers were recorded in the Excel spreadsheet. These questions were:

1) "*Do you think that multifocal contact lenses are a good alternative to your usual correction for presbyopia?"*
2) *"Which of the two contact lenses you tried did you prefer?"*
3) *"Do you think you will continue wearing multifocal contact lenses?"*

4.7 Statistical tests used

4.7.1 Spreadsheets and statistical analysis systems used

An Excel spreadsheet was designed containing clinical data for all participants who started the research. For statistical purposes, this was then ported into SPSS (version 21.0.0.0 64-bit edition). The trial was designed as a repeated-measures study. The sample population of 62 participants was first fitted with Lens 1 and after the washout period fitted with Lens 2. Lens allocation was randomised. Not all 62 participants completed both the first and second period, but all data was recorded in the spreadsheet, including the data from the five participants that discontinued. Reasons for not continuing the trial were noted and will be discussed later in the thesis.

4.7.2 Paired (repeated measures) statistics

In the results chapter the frequency distributions are plotted for the raw data to illustrate the distribution of the data and because, in secondary analyses, the distributions of these raw data determine the tests that should be used. However, for the primary analyses a paired analysis is appropriate, such as a paired t-test test. For this test, it is not the distribution of the raw data that is important but rather the distribution of the variable that is the difference between the paired measurements (Pallant, 2007; McDonald, 2014). Both these references stress that only if the difference data are severely non-normal, do non-parametric analyses need to be used. However, neither author specify how they define “severely”. Therefore, in this thesis the variables for the difference in paired measurements are tested for normality using the Shapiro-Wilk test. Where the difference data do not differ significantly from a normal distribution ($p \geq 0.05$) then paired t-tests are used. Where the data markedly differ from a normal distribution ($p < 0.01$) then the non-parametric

Wilcoxon signed ranks test is used. For borderline data ($0.01 \leq p < 0.05$) both the paired t-test and the Wilcoxon signed ranks test are used. This follows the advice of Skene et al. (2016) that if there is doubt about whether a variable is normally or not normally distributed then the data should be analysed both ways.

For parametric analyses, the paired t-test for repeated measures was calculated using the formula seen below:

$$t = \frac{M_D - \mu_D}{s_{M_D}}$$

with: M_D = sample mean difference
μ_D = sample difference
S_{M_D} = standard error

Where appropriate (e.g. stereoacuity and contrast sensitivity results), data were converted within Excel to the logarithmic function ($\log_{10}$) and SPSS was then used to create the necessary graphs.

For non-parametric analyses and the questionnaire and diary data, the Wilcoxon test for Two-Related-Samples was used for stereoacuity data and the final participant preference (see page 141). The Chi-square test of association was used for analysing proportions.

Secondary analyses used parametric and non-parametric tests as appropriate.

4.8 Summary

This chapter has described in detail the different objectives of this comparison study and explained the experimental structure of the trial. It gave details of the two contact lens modalities as well as the outcome variables, which were chosen for this trial. Finally, it described the statistical tools and specific tests used to complete the statistical analysis. The following chapter will present the results.

Chapter 5

Results

5.0 General descriptive data

Table 5: General Descriptive Data of Participants Who Started and Completed Both Periods of the Trial

	Trial Started	**Trial Completed**
Participants	62	57
Mean age	54.0 (41-60 years)	52.9 (41-60 years)
Females	48	43
Males	14	14
% Males	23%	25%
Mean Spherical Equivalent Refraction	-0.97D, +2.00Add (-7.50D to +5.00D, +1.00D to +2.50DAdd)	-0.86D~~S~~, +2.00Add (-7.50D to +5.00D, +1.00D to +2.50D Add)

The final fit of all trial lenses participants used in this study was acceptable (as defined in Section 4.3.2) and no participants had to abandon the trial because of poor lens fitting.

5.0.1 Participant Retention

Only five of the 62 participants that entered this trial did not complete both periods. Four of these were neophytes, who found insertion and removal too difficult and time consuming to continue with the lens wear. These participants were counselled and offered repeated instruction, but were not comfortable to continue with the trial and discontinued. One participant appeared to experience an allergic reaction to the silicone hydrogel material This manifested itself within the first twenty minutes of lens wear with extreme chemosis and epiphora in both eyes, accompanied by blurry vision and discomfort. The trial for this participant was instantly abandoned and both contact lenses removed, after which both eyes slowly recovered. The participant was counselled according to

guidelines issued by the College of Optometrists and the manufacturer informed of this adverse reaction. This participant was then noted on the spreadsheet as unsuitable to continue.

5.1 Statistical analysis

5.1.1 Testing for a period effect within the four main measures: binocular photopic distance VA, binocular photopic near VA, stereopsis (at distance and near) and contrast sensitivity (in photopic, mesopic and scotopic lighting conditions)

5.1.1.1 Binocular photopic distance VA

Using the statistical tests described in detail in the methods chapter above, graphs were constructed showing scatterplots of the four main variables to investigate whether a period effect was evident for each of these variables. The first graph uses the data from the sample population of the primary variable binocular photopic distance VA, outlining Period 1 and Period 2 (see Figure 14 below). 57 participants completed both periods for this variable.

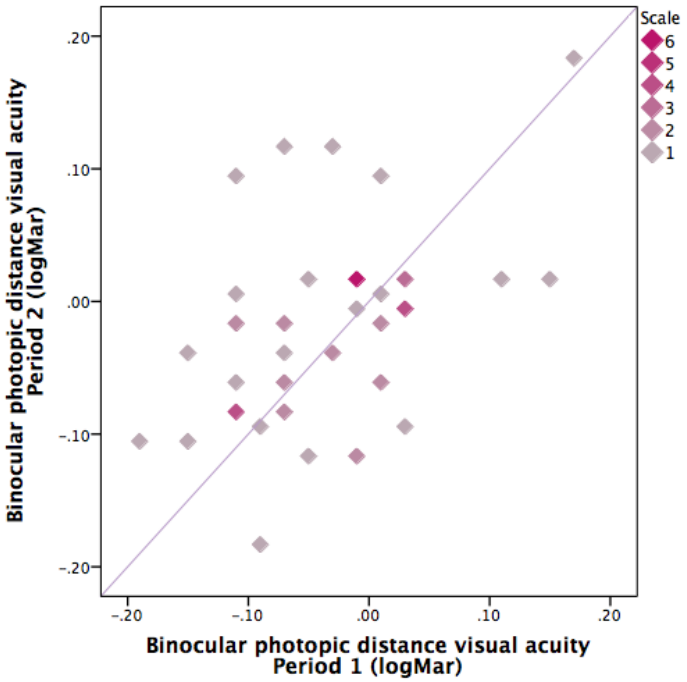


Figure 14: Masked Data for the Main Variable: Binocular Photopic Distance VA Period 1 and Period 2. Some data points are overlapping and, as indicated in the scale, the depth of colour of the symbols reflects the number of participants that overlap (in this graph, the lightest colour represents 1 participant and the darkest represents 6 participants)

It was confirmed that no period effect was evident, as results for Period 1 and Period 2 showed no significant difference, testing the data for frequency and distribution. Statistical analysis is reported in section 5.1.2 of this chapter.

5.1.1.2 Binocular photopic near VA

The same procedure was followed for the second variable, binocular photopic near VA. The same population of participants was used to construct the graphs for this variable, with 57 participants completing Period 1 and Period 2. For this data, the graphs again indicated that no period effect was evident, with both Period 1 and period 2 showing very similar results, seen in Figure 15 below.

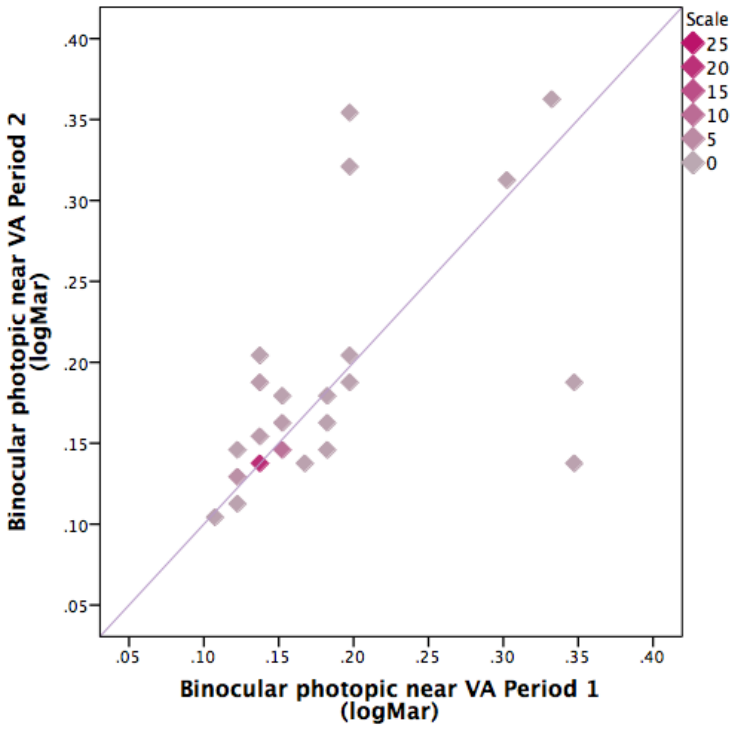


Figure 15: Masked Data for Photopic Binocular Near VA Period 1 and Period 2. Some data points are overlapping and, as indicated in the scale, the depth of colour of the symbols reflects the number of participants that overlap (in this graph, the lightest colour 0 represents 1-4 participants and the darkest 25 represents 21-25 participants).

5.1.1.3 Stereoacuity at distance and near

The Wilcoxon Signed Ranks test was then performed for the third variable, stereoacuity at distance and near. These data were found not to conform to a normal distribution curve. Stereoacuity measurements use exponential scales, in some cases only an approximation of an exponential scale. When analysing these results, a large difference between mean and median was found. Therefore, results were first transformed into log scale measurement, so that the transformed data followed a linear scale. Non-parametric statistics were used for the analysis of this variable. 57 participants completed Period 1 and Period 2 for both distance and near stereopsis. The two resulting graphs can be seen below in Figures 16 and 17.

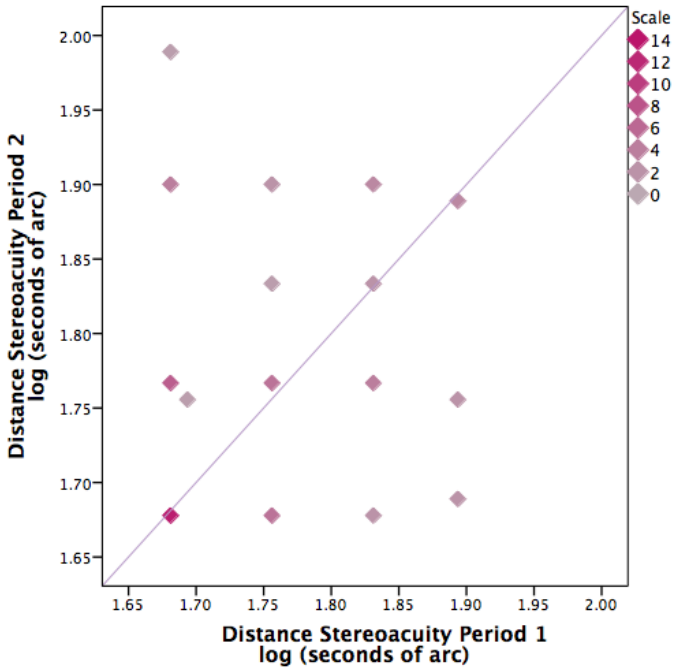


Figure 16: Masked Data for Distance Stereoacuity Period 1 and Period 2. Some data points are overlapping and, as indicated in the scale, the depth of colour of the symbols reflects the number of participants that overlap (in this example, the lightest colour 0 represents 1 participant and the darkest colour 14 represents 13 or 14 participants).

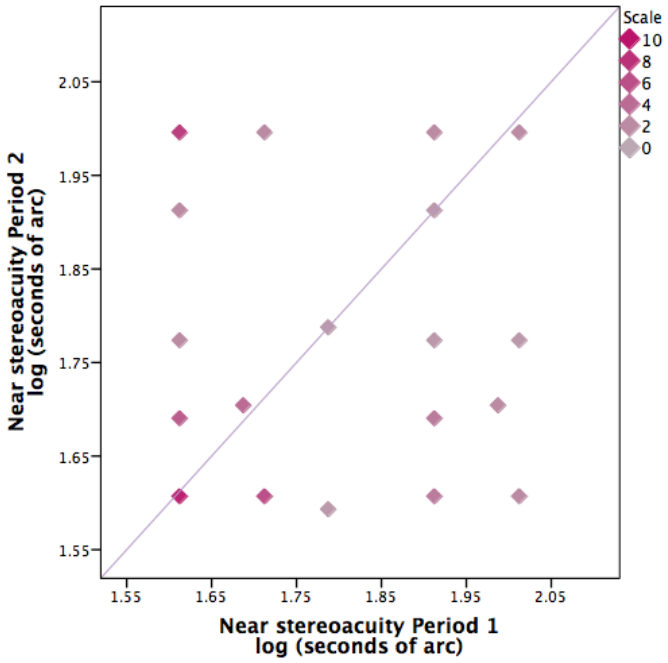


Figure 17: Masked Data for Near Stereoacuity Period 1 and Period 2. Some data points are overlapping and, as indicated in the scale, the depth of colour of the symbols reflects the number of participants that overlap (in this graph, the lightest colour 0 represents 1 participant and the darkest colour 10 represents 9 or 10 participants).

5.1.1.4 Binocular contrast sensitivity in photopic, mesopic and scotopic lighting conditions

Graphs for the fourth variable contrast sensitivity were constructed in photopic, mesopic and scotopic lighting conditions to conclude the testing for the existence of a period effect. The letter chart brightness in all three lighting conditions was kept constant, while the surrounding light levels were altered according to the trial design. The sample population for contrast sensitivity in all three lighting conditions consisted again of 57 participants. The graphs can be observed below in Figures 18, 19 and 20.

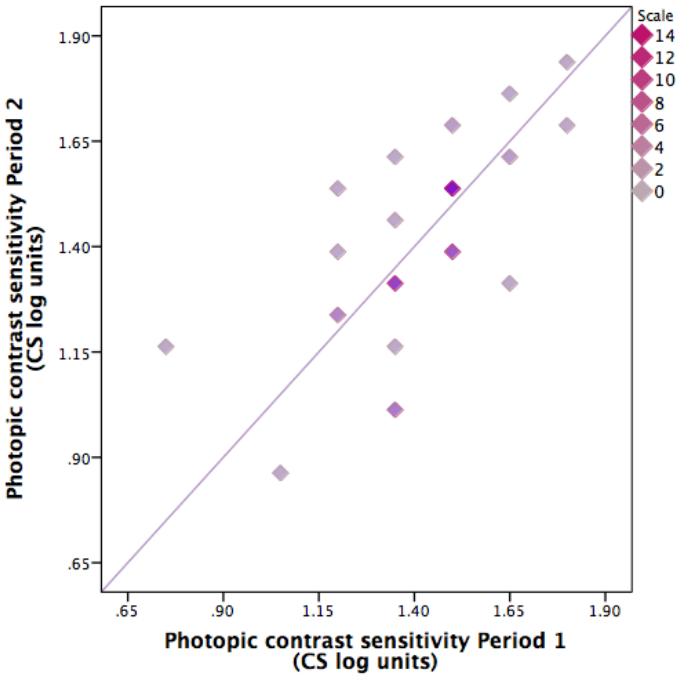


Figure 18: Masked Data for Photopic Distance Contrast Sensitivity Period 1 and Period 2. Some data points are overlapping and, as indicated in the scale, the depth of colour of the symbols reflects the number of participants that overlap (in this graph, the lightest colour 0 represents 1 participant and the darkest colour 14 represents 13 or 14 participants).

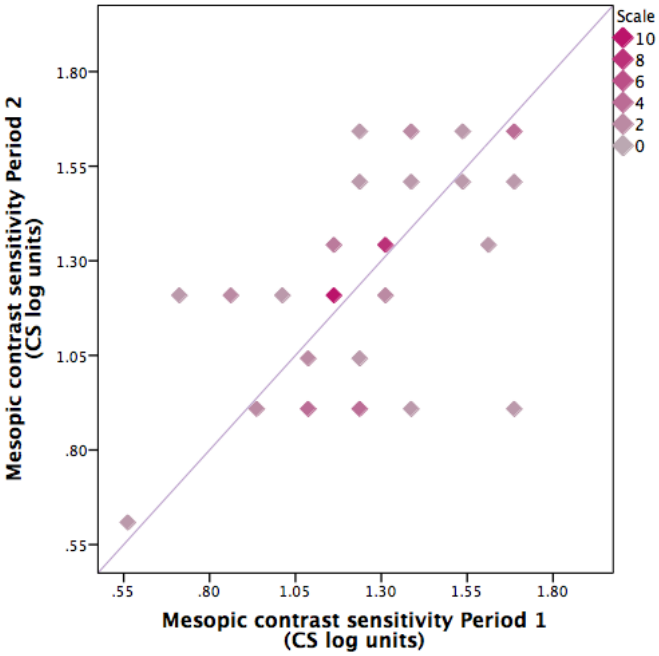


Figure 19: Masked Data for Mesopic Distance Contrast Sensitivity Period 1 and Period 2. Some data points are overlapping and, as indicated in the scale, the depth of colour of the symbols reflects the number of participants that overlap (in this graph, the lightest colour 0 represents 1 participant and the darkest colour 10 represents 9 or 10 participants).

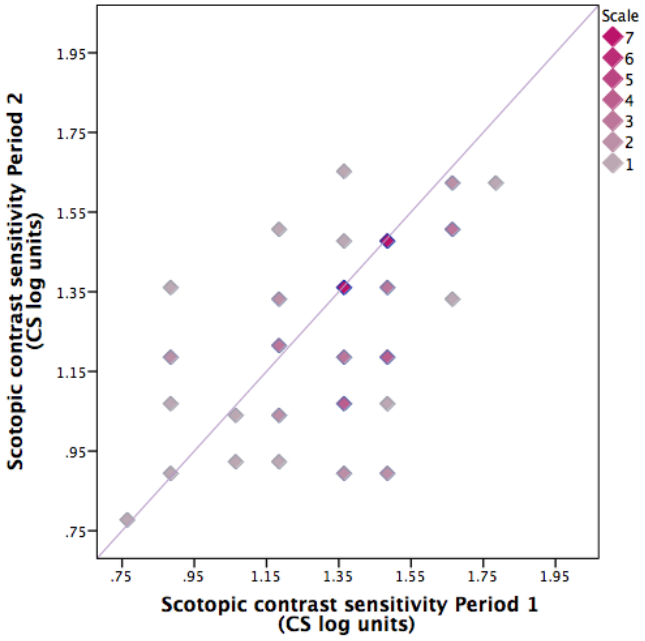


Figure 20: Masked Data for Scotopic Distance Contrast Sensitivity Period 1 and Period 2. Some data points are overlapping and, as indicated in the scale, the depth of colour of the symbols reflects the number of participants that overlap (in this graph, the lightest colour represents 1 participant and the darkest colour represents 7 participants).

5.1.2 Frequency distributions and paired analyses for the four main variables, binocular photopic distance VA, binocular photopic near VA, stereoacuity (at distance and near) and contrast sensitivity (in photopic, mesopic and scotopic lighting conditions)

5.1.2.1. Binocular photopic distance VA

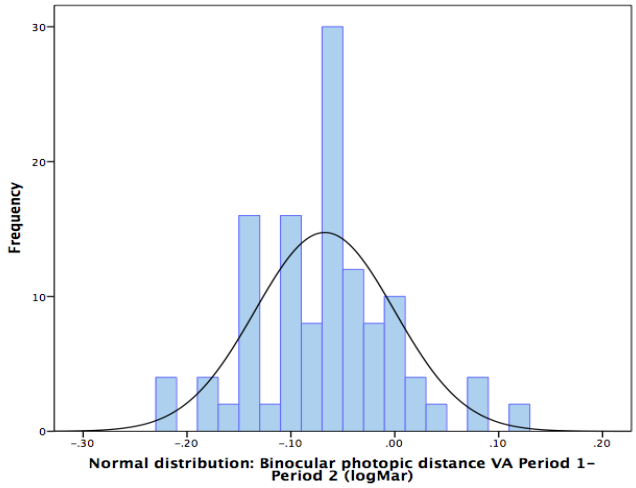


Figure 21: Histogram for the Distribution of Binocular Photopic Distance VA, showing pooled data for Period 1 and Period 2

A frequency distribution of the pooled raw data is illustrated in Figure 21.

The Shapiro-Wilk test for normality indicated that the distribution of the difference between paired measurements for binocular photopic distance VA for Period 1 and Period 2 departed (just significantly) from a normal distribution (p=0.042). As specified in Section 4.7.2, both parametric and non-parametric statistical analyses were carried out.

Table 6: Paired t-test Analysis–for Binocular Photopic Distance VA Period 1 and Period 2

	Mean	N	Std. Deviation	Std. Error Mean	t
Binocular photopic distance VA Period 1	-.0372	57	.06829	.00905	-1.511 (p=.134)
Binocular photopic distance VA Period 2	-.0235	57	.06667	.00883	

The difference for the binocular photopic distance VA between Period 1 and Period 2 showed no statistically significant difference with t=-1.511 (p=0.134) and a difference between the means of 0.0137. The difference between the two statistical mean values was smaller than 1 letter on the LogMAR distance vision acuity chart. A non-parametric confirmatory test with the Wilcoxon signed ranks test confirmed that the data for the two periods did not differ significantly (p=0.14).

5.1.2.2 Binocular photopic near VA

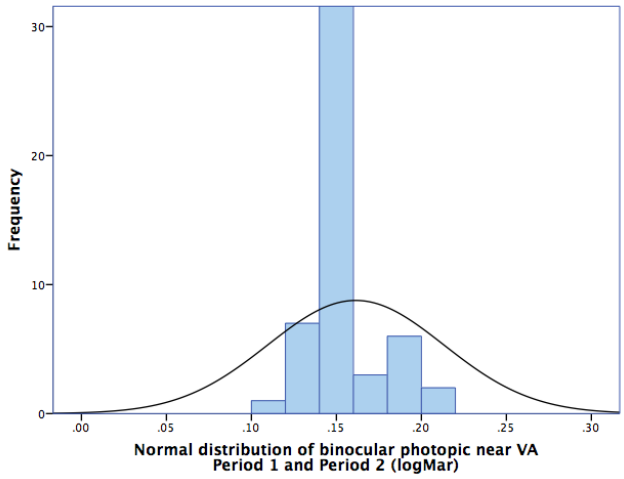


Figure 22: Histogram for the Distribution of Binocular Photopic Near VA Period 1 and Period 2

A frequency distribution of the pooled raw data is illustrated in Figure 22.

The Shapiro-Wilk test for normality indicated that the distribution of the difference between paired measurements for binocular photopic near VA departed from a normal distribution (p=0.015). As specified in Section 4.7.2, both parametric and non-parametric analyses were carried out.

Table 7: Paired t-test Analysis for Binocular Photopic Near VA Period 1 and Period 2

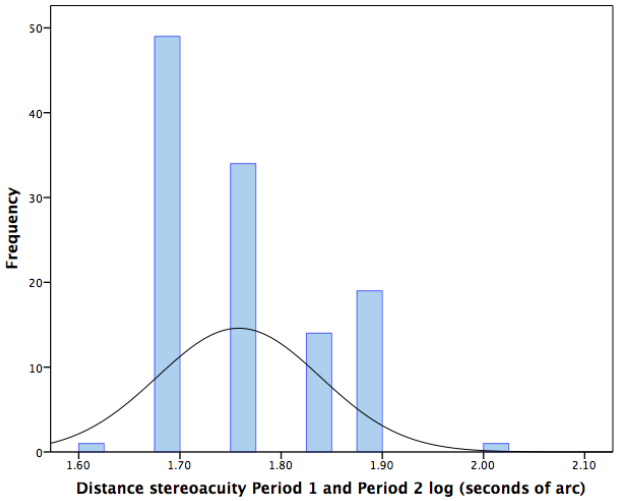
	Mean	N	Std. Deviation	Std. Error Mean	t
Binocular photopic near VA Period 1	.1421	57	.08451	.01119	1.174 (p=.245)
Binocular photopic near VA Period 2	.1511	57	.08606	.01140	

The difference for the binocular photopic near VA between Period 1 and Period 2 showed no statistically significant difference with t=1.174 (p=0.245) and a difference between the means of 0.009.

Both lenses performed very similarly to each other for this variable. A non-parametric confirmatory test with the Wilcoxon Signed Ranks test confirmed that the data for the two periods did not differ significantly (p=0.79).

5.1.2.3 Stereoacuity at distance and near

To correct for the non-linear scaling, as discussed above in Section 5.1.1.3, all data for stereoacuity were converted to logarithmic equivalents (log_{10}). Frequency distributions for the pooled data are shown in Figure 23.



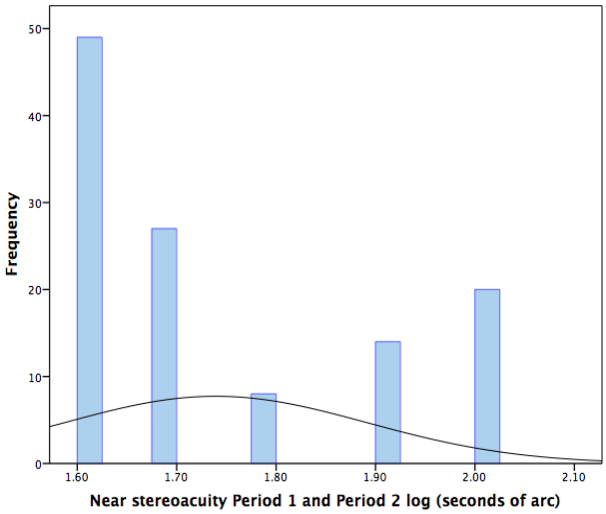


Figure 23: Histograms for the Distribution of Binocular Distance and Near Stereoacuity, showing pooled data for Period 1 and Period 2

The Shapiro-Wilk test for normality indicated that the distribution of the difference between paired measurements for stereoacuity departed from a normal distribution for both, the distance (p=0.002) and near (p=0.003) data. As specified in Section 4.7.2, non-parametric analyses were carried out. The Wilcoxon Signed Ranks test confirmed that the data for the two periods did not differ significantly, both for distance (p=0.581) and near (p=0.617) testing.

Table 8: Wilcoxon Signed Ranks—Test Analysis for Distance Stereoacuity Period 1 and Period 2

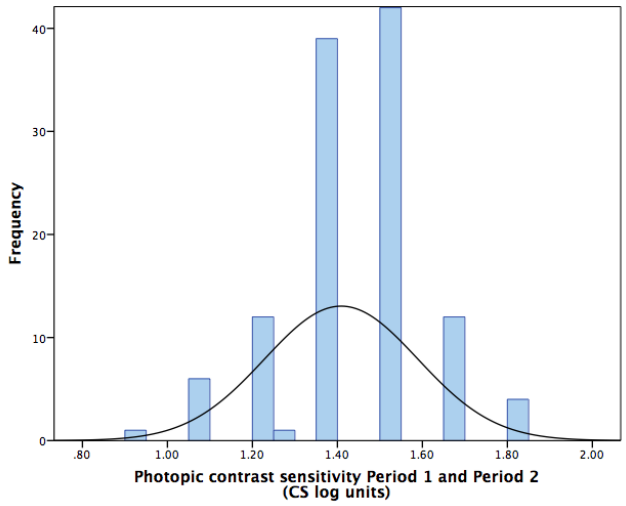
	Mean	**N**	**Exact Sig. (2-tailed)**	**Z (based on positive Ranks)**
Distance stereoacuity Period 1	1.7644	57	.589	-.551 (p=.581)
Distance stereoacuity Period 2	1.7519	57		

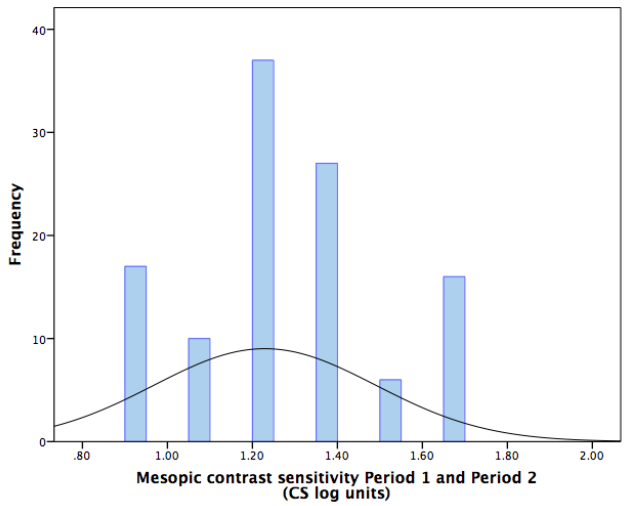
Table 9: Wilcoxon Signed Ranks–Test Analysis for Near Stereoacuity Period 1 and Period 2

	Mean	N	Exact Sig. (2-tailed)	z (based on positive ranks)
Near stereoacuity Period 1	1.7340	57	.624	-.499 (p=.617)
Near stereoacuity Period 2	1.7479	57		

5.1.2.4 Contrast sensitivity in photopic, mesopic and scotopic lighting conditions

Frequency distributions for the pooled data are shown in figure 24.





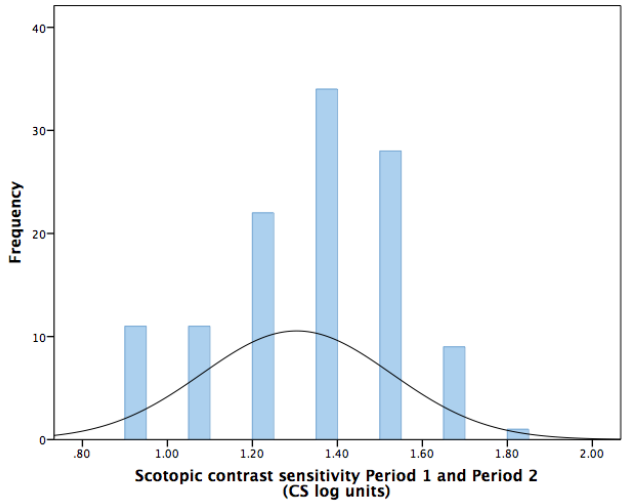


Figure 24: Histograms for the Distribution of Photopic, Mesopic and Photopic Contrast Sensitivity, showing pooled data for Period 1 and Period 2

For this variable, the Shapiro-Wilk test for normality indicated that the distribution of the difference between paired measurements in photopic, mesopic and scotopic lighting conditions departed from a normal distribution (photopic p=0.024, mesopic p=0.020, scotopic p= 0.029). As specified in Section 4.7.2, both parametric and non-parametric analyses were carried out

For photopic lighting conditions, the parametric test showed no statistically significant difference (t=-1.474, p=0.143 and a difference between the means of 0.029, equal to one letter on the Thomson test chart (Table 10). A Wilcoxon Signed Ranks test confirmed this result with z=-1.506 (p=0.132).

Table 10: Paired t-test Analysis for Photopic Distance Contrast Sensitivity Period 1 and Period 2

	Mean	N	Std. Deviation	Std. Error Mean	t
Photopic distance contrast sensitivity Period 1	1.4237	57	.17272	.02288	-1.474 (p=.143)
Photopic distance contrast sensitivity Period 2	1.3947	57	.19219	.02546	

For mesopic conditions, the outcome showed t=0.000 (p=1) with no difference between both means (Table 11). The scatterplot in Figure 19 above documents a difference within the data for Period 1 and Period 2 within the sample population, although the means were identical. This result is not statistically significant, with no difference between both means for the twilight condition. A Wilcoxon Signed Ranks test confirmed this result with z=-0.110 (p=0.912).

Table 11: Paired t-test Analysis for Mesopic Distance Contrast Sensitivity Period 1 and Period 2

	Mean	N	Std. Deviation	Std. Error Mean	t
Mesopic distance contrast sensitivity Period 1	1.2289	57	.25894	.03430	.000 (p=1)
Mesopic distance contrast sensitivity Period 2	1.2289	57	.26049	.03450	

For contrast sensitivity in scotopic lighting conditions, the difference between the means was found with t=-2.859 (p=0.006), which is statistically significant with a difference between the means of 0.0789, which equates to 1.5 letters on the Thomson contrast sensitivity chart. A Wilcoxon signed ranks test confirmed this result with z=-2.581 (p=0.010).

Table 12: Paired t-test Analysis for Scotopic Distance Contrast Sensitivity Period 1 and Period 2

	Mean	N	Std. Deviation	Std. Error Mean	t
Scotopic distance contrast sensitivity Period 1	1.3421	57	.22216	.02943	-2.859 (p=.006)
Scotopic distance contrast sensitivity Period 2	1.2632	57	.22491	.02979	

5.1.3 Results for the re-ordered data for Lens A and Lens B, testing for a lens effect within the four main measures: binocular photopic distance VA, binocular photopic near VA, stereoacuity (at distance and near) and contrast sensitivity (in photopic, mesopic and scotopic lighting conditions)

Having established that there were no consistent order effects the next stage of the analysis was for all variables to be re-ordered to compare Lens A against Lens B. Using the initial Excel spreadsheet the data were re-arranged accordingly, then again converted into SPSS. The graphs were repeated for all variables, using the above SPSS version, while taking care not to lose the double blind masking. The latter was achieved by previous labeling of the lenses as Lens A and Lens B at the fitting stage and worked successfully, leaving the researcher masked to the end of the results analysis. In other words, although the researcher would become aware during the analysis, whether Lens A was tending to perform better than Lens B, they were not aware of the identity of either lens.

Data for 57 participants were included in the analysis for all four main variables. The results comparing Lens A and Lens B within the re-ordered data showed no clinically significant difference for the first variable, binocular photopic distance VA. The graphs can be observed in Figure 25 below and the statistical analysis is reported in section 5.1.4 of this chapter.

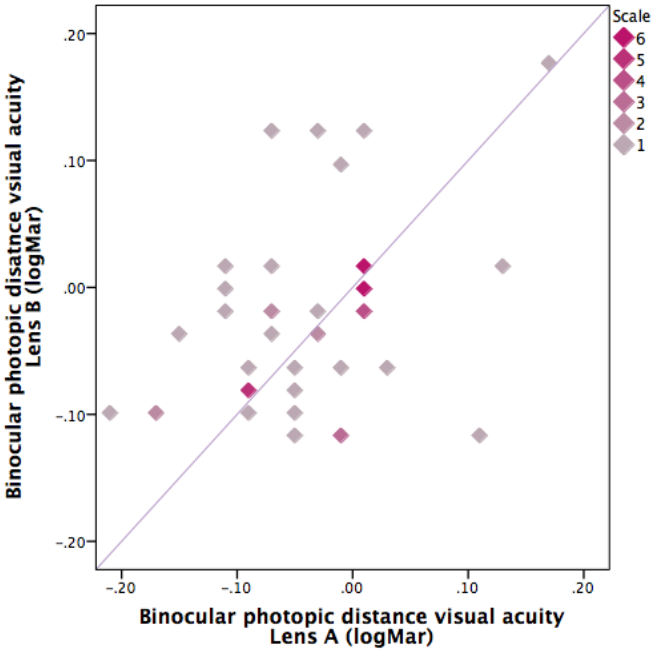


Figure 25: Re-ordered Data for Main Variable: Binocular Photopic Distance VA Lens A and Lens B. Some data points are overlapping and, as indicated in the scale, the depth of colour of the symbols reflects the number of participants that overlap (in this graph, the lightest colour represents 1 participant and the darkest colour represents 6 participants)

The same procedure was followed for binocular photopic near VA Lens A and Lens B. Again no clinically significant difference was detected when comparing the data set for the second variable for Lens A and Lens B seen in Figure 26 below.

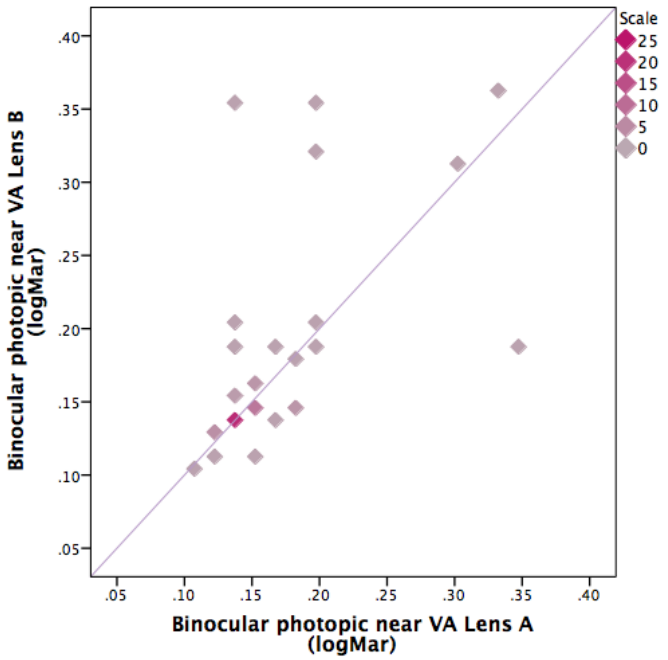


Figure 26: Re-ordered Data for Binocular Photopic Near VA Lens A and Lens B. Some data points are overlapping and, as indicated in the scale, the depth of colour of the symbols reflects the number of participants that overlap (in this graph, the lightest colour 0 represents 1 to 4 participants and the darkest colour 25 represents 21 to 25 participants)

The same procedure was followed for the third variable, distance and near stereoacuity.

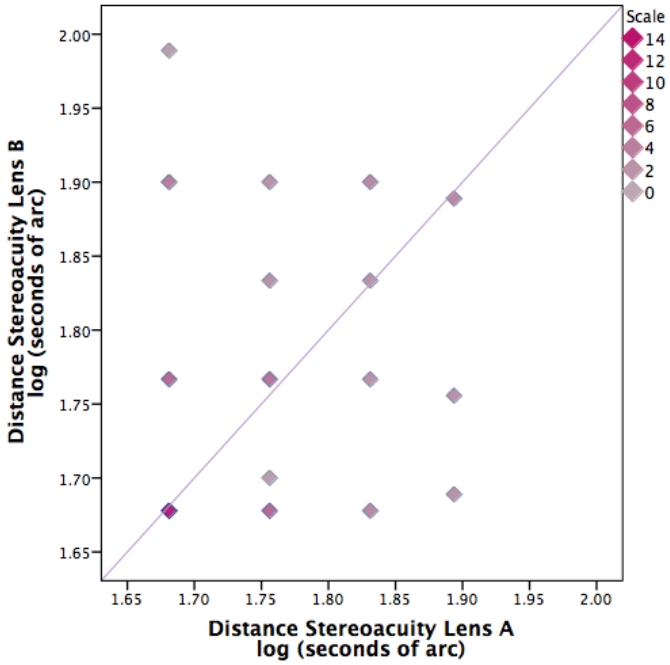


Figure 27: Re-ordered Data for Distance Stereoacuity Lens A and Lens B. Some data points are overlapping and, as indicated in the scale, the depth of colour of the symbols reflects the number of participants that overlap (in this graph, the lightest colour 0 represents 1 participant and the darkest colour 14 represents 13 or 14 participants).

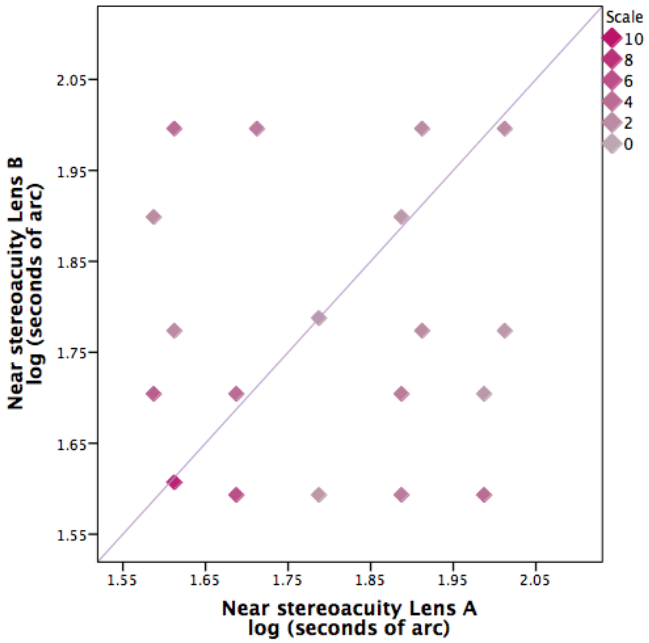


Figure 28: Re-ordered Data for Near Stereoacuity Lens A and Lens B. Some data points are overlapping and, as indicated in the scale, the depth of colour of the symbols reflects the number of participants that overlap (in this graph, the lightest colour 0 represents 1 participant and the darkest colour 10 represents 9 or 10 participants).

The stereoacuity data used for the analysis were converted into $\log_{10}$, as was done earlier in the chapter for Period 1 and Period 2, to adhere closely to a linear scale. The results can be seen in Figures 27 and 28 above. These data showed no apparent difference in performance for distance and near stereoacuity.

Graphs were then constructed with the same objective for the last variable contrast sensitivity in photopic, mesopic and scotopic lighting conditions. The sample population for contrast sensitivity in all three lighting conditions consisted again of 57 participants. The graphs can be observed below in Figures 29, 30 and 31.

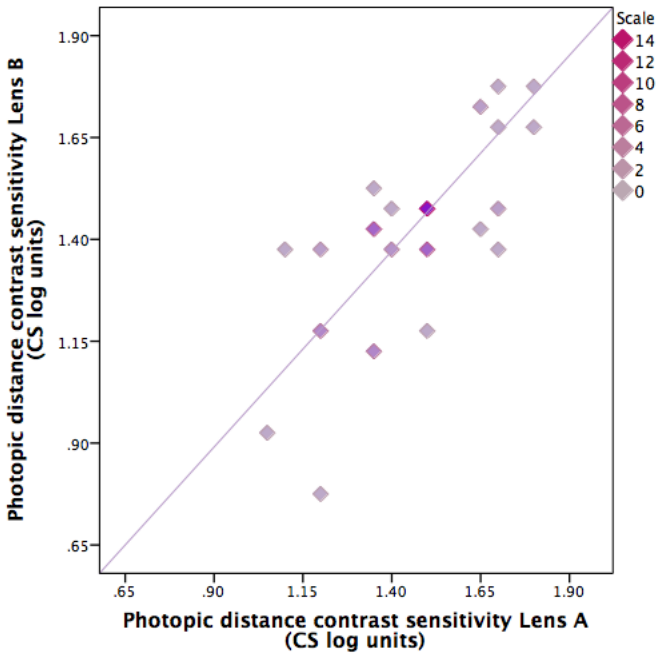


Figure 29: Re-ordered Data for Photopic Distance Contrast Sensitivity Lens A and Lens B. Some data points are overlapping and, as indicated in the scale, the depth of colour of the symbols reflects the number of participants that overlap (in this graph, the lightest colour 0 represents 1 participant and the darkest colour 14 represents 13 or 14 participants).

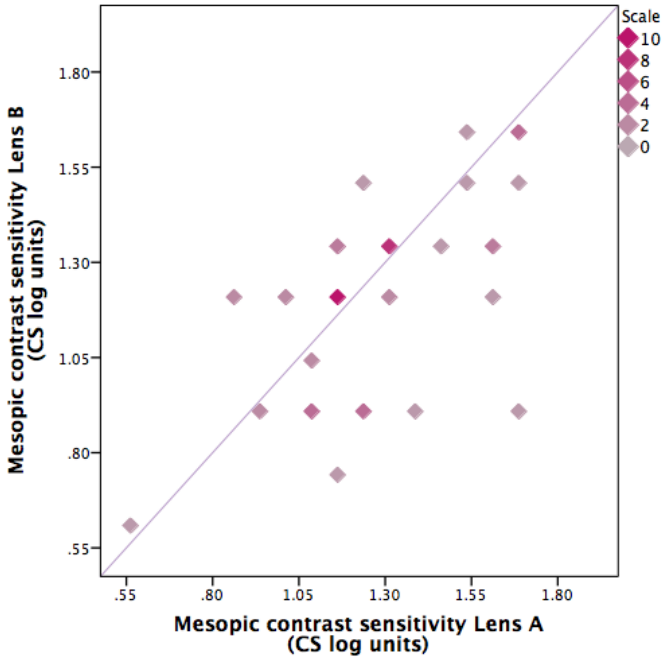


Figure 30: Re-ordered Data for Distance Mesopic Contrast Sensitivity Lens A and Lens B Some data points are overlapping and, as indicated in the scale, the depth of colour of the symbols reflects the number of participants that overlap (in this graph, the lightest colour 0 represents 1 participant and the darkest colour 10 represents 9 or 10 participants).

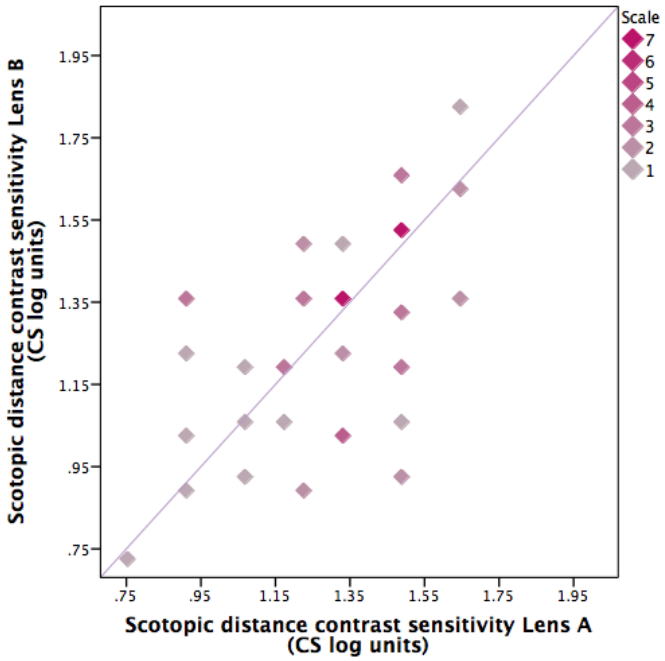


Figure 31: Re-ordered Data for Scotopic Distance Contrast Sensitivity Lens A and Lens B Some data points are overlapping and, as indicated in the scale, the depth of colour of the symbols reflects the number of participants that overlap (in this graph, the lightest colour represents 1 participant and the darkest colour represents 7 participants).

5.1.4 Frequency distributions and paired analyses of the re-ordered data for Lens A and Lens B for the four main variables binocular photopic distance VA, binocular photopic near VA, stereoacuity (at distance and near) and contrast sensitivity (in photopic, mesopic and scotopic lighting conditions)

5.1.4.1 Binocular photopic distance VA

A frequency distribution of the re-ordered pooled data is illustrated in Figure 32.

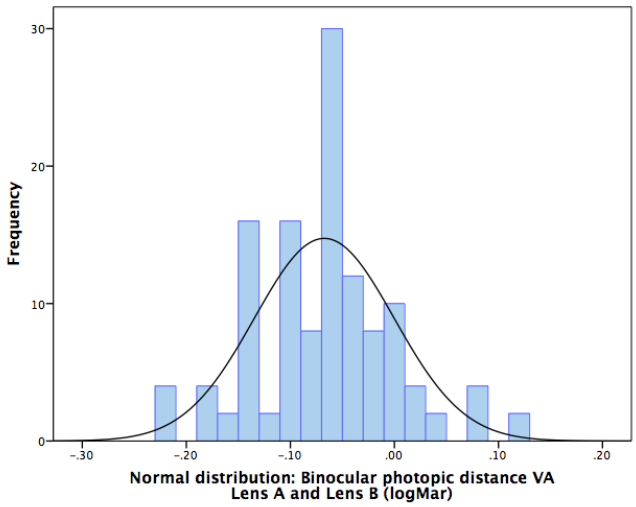


Figure 32: Histogram for the Distribution of Binocular Photopic Distance VA, showing the pooled data for Lens A and Lens B

The Shapiro-Wilk test for normality indicated that the distribution of the difference between paired measurements for binocular photopic distance VA for Lens A and Lens B departed significantly from a normal distribution (p=0.021). As specified in Section 4.7.2, both parametric and non-parametric statistical analyses were carried out.

Table 13: Paired t-test Analysis–for Binocular Photopic Distance VA Lens A and Lens B

	Mean	N	Std. Deviation	Std. Error Mean	t
Binocular Photopic Distance VA Lens A	-0.0698	57	.06281	.00832	-1.535 (p=.128)
Binocular Photopic Distance VA Lens B	-0.0498	57	.07072	.00937	

The difference for the binocular photopic distance VA between Lens A and Lens B (Table 13) showed no statistically significant difference with t=-1.535 (p=0.128) and a difference between the means of 0.02. A non-parametric Wilcoxon signed ranks test confirmed this result with z=-0.927 (p=0.354).

5.1.4.2 Binocular photopic near VA

The same procedure was applied again for binocular photopic near VA for Lens A and Lens B.

A frequency distribution of the re-ordered pooled data is illustrated in Figure 33.

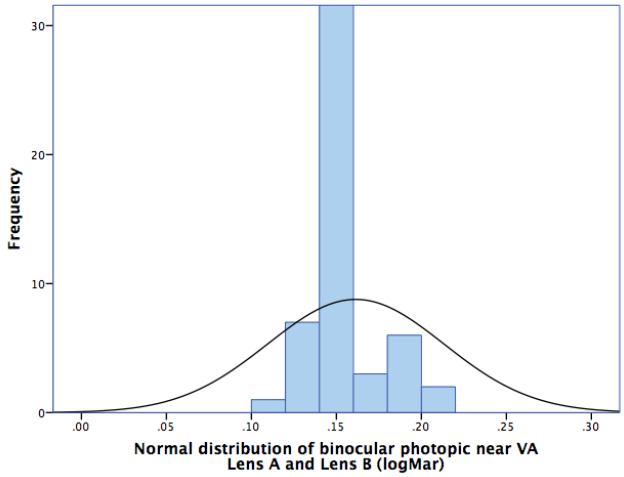


Figure 33: Histogram for the Distribution of Binocular Photopic Near VA, showing the pooled data for Lens A and Lens B

The Shapiro-Wilk test for normality indicated that the distribution of the difference between paired measurements for binocular photopic near VA departed from a normal distribution (p=0.016). As specified in Section 4.7.2, both parametric and non-parametric analyses were carried out.

Table 14: Paired t-test Analysis for Binocular Photopic Near VA Lens A and Lens B

	Mean	N	Std. Deviation	Std. Error Mean	t
Binocular Photopic Near VA Lens A	.1598	57	.05085	.00646	1.175 (p=.244
Binocular Photopic Near VA Lens B	.1614	57	.5184	.00687	

The difference for the binocular photopic near VA between Lens A and Lens B showed no statistically significant difference with t=1.175 (p=0.24) and a difference between the means of 0.016. A non-parametric Wilcoxon signed ranks test confirmed the results with z=-0.188 (p=0.851).

5.1.4.3 Stereoacuity at distance and near

Frequency distributions for the pooled stereoacuity data are shown in Figure 34.

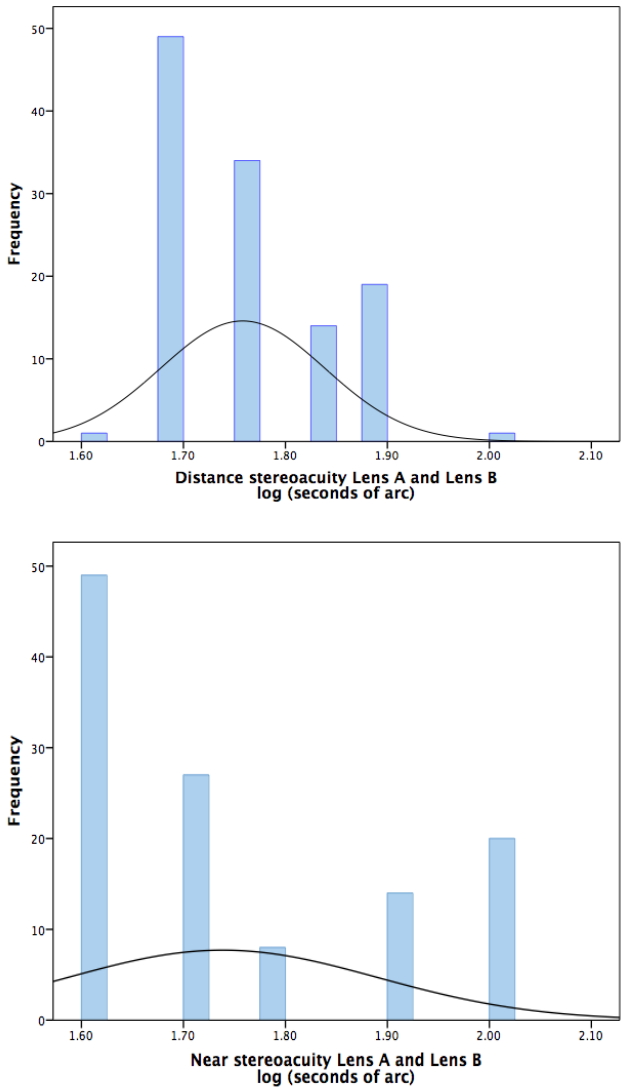


Figure 34: Histogram for the Distribution of Binocular Distance and Near Stereoacuity, showing the pooled data for Lens A and Lens B

The Shapiro-Wilk test for normality indicated that the distribution of the difference between paired measurements for stereoacuity departed from a normal distribution for both distance (p=0.001) and near (p=0.002) stereoacuity. As specified in Section 4.7.2, non-parametric analyses were carried out. The Wilcoxon Signed Ranks test confirmed that the data for the lens types did not differ significantly, both for distance (Table 15) and near (Table 16).

Table 15: Wilcoxon Signed Ranks—Test Analysis for Distance Stereoacuity Lens A and Lens B

	Mean	**N**	**Exact Sig. (2-tailed)**	**Z (based on positive ranks)**
Distance stereoacuity Lens A	1.7482	57	.334	-.980
Distance stereoacuity Lens B	1.7654	57		(p=.327)

Table 16: Wilcoxon Signed Ranks-Test Analysis for Near Stereoacuity Lens A and Lens B

	Mean	**N**	**Exact Sig. (2-tailed)**	**z (based on positive ranks)**
Near stereoacuity Lens A	1.7267	57	.365	-.918
Near stereoacuity Lens B	1.7512	57		(p=.359)

5.1.4.4 Contrast sensitivity in photopic, mesopic and scotopic lighting conditions

Frequency distributions for the pooled contrast sensitivity data are shown in Figure 35.

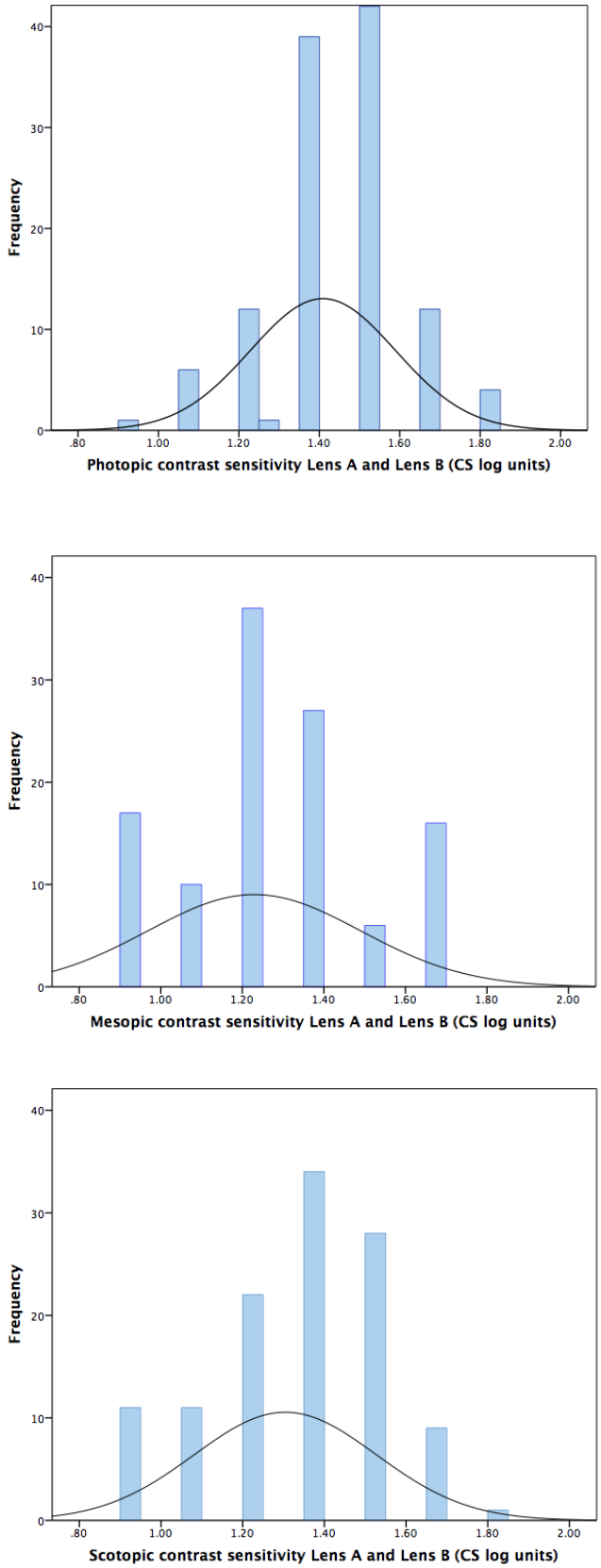


Figure 35: Histograms for the Distribution of Photopic, Mesopic and Scotopic Contrast Sensitivity, showing the pooled data for Lens A and Lens B

For this variable, the Shapiro-Wilk test for normality indicated that the distribution of the difference between paired measurements in photopic, mesopic and scotopic lighting conditions departed from a normal distribution (photopic p=0.037, mesopic p=0.023, scotopic p=0.018). As specified in Section 4.7.2, both parametric and non-parametric analyses were carried out.

For photopic lighting, the paired t-test revealed t=2.517 (p=0.013), a statistically significant result and a difference between the means of 0.0447, seen in Table 17 below. The Wilcoxon Signed Ranks test confirmed this result with z =2.366 (p=0.018).

Table 17: Paired t-test Analysis for Photopic Distance Contrast Sensitivity Lens A and Lens B

	Mean	N	Std. Deviation	Std. Error Mean	t
Photopic distance contrast sensitivity Lens A	1.4456	57	.16805	.02226	2.517
Photopic distance contrast sensitivity Lens B	1.4009	57	.19144	.02536	(p=.013)

For mesopic conditions, the paired t-test revealed no significant difference in the performance of the two lenses t=1.350 (p=0.182) and a difference between both means of 0.0403, seen in Table 18 below. This result was confirmed with the Wilcoxon Signed Ranks test z=1.203 (p=0.229).

Table 18: Paired t-test Analysis for Mesopic Distance Contrast Sensitivity Lens A and Lens B

	Mean	N	Std. Deviation	Std. Error Mean	t
Mesopic distance contrast sensitivity Lens A	1.2605	57	.28327	.03752	1.350 (p=.182)
Mesopic distance contrast sensitivity Lens B	1.2202	57	.24997	.03311	

For contrast sensitivity in scotopic lighting conditions, the paired t-test revealed no significant difference in the performance of the two lenses t=-0.912, (p=0.364) and difference between the means of 0.040, which equates to 0.5 letter on the LogMAR contrast sensitivity chart. The Wilcoxon Signed Ranks test confirmed this result with z=0.997 (p=0.319). The results can be seen in Table 19 below.

Table 19: Paired t-test Analysis for Scotopic Distance Contrast Sensitivity Lens A and Lens B

	Mean	N	Std. Deviation	Std. Error Mean	t
Scotopic distance contrast sensitivity Lens A	1.3281	57	.22796	.03019	-.912 (p=.364)
Scotopic distance contrast sensitivity Lens B	1.3018	57	.22440	.02972	

5.1.5 Results for the questionnaire data for Period 1 and Period 2 and the re-ordered data for Lens A and Lens B for part 1 of the questionnaire

The questionnaire used for this trial, forming part of the participants' subjective evaluation of the two contact lenses, was the VF-14 visual function questionnaire, adapted for the present study, as described in more detail in the methods chapter and Appendix 6. The results were scored so that lower scores indicate better performance (fewer difficulties). To break down the results into usable data, the 14 questions in the first section of the questionnaire were divided into 3 categories. These were subjective distance vision, subjective intermediate vision and subjective near vision. Questions were allocated according to their relevance. This resulted in four relevant

questions for distance vision (questions number 6, 10, 13 and 14), four for intermediate vision (questions number 5, 9, 11 and 12) and six questions relevant to assess near vision with the contact lenses (questions 1, 2, 3, 4, 7 and 8). A copy of the questionnaire is labeled as Appendix 6 included at the end of this thesis. The numerical columns were entered into Excel and then ported into SPSS to produce frequency graphs by averaging the scores in each group. The first set of results seen below in Figures 36, 37 and 38 are the results for the masked data of Period 1 and Period 2, split into distance, intermediate and near vision. These graphs are then followed by Figures 39, 40 and 41, showing graphs for the re-ordered data with the results for Lens A and Lens B.

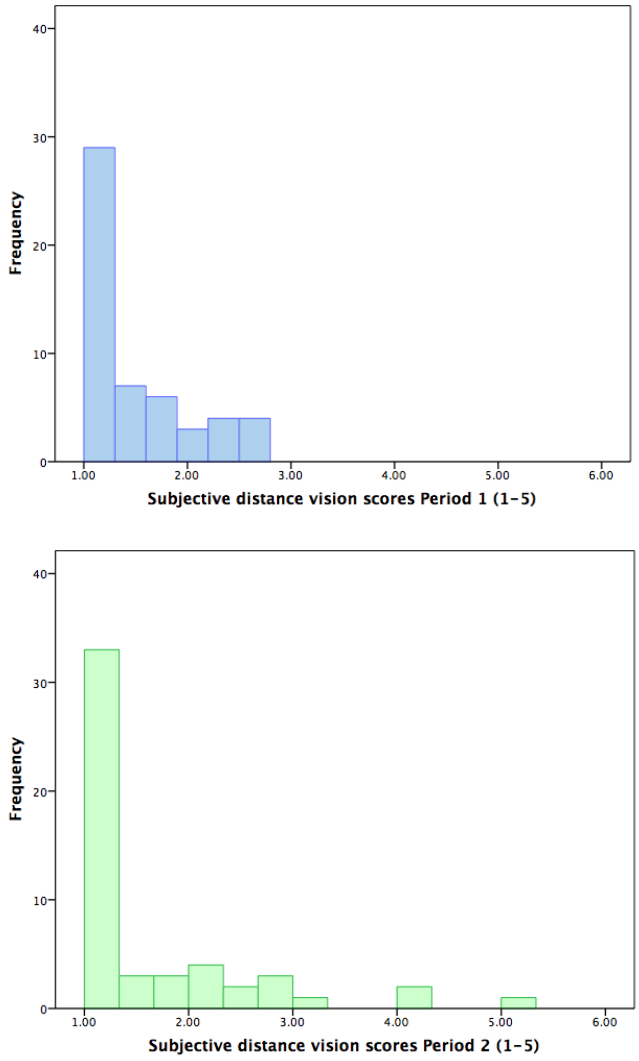
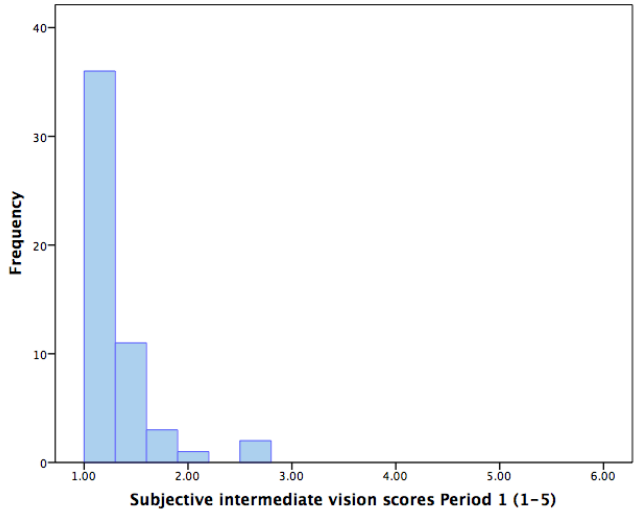


Figure 36: Frequency of Scores for Subjective Distance Vision (Period 1 and Period 2)



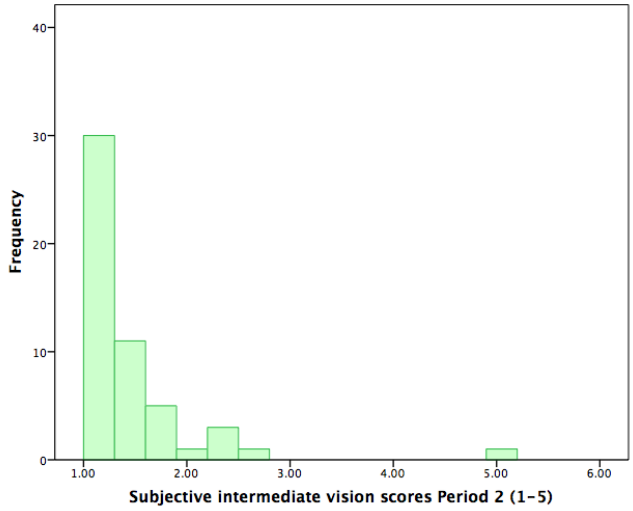
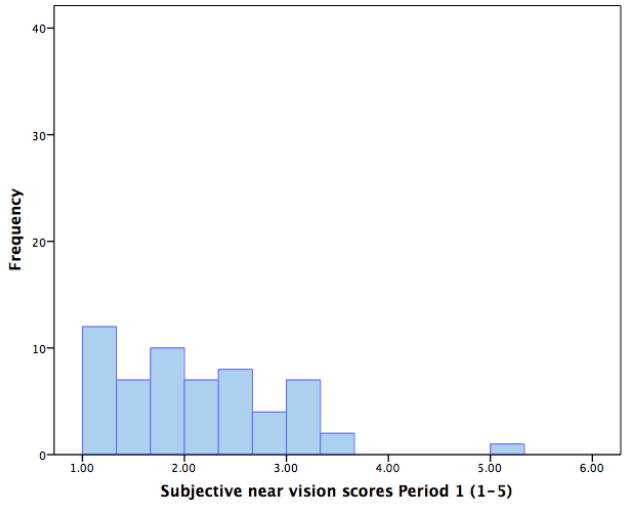


Figure 37: Frequency of Scores for Subjective Intermediate Vision (Period 1 and Period 2)



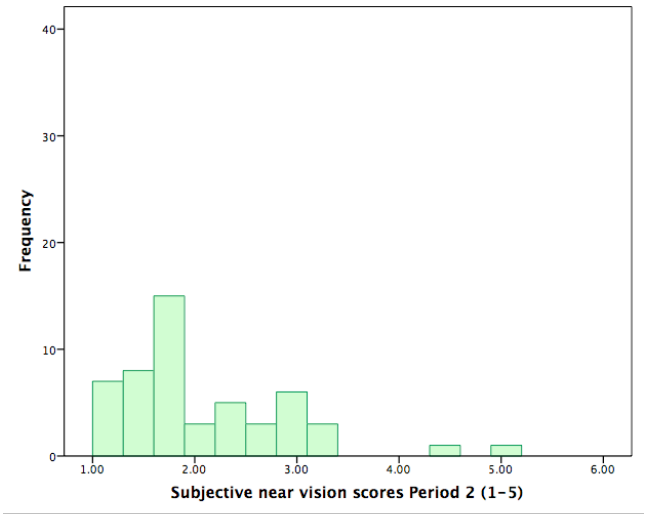


Figure 38: Frequency of Scores for Subjective Near Vision (Period 1 and Period 2)

5.1.6 Results for the questionnaire data Lens A and Lens B

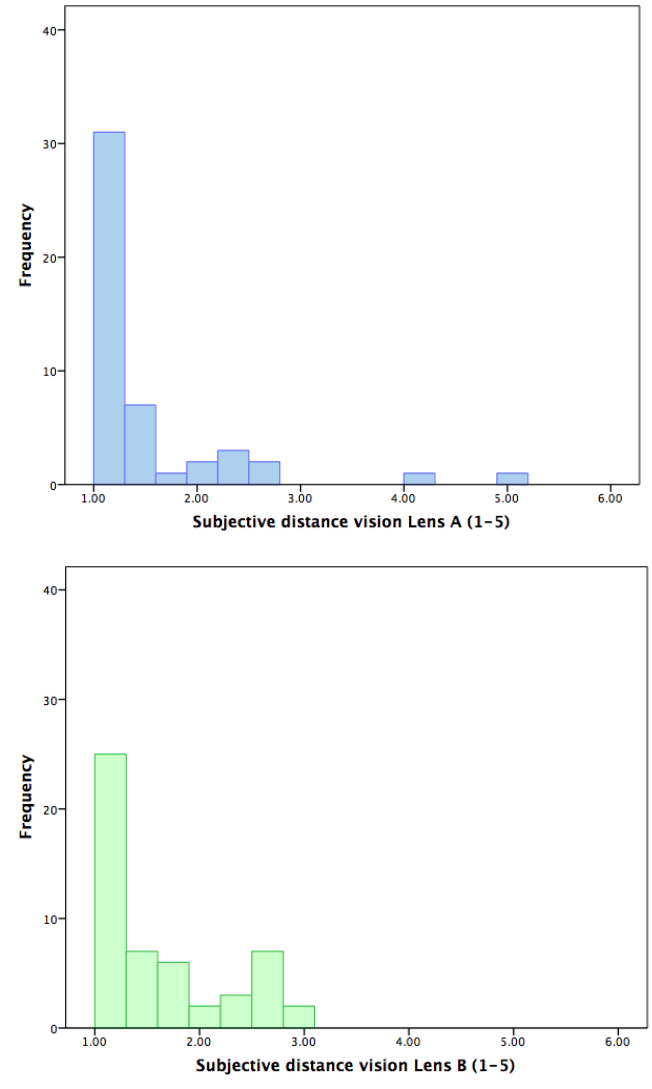
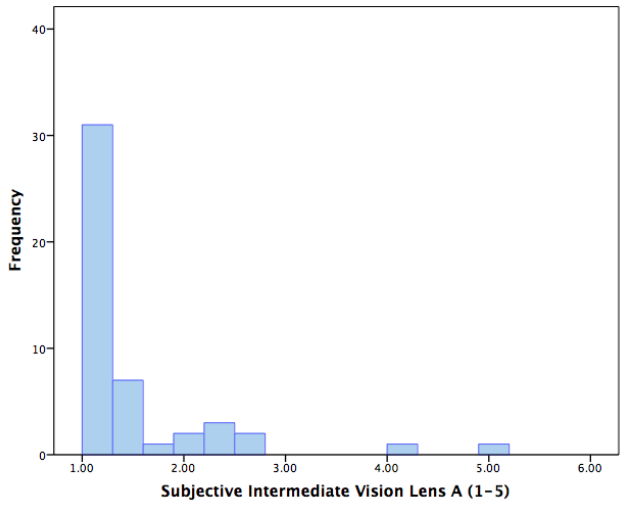


Figure 39: Frequency of Scores for Subjective Distance Vision (Lens A and Lens B



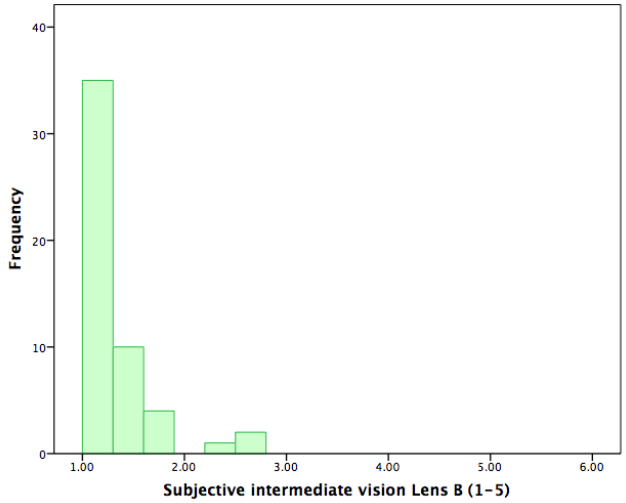
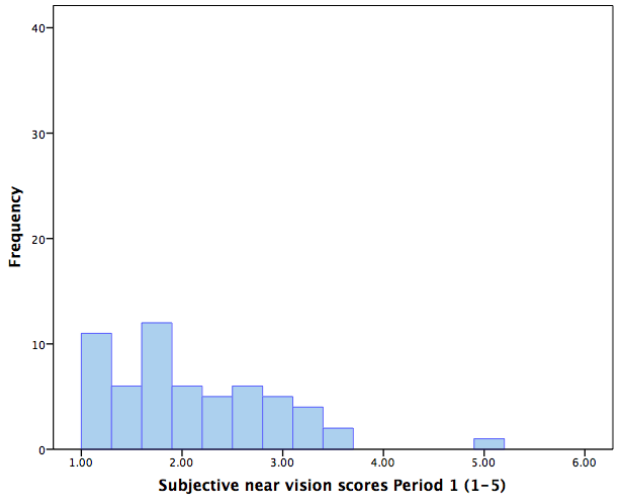


Figure 40: Frequency of Scores for Subjective Intermediate Vision (Lens A and Lens B)



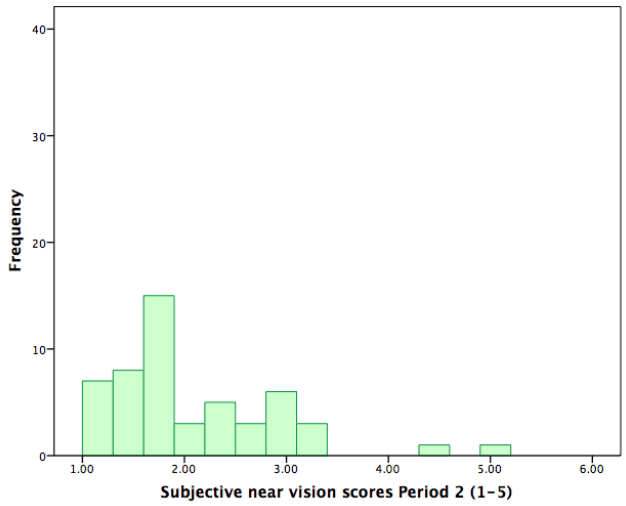


Figure 41: Frequency of Scores for Subjective Near Vision (Lens A and Lens B)

The Wilcoxon test for Two-Related-Samples was used to compare the frequency scores for Lens A and B and the results can be observed in Table 20 below. All p-values for these frequencies showed results that were not statistically significant.

Table 20: Frequency of Scores for Distance, Intermediate and Near Vision for Lens A and Lens B

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Distance VA scores Lens A	1.4730	53	.78164	.105	-1.629 (p=.103)
Distance VA scores Lens B	1.5690	52	.62570		

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Intermediate VA scores Lens A	1.3817	53	.63565	.147	.1.461 (p=.144)
Intermediate VA scores Lens B	1.2433	52	.38706		

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Near VA scores Lens A	2.1070	56	.9300	.092	-1.688 (p=.091)
Near VA scores Lens B	1.8781	54	.7328		

5.1.7 Subjective comments in part 2 of the questionnaire

The second part of the questionnaire data consisted of a comments box that was added at the bottom of the questionnaire. This box was added as an optional box, since it was felt that participants might want to add any individually relevant concerns. Not every participant made entries here. The table below lists the comments added in this section of the questionnaire by each participant, directly transcribed. These were entered into the table and then color coded (blue = Lens A and green = Lens B) to identify the relevance for Lens A and Lens B accordingly. All transcribed results can be observed in Table 21 below.

Table 21: Subjective Comments for Period 1 and Period 2, Relevant to Lens A and Lens B

Participant Number	Subjective Comments Period 1 (◎ = Lens A)	Subjective Comments Period 2 (⊡ = Lens B)
1/10805		Uncomfortable to wear, discontinued trial due to severe headaches and blurring vision
2/19549	Comfortable to wear. Computer is easier to focus. (Congestion in corners of eyes after putting in lenses + then applying eye make up	I can play green bowls well. The vision is not distorted as it was with previous lenses I have tried. Lovely to were. So light. You forget that you are wearing lenses.
3/10356	To begin with I found the lens easy to insert, but difficult to remove. I have needed to use eye drops 4x daily and there is much improvement. This is preventing dryness and	I have found theses lenses easy to insert and remove providing I moisten each eye. I can wear them for 10 hours, but my eyes are sometimes score on

	soreness after use! Driving at night: The lights have halos and there is also increased glare. I have found it easier to look at the road rather than the lights. The lenses are comfortable and an improvement on my old lenses. I still need my glasses for small print, writing, computer work and some sewing activities.	removal so I try to remove them for a shorter time sequence. I am able to see well, but if doing prolonged episodes of fine work (Ie: sewing ore reading and writing in a poor light), I sometimes need my glasses. On the whole the last batch of lenses in the trial have been outstandingly better than the previous trial lenses.
4/8770	My near vision is better than with my previous prescription lenses, but not as good as with no lenses in. My far vision is not as sharp. Overall, I would not wish to go back to my old lenses.	
5/14290	Left-hand lens never as comfortable as the right and always seemed to tire earlier than the right. Seemed to take longer to adjust to close-up paperwork/computer work than for distance, giving me a frowning effect.	These lenses were about on par performance-wise as the first test lenses. Gave up after two weeks, as I just could not get them out at the end of the day without considerable discomfort to my eyes.
6/8152		Reading small print difficult, reading work on PC: had to enlarge in many cases, do not want these again, near distance also poor. Lens difficult to remove at the end of the day.
7/3699	I noted that vision particularly for reading deteriorated as the day progressed, particularly in later evening	Main difficulty in reading very small food labels for example. Wearing lenses became more uncomfortable from early evening. May have been due to left lens being damaged on two occasions.
8/450	Reading music scores difficult	
9/8252	Vision nice and clear but eyes did get a little dry	Eyes became very dry and took over 3 hours to get out. Fine to put in but after 4.5 hours, just wanted them out and would not have again.
10/8936	For playing/teaching piano middle distance is great. My reading glasses, which I use for sewing are much more effective.	Vision slightly more variable with occasional blurring of one or other of the lenses. Left lens not quite as good as right lens. Distance vision slightly less good, but near vision, particularly sewing excellent. Lenses had habit of inverting on the finger, making them slightly harder to put in.
11/8945		Very comfortable – good fit. Colouring does help for putting in ands into

		solution.
12/75		I found these lenses often uncomfortable and my vision generally misty and distorted.
13/6550	Friday 15th 3pm: watery eyes, took them out in evening for a rest. Could be that I was tired, though. Saturday 16th Feb 5am: Took 15 minutes to focus on close-up things. Took them out at 2pm after work.	1st week: Only fault I found so far is I have more trouble getting the lenses into my eyes. 4th week: struggled to focus with left lens.
14/8779	Had difficulty with reading until lenses were adjusted.	Lenses not as good towards the end of the trial period. Less clarity and more difficulty with focussing.
15/8218	I work in a jeweller. When doing close work, like stringing pearls or repairing jewellery, I have to wear reading glasses as well as lenses to enable me to carry out my work, but most of the days wearing the lenses, I found very good.	These were more difficult to get out of the eyes, much worse for driving, especially at night. Had to stop wearing them. Also: I had a lot of twitching in the eyes.
16/6695		
17/9265	The lenses have been very good – brilliant to be able to see up close and in the distance with one set. Close vision deteriorated towards the end of the wearing period and eyes became drier as the day went on. Need a little time to adjust when first put in, but generally very pleased. Computer vision has been particularly good.	These were the most uncomfortable lenses and more difficult to put in than the others. Reading was very difficult – I was glad when the trial period came to an end.
18/7769		
19/8964	I found if I turned my head side to side quickly eg.: talking to one person then another during interview, I became a little dizzy. Unable to read any reviews or newspaper and if tried words/print looked as if was jumping around and gave me a headache.	
20/20922		
21/2703	Adjusting to vision at different distances is often a little slow. Blinking often causes a temporary blur, especially out of doors. I don't seem to have ticked many activities, not because I haven't done anything at all, just not for an hour. My unaided long distance is excellent, so although it is ok when wearing lenses, it is not quite as good as unaided. Near vision is hard work when	

	trying to read a book or magazine.	
22/739		
23/1786		
24/1090		
25/9266	I have found these lenses great, but think you could have asked questions about housework, ironing etc. For cooking I have found the lenses are very good. Although I found the lenses a little difficult for night driving. This was because the distance vision was not as good as in my gas permeable lenses, but found that I did not get the halo effect from car and streetlights. Cannot wait to try the next pair and don't ever want to go back to my old lenses.	In comparison with the first set of lenses, these no way compare with them for close-up or distance.
26/6892	Lenses were worn for approximately 15 hours every day. Occasionally, became sticky on the eye, particularly towards the end of the day and more so towards the end of the trial.	
27/8901	Lenses worn for up to 15 hours a day. Vision disrupted when gardening and reading, but mostly when interchanging between reading on paper and reading on screen at work. Lenses stick on a regular basis and can be difficult to put in. Regularly aware of lenses from day one. Remind me of my daily disposables, which can be uncomfortable.	Worn lenses up to 15 hours a day. Occasional difficulty adjusting between long and short distances.
28/9387	The initial improvement in reading was due to the change in sight from the last set. After 2-3 days the reading ability got worse and certainly less clear as long and intermediate vision.	Poor lighting conditions affect my ability to read smaller print.
29/9386		
30/767	Contact lenses were fine for hand sewing but when doing machine embroidery harder, difficult to see needle to thread. I didn't read a book, tried but felt my eyes straining! Same for newspaper, headlines fine, but smaller print more difficult.	These lenses have been very easy to put in and extract and very comfortable to wear. The best lenses for me and out of the 2 trials they have been very flexible, soft and hard wearing.
31/8708		
32/8701		

33/3328		
34/2095		
35/9267		
36/16991	Some difficulty reading small print especially in dim light at night	Second set seemed more comfortable, but maybe because I am used to wearing them, now? Still can't read small print well in low light or at night.
37/20937		Only wore them for 2 days because they were so uncomfortable.
38/13003	Very comfortable, but not a major improvement for close vision eg., reading. Fine for computer work and distance vision.	Medium (Watching TV) and distance vision not as sharp as previous lens, although I appreciate these are a different prescription.
39/2720	1stly: Never having worn contact lenses very pleased how easy to put in and take out. 2nd: Surprised how comfortable although after being in all day not as comfortable at night. 3: Even after adjusting lens prescription driving most difficult task. Anything beyond 30M becomes less sharp (read signs, number plates, traffic further away, glasses no problem) 4) Overall I think, once prescription exact for distance, cls preferred over glasses	Just when wearing close on a computer words seemed blurred. Uncomfortable when eyes dry or end of day. Obviously harder than first set, so lenses less comfortable.
40/1641	Difficulty with near vision, wore in poor light.	Less comfortable than first set of lenses. Distance vision not as clear. Would think hard about wearing lenses if these were the only option.
41/2093	Fluorescent lighting made distance vision blurred, as well as poor lighting and being tired. Lens seemed better in the first week, more comfortable as time went on.	My medium to long vision is not as good with the lens in.
42/6093		
43/16545		
44/6687	I loved the increased vision these lenses gave me particularly with small print. However, I did find that they became uncomfortable towards the end of the trial.	Did not find these lenses very comfortable.
45/6051		
46/16125	The lenses themselves became more comfortable and able to wear for most of the day. Found them frustrating for fine work, as a nurse – with sutures and procedure or reading small print menu. Diary only	Towards the end of the day – these contacts made my eyes uncomfortable and needed to remove them – but comfortable during the day.

	allowed activities done for 1 hour - transferring batch numbers from vials onto computer very difficult. Driving at night was particularly bad – as headlights became blurs – so then was forced to remove them – if had to drive in the dark.	
47/6892		
48/5608		
49/4564	Took a long time to master putting in and taking out. My left eye is irritated at times. Have had to wear +1.5D reading glasses for close work.	Theses lenses were better generally on all aspects of vision, but irritated somewhat.
50/1074	For computer work I would normally take out the lenses.	
51/371	Near vision improved slightly when the prescription changed. Vision seemed to improve as worn throughout the day. Not good when had fluid on as could see a rim around the lens.	Middle distance vision slightly blurred.
52/6802	These lenses were extremely comfortable in use but lacked the clarity of my glasses for longer vision and the close vision was limited to 60cm for clarity.	These lenses provided excellent vision for intermediate, distance and closer vision, but failed to perform for distance (driving). They became dry and itchy despite daily cleaning and finally had to be removed.
53/4430		Very focussed work eg.: removing sutures, hard to focus into small detail.
54/4829	Reading more difficult when tired, good g=light levels make a big difference, but distance TV quite difficult to read.	Reading small print in low light can be challenging. Diving in dark/wet conditions - can be dazzled
55/4309	Have found different lighting affects my vision. Also trying to use my mobile to read text messages can be tricky to see the screen.	Distance a little fuzzy/distorted. Intermediate vision not so good eg.: set a table, trying to read name badges of people at a seminar. Close-up ok but sometimes still a little fuzzy/distorted.
56/6793	I do a lot of close work, particularly reading in public, giving reports etc, so the lenses proved to be very frustrating at times.	Possible the lens material makes them difficult to wear. Always stuck together when removing from eye.
57/5503	The most difficulty I have experienced is in between what is classed as intermediate or long distance eg.: 5m away. I have only just started to loose	I developed sore eyes after 2.5 weeks. The left eye looked quite red and veins very obvious. The right eye was just slightly red. After wearing spectacles for a

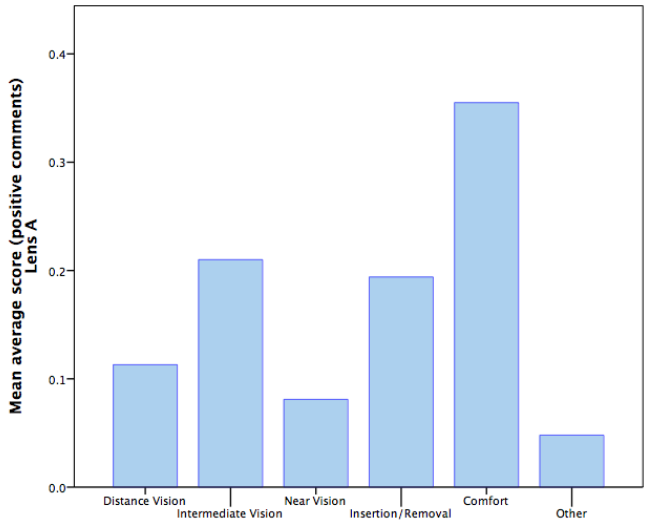
	accommodation, so I can see small print close to unaided, but it takes a split second to focus. My near vision is worse wearing these lenses than my usual ones, which are just to correct myopia. I am very impressed how comfortable they are. I am used to daily disposables and was surprised how easy the lens care is for these. I feel the quality of my vision has deteriorated over the period a little.	couple of days, returned to wearing contact lenses, but my eyes were irritated very quickly.
58/5573	Problem with right hand lens initially, particularly for driving. Resolved with new lens.	
59/7063		
60/2376		
61/5838		
62/7310	The right lens was more uncomfortable than the left lens. My job is accounts and office work and I really struggled with close work and computer work.	Driving was more difficult this time. I once had to stop the car and take out my lenses. Office work is still quite difficult.

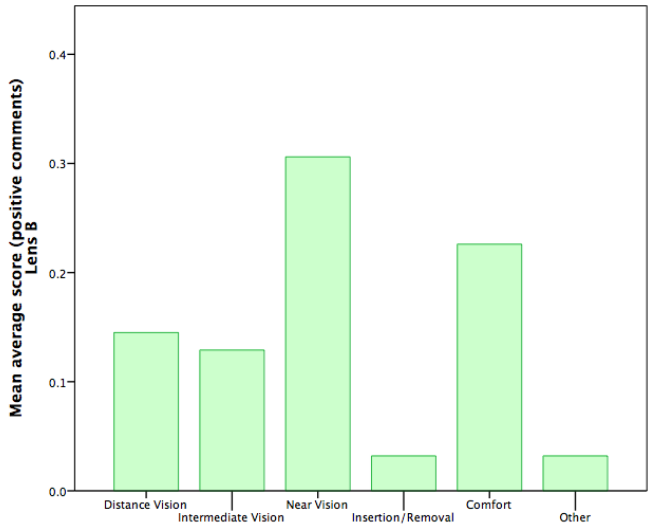
All scores were then given a gravity rating of 1, 2 or 3, depending how strongly the comment was articulated. This rating can be seen colored in black for good, better, best scores and red for bad, worse, worst scores. The scores were entered in a separate table in SPSS and divided into six categories for each lens, Lens A and Lens B. The categories were distance VA, intermediate VA and near VA, insertion/removal, comfort and other comments. These results can be seen in Table 22 below (also Appendix 8 for magnified view).

Table 22: Severity Ratings of Subjective Scores in Questionnaire for Lens A and Lens B (◎ = good, better best score ⊡ = bad, worse and worst score (-))

Participant No	DV Lens A	IntV Lens A	NV Lens A	Insertion Removal Lens A	Comfort Lens A	Other Lens A	DV Lens B	IntV Lens B	NV Lens B	Insertion Removal Lens B	Comfort Lens B	Other Lens B
1/10805					-3							
2/19549		3			3	-2	3				3	
3/10356			-1	3	-1	-2			-1	2	2	
4/8770							-1		2			
5/14290					-3				-2		-2	
6/8152								-2	-3	-2		
7/3699			-2						-2		-1	
8/450		-2										
9/8252				-3			3	3	3		-1	
10/8936		3					-1		3	-2		
11/8945											3	2
12/75											-3	
13/6550			-1							-1		
14/8779	1	1	1						-1			
15/8218			-2				-3			-2		
16/6695												
17/9265	3	3	3		-1							
18/7769												
19/8964			-3		-2							
20/20922												
21/2703							-1					
22/739												
23/1786												
24/1090												
25/9266	-1				3		-1		-1			
26/6892											-1	
27/8901	-1		-1				-1		-1		-2	
28/9387	3	3	-1			3			-1			
29/9386												
30/767				3	3				2			
31/8708												
32/8701												
33/3328												
34/2095												
35/9267												
36/16991			-2		2				-2			
37/20937					-3							
38/13003	-1	-1							1		3	
39/2720	-2			3	3			-2			-3	
40/1641			-3				-2				-2	
41/2093	-2				2			-2				
42/6093												
43/16545												
44/6687					-3				3		1	
45/6051												
46/16125					-1		-3		-2		2	
47/6892												
48/5608												
49/4564			-2	3	-1		2	2	2		-1	
50/1074		-1										
51/371			1					-1				
52/6802	-2		-1		3		1	3	3		-2	
53/4430									-2			
54/4829		-2	-1				-1		-1			
55/4309		-2	-2				-1	-1	-1			
56/6793					-2				-2			
57/5503			-1		3						-3	
58/5573				-1								
59/7063												
60/2376												
61/5838												
62/7310		-1	-1		-2		-1	-1				
Average of positive scores	2.33	2.6	1.66	3	2.63	3	2.25	2.67	2,5	2	2.33	2
Average of negative scores (-)	1.5	1.5	1.6	2	2	2	1.45	1.5	1.57	1.75	1.91	0

These positive and negative researcher-derived scores were averaged for each category, individually showing Lens A and Lens B. These can be observed in four bar charts in Figure 42 below.


Mean average score (positive comments) Lens A
0.0
0.1
0.2
0.3
0.4
Distance Vision
Intermediate Vision
Near Vision
Insertion/Removal
Comfort
Other


Mean average score (positive comments) Lens B
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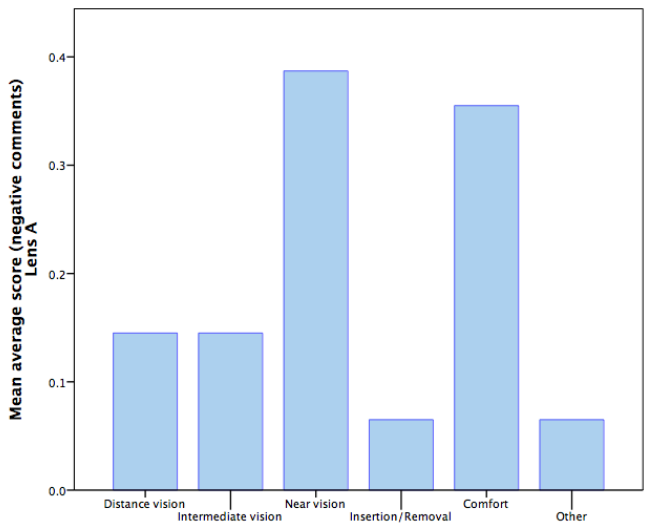
0.1
0.2
0.3
0.4
Distance Vision
Intermediate Vision
Near Vision
Insertion/Removal
Comfort
Other


Mean average score (negative comments) Lens A
0.0
0.1
0.2
0.3
0.4
Distance vision
Intermediate vision
Near vision
Insertion/Removal
Comfort
Other

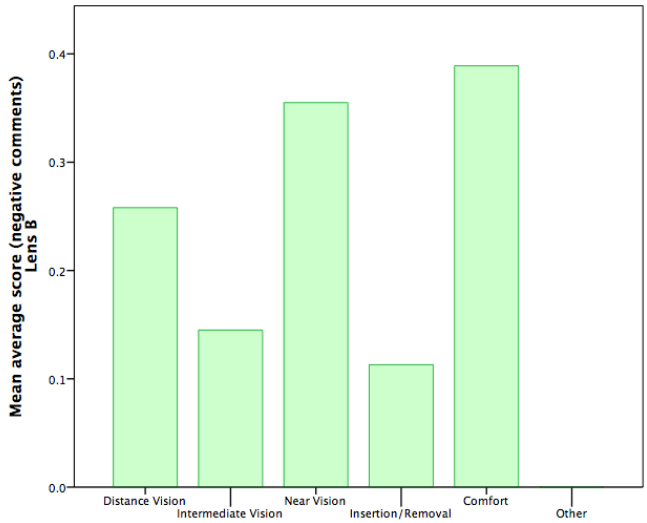


Figure 42: Mean of the Averaged Questionnaire Scores for Lens A and Lens B

The researcher-derived scores of the subjective questionnaire comments were compared statistically for each lens. Only a few questionnaires included comments and so paired analyses were not appropriate here. Negative comments were scored as minus values and since the data constituted ordinal variables non-parametric statistics were used. For each variable (distance vision, intermediate vision, near vision, insertion/removal, comfort, other) the ranked scores did not differ significantly for the two lens types Wilcoxon test for Two-Related-Samples, $z < -1.8$, $p < 1$).

Table 23: Comparison of Mean Average Questionnaire Scores for Lens A and Lens B using the Wilcoxon test for Two-Related-Samples

	Mean	**N**	**Std. Deviation**	**Exact Sig. (2-tailed)**	**Z** (based on positive ranks)
Distance VA average positive score Lens A and B	-.22	9	2.048	1.000	-.000 (p=1)
Distance VA average negative score Lens A and B	-.47	15	1.885		

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Intermediate VA average positive score Lens A and B	.50	10	2.321	.555	-.705 (p=.481)
Intermediate VA average negative score Lens A and B	-.11	9	2.147		

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Near VA average positive score Lens A and B	-1.06	18	1.474	.078	-1.820 (p=.687)
Near VA average negative score Lens A and B	- .14	22	2.054		

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Insertion/Removal average positive score Lens A and B	1.33	6	2.658	.188	-1.633 (p=.102)
Insertion/Removal average negative score Lens A and B	-1.00	5	1.732		

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Comfort average positive score Lens A and B	-.05	20	2.460	.665	-.473 (p=.636)
Comfort average negative score Lens A and B	-.41	17	2.238		

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Other average positive score Lens A and B	-.33	3	2.887	1.000	-.000 (p=1)
Other average negative score Lens A and B	2.00	1	0.000		

5.1.8 Results for the diary data for Period 1 and Period 2 and the re-ordered data for Lens A and Lens B

Below, the respective graphs for the diary data can be observed as described in section 4.6.1 of the methods chapter. These data were first split into Period 1 and Period 2 and then re-ordered to display the results for Lens A and Lens B. 49 participants completed both periods of diary entries. Graphs display the participant's subjective expression of distance, intermediate and near vision while wearing each contact lens, as well as the subjective perception of their comfort.

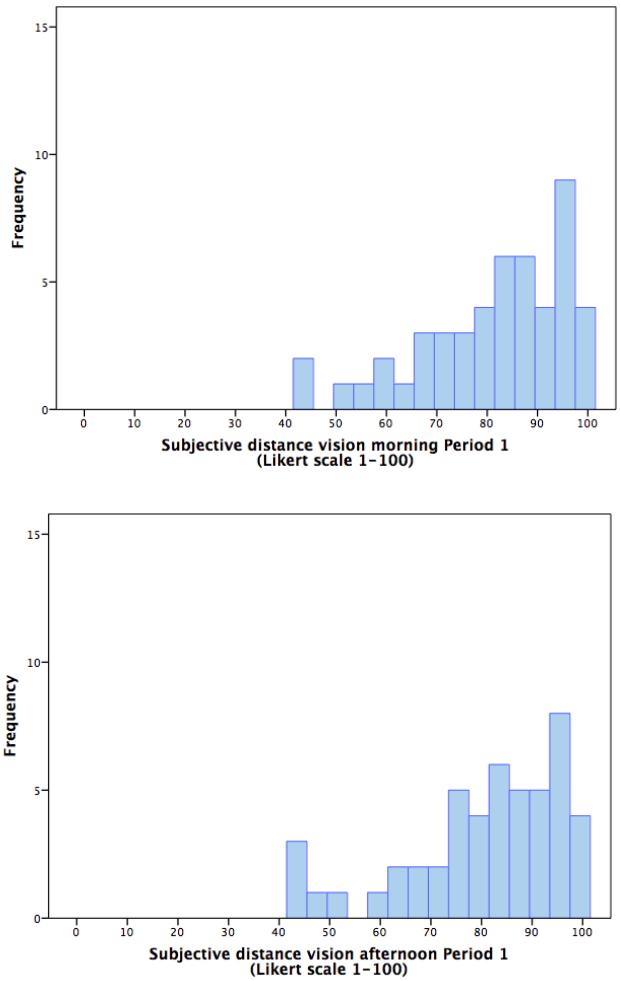
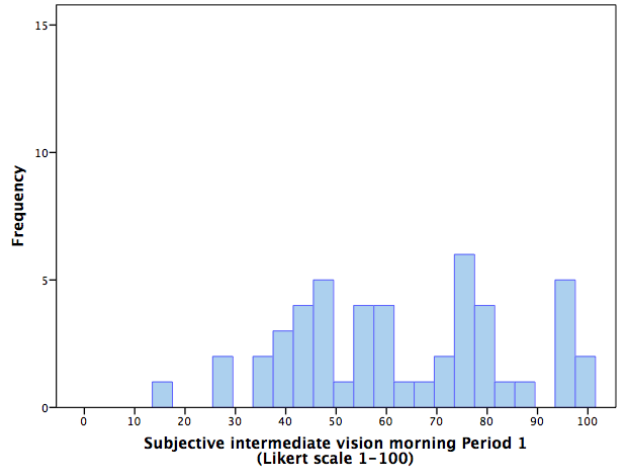


Figure 43: Frequency of Diary Scores for Subjective Distance Vision (Period 1 Morning and Afternoon)



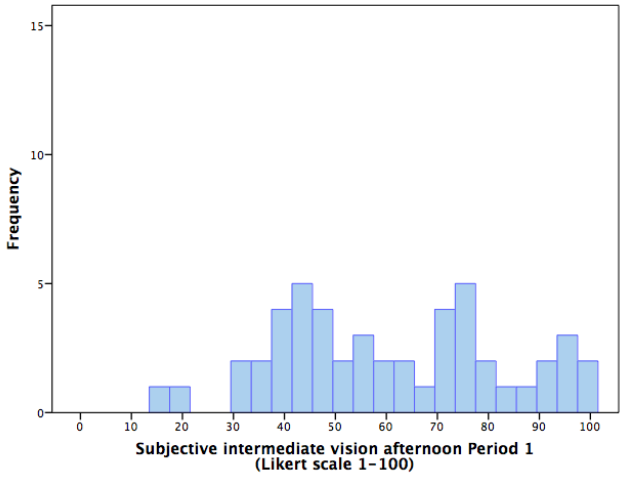
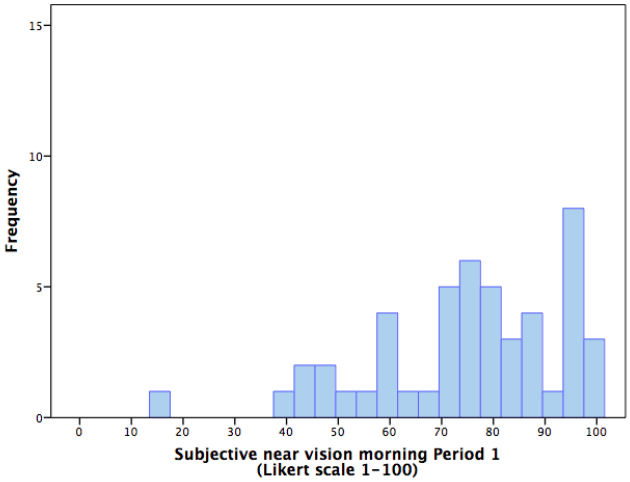


Figure 44: Frequency of Diary Scores for Subjective Intermediate Vision (Period 1 Morning and Afternoon)



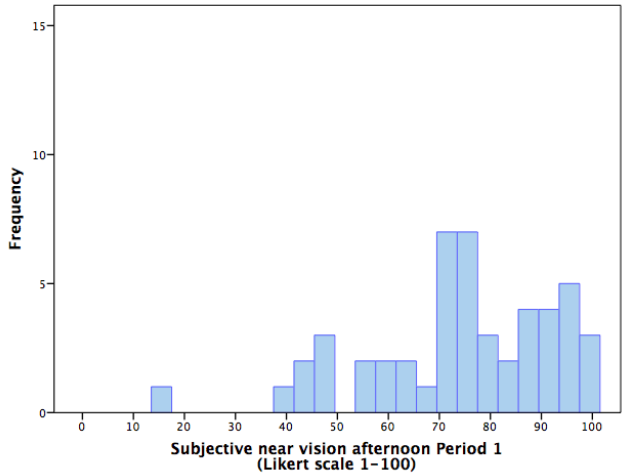
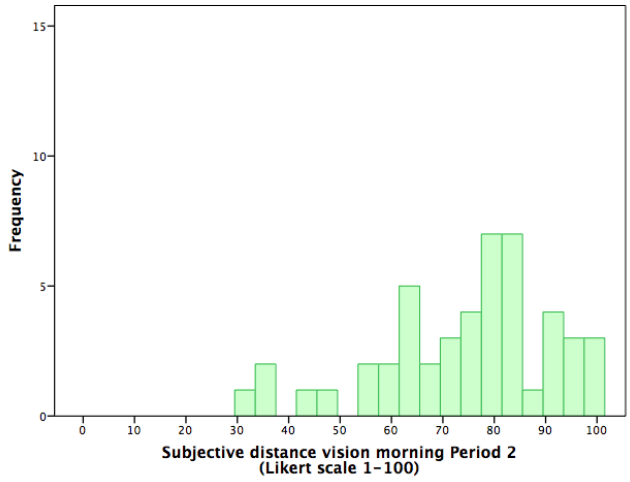


Figure 45: Frequency of Diary Scores for Subjective Near Vision (Period 1 Morning and Afternoon



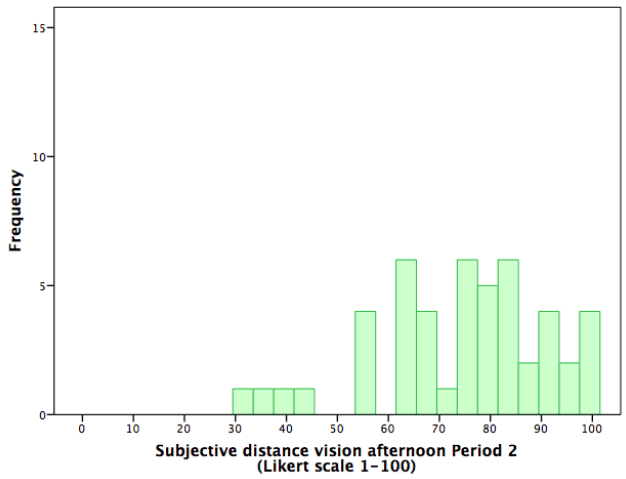
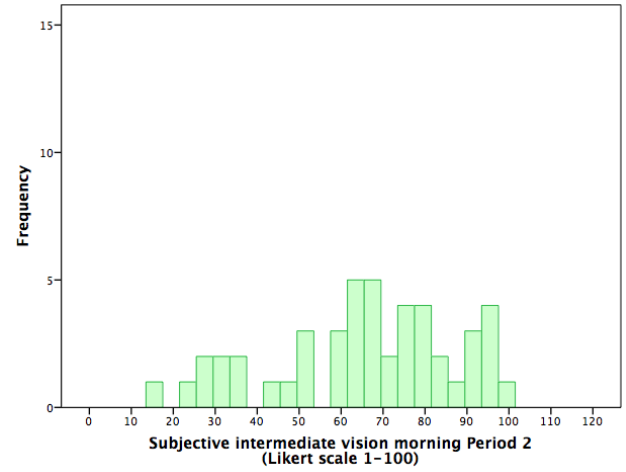


Figure 46: Frequency of Diary Scores for Subjective Distance Vision (Period 2 Morning and Afternoon)



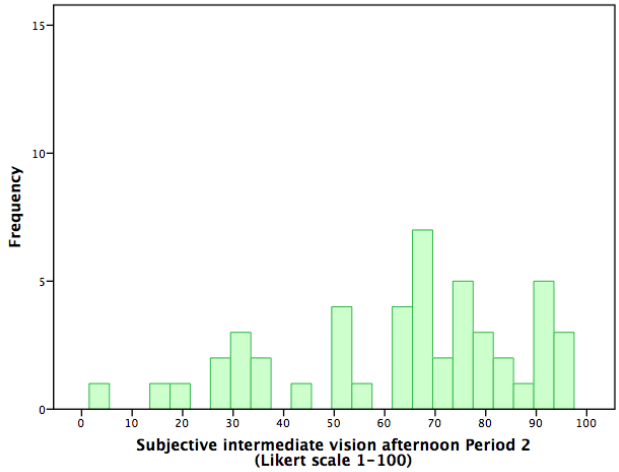
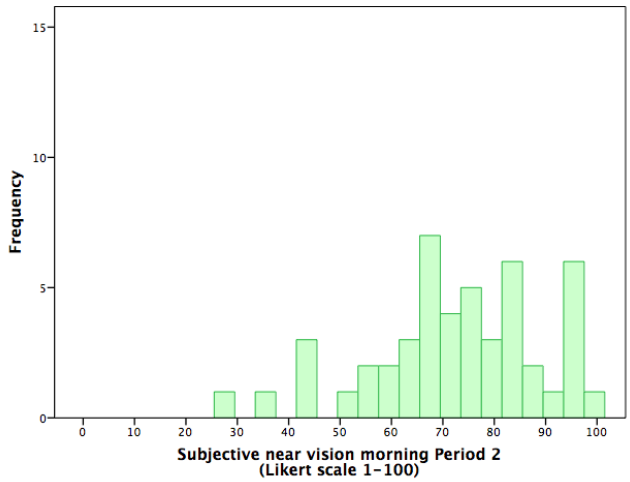


Figure 47: Frequency of Diary Scores for Subjective Intermediate Vision (Period 2 Morning and Afternoon)



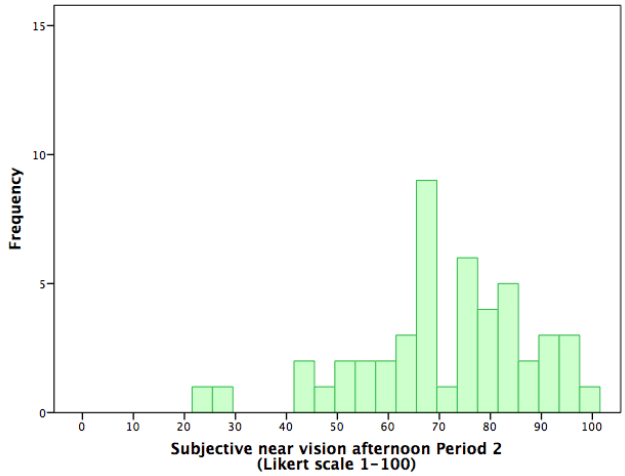


Figure 48: Frequency of Diary Scores for Subjective Near Vision (Period 2 Morning and Afternoon)

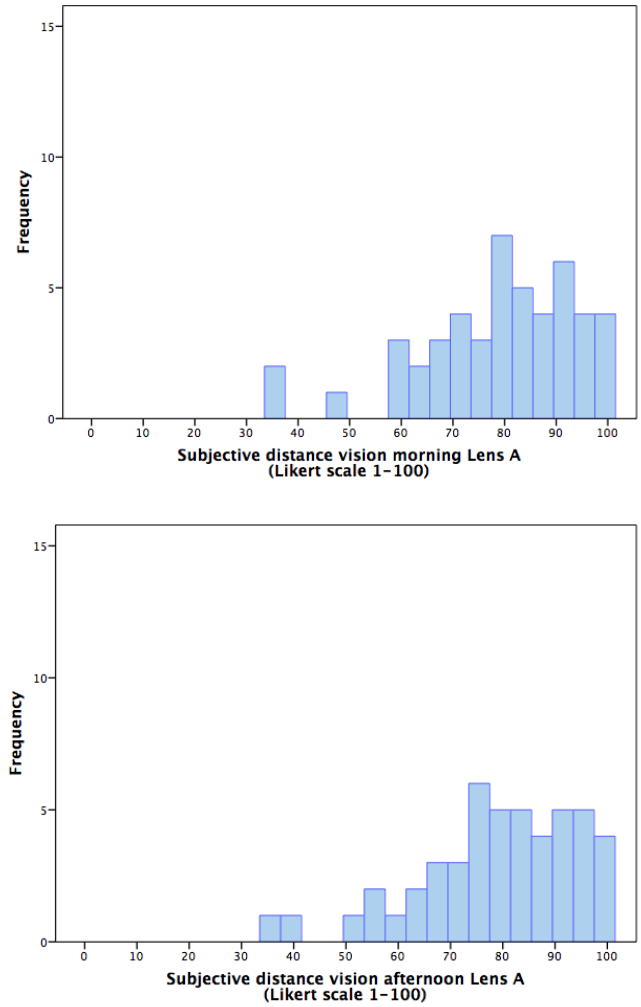
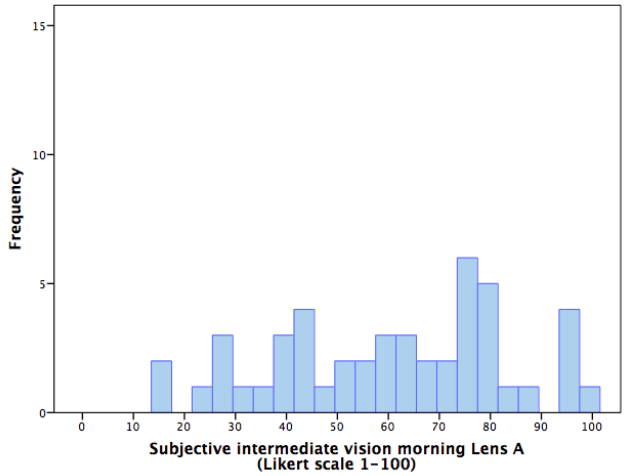


Figure 49: Frequency of Diary Scores for Subjective Distance Vision (Lens A Morning and Afternoon)



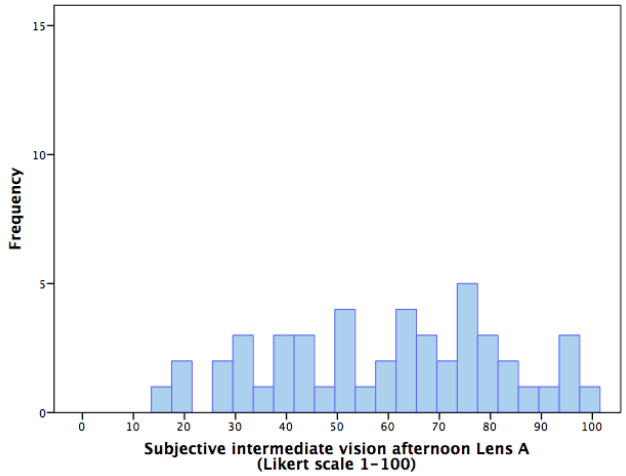
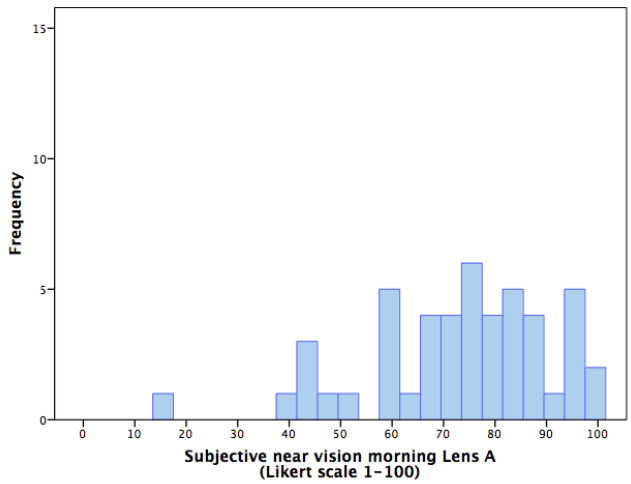


Figure 50: Frequency of Diary Scores for Subjective Intermediate Vision (Lens A Morning and Afternoon)



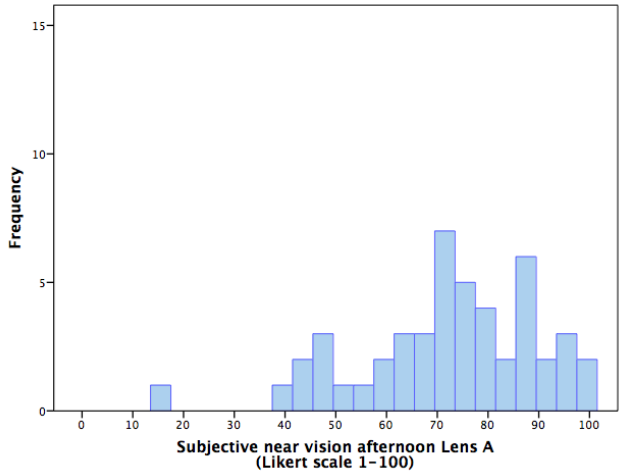
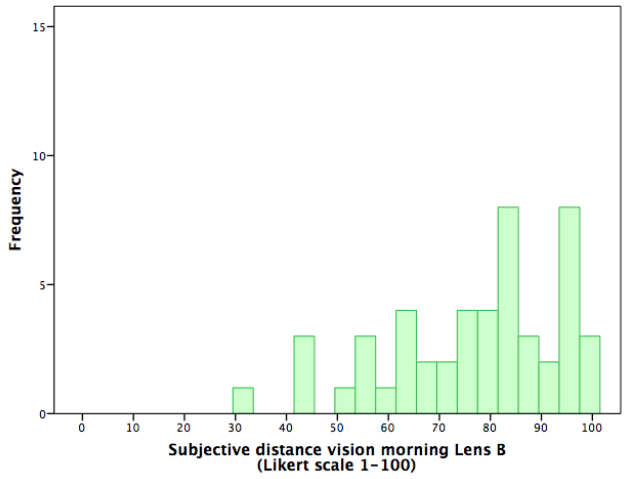


Figure 51: Frequency of Diary Scores for Subjective Near Vision (Lens A Morning and Afternoon)



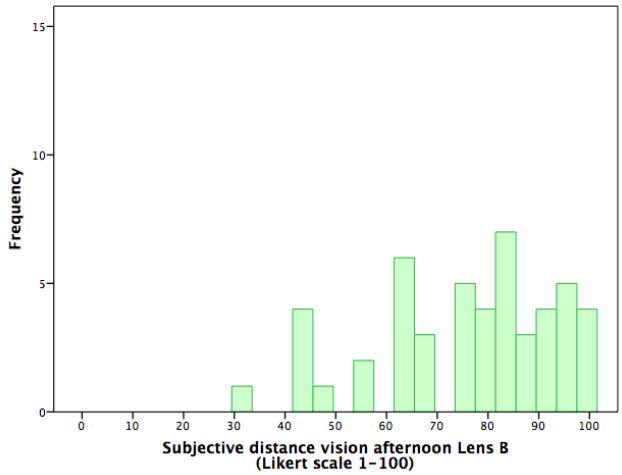


Figure 52: Frequency of Diary Scores for Subjective Distance Vision (Lens B Morning and Afternoon)

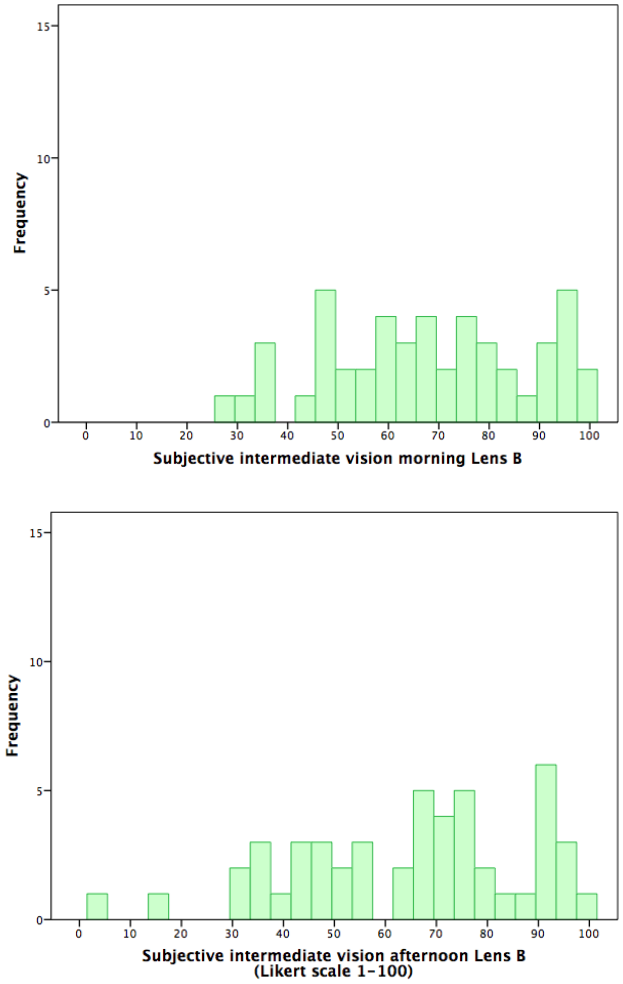
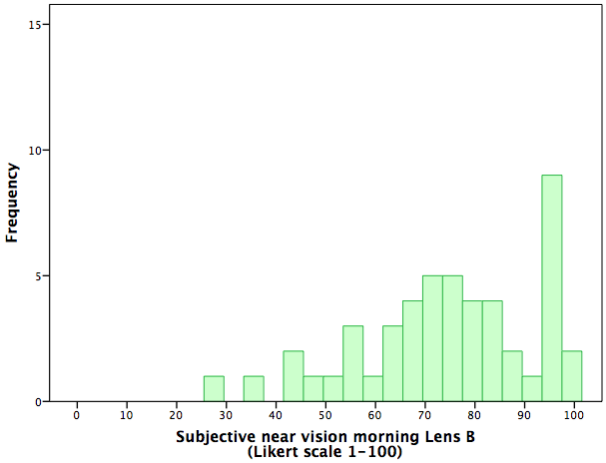


Figure 53: Frequency of Diary Scores for Subjective Intermediate Vision (Lens B Morning and Afternoon)



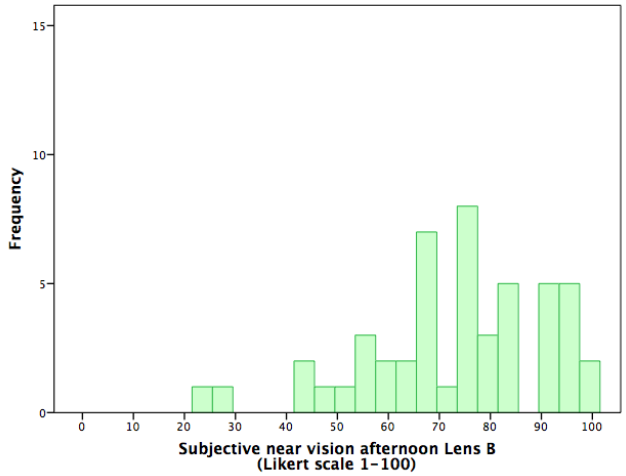
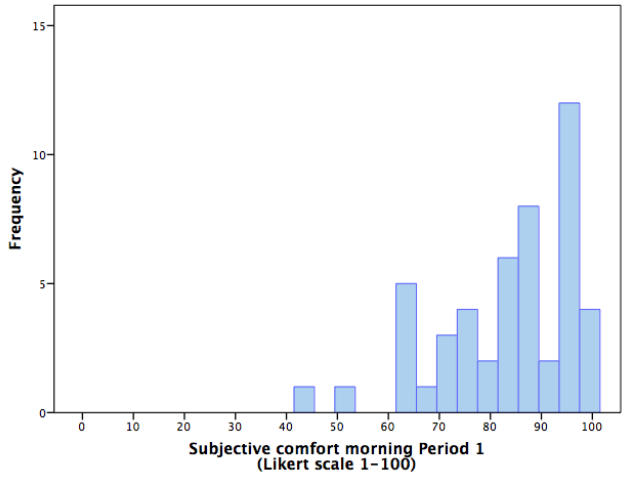


Figure 54: Frequency of Diary Scores for Subjective Near Vision (Lens B Morning and Afternoon)



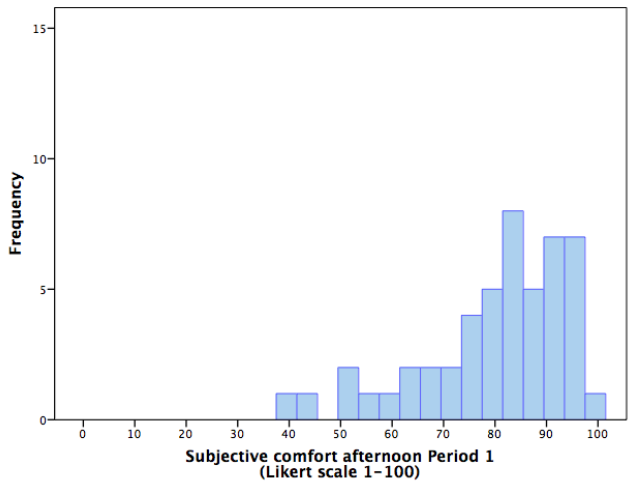
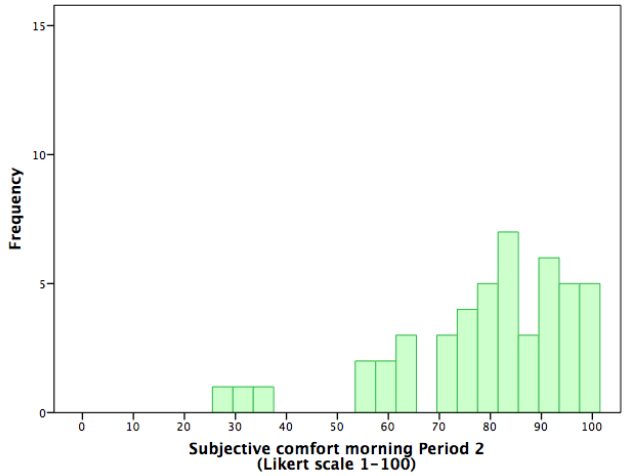


Figure 55: Frequency of Diary Scores for Subjective Comfort (Period 1 Morning and Afternoon)



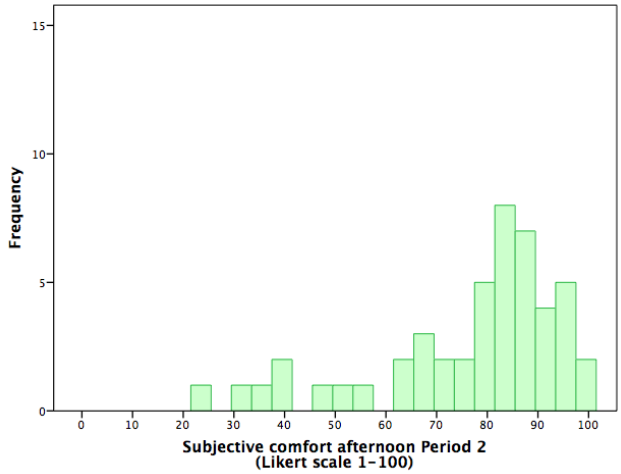
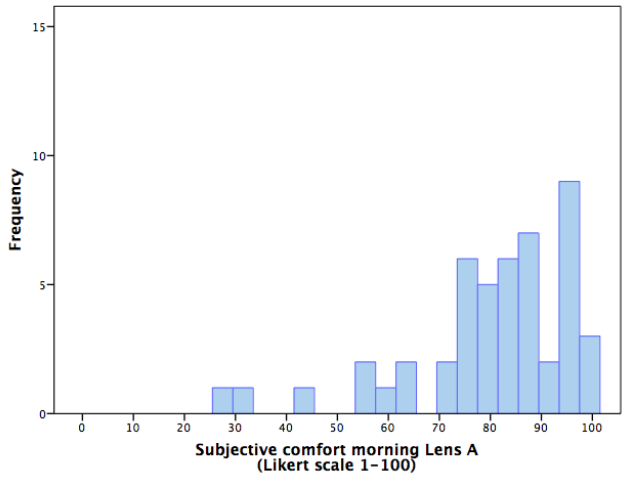


Figure 56: Frequency of Diary Scores for Subjective Comfort (Period 2 Morning and Afternoon)



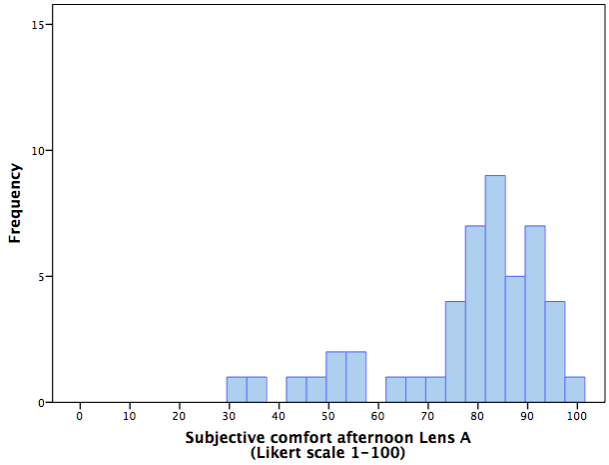
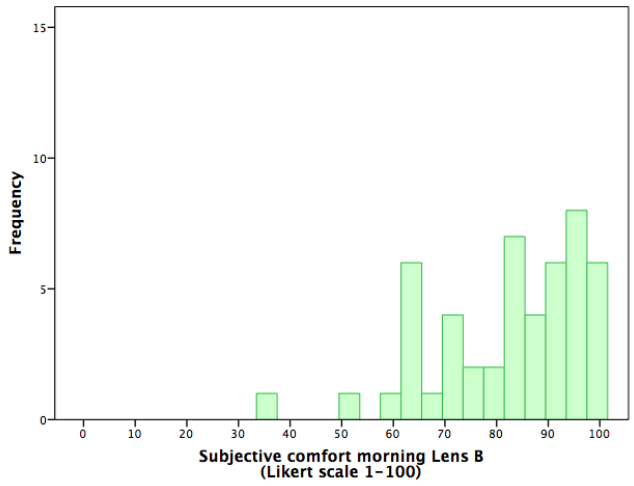


Figure 57: Frequency of Diary Scores for Subjective Comfort (Lens A Morning and Afternoon)



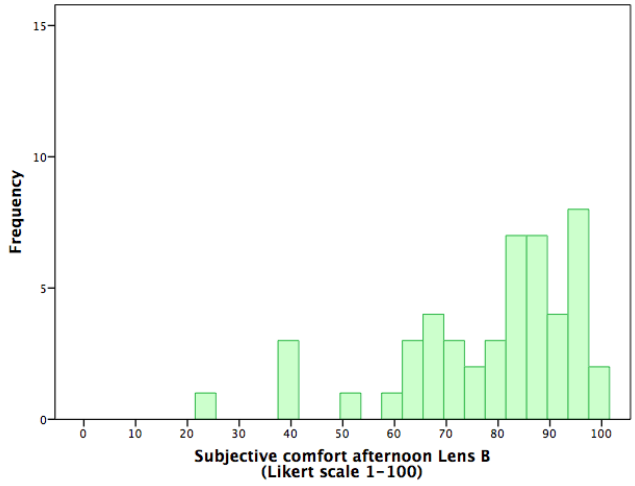


Figure 58: Frequency of Diary Scores for Subjective Comfort (Lens B Morning and Afternoon)

Wilcoxon tests for Two-Related-Samples were performed to compare the frequency of the diary scores for distance vision, intermediate vision, near vision and comfort for Lens A and Lens B (morning and afternoon) and results are shown in Table 24 below. All p-values were not statistically significant for these tests.

Table 24: Comparison of Diary Scores for Subjective Distance Vision, Intermediate Vision, Near Vision and Comfort for Lens A and Lens B

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Distance VA scores morning Lens A	79.00	48	15.518	.314	-1.02 (p=.308)
Distance VA scores morning Lens B	76.98	48	17.197		

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Intermediate VA scores morning Lens A	60.58	48	22.714	.195	-1.306 (p=.192)
Intermediate VA scores morning Lens B	66.06	48	21.132		

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Near VA scores morning Lens A	73.06	48	18.078	.457	-.752 (p=.452)
Near VA scores morning Lens B	74.48	48	17.680		

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Comfort scores morning Lens A	80.17	48	16.374	.714	-.373 (p=.709)
Comfort scores morning Lens B	82.13	48	14.397		

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Distance VA scores afternoon Lens A **Distance VA scores afternoon Lens B**	78.83 76.00	48 48	15.314 17.685	.233	-1.200 (p=.230)

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Intermediate VA scores afternoon Lens A **Intermediate VA scores afternoon Lens B**	59.54 64.63	48 48	22.431 23.228	.151	-1.441 (p=.149)

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Near VA scores afternoon Lens A **Near VA scores afternoon Lens B**	71.90 73.15	48 48	17.487 18.152	.435	-.790 (p=.430)

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Comfort scores morning Lens A **Comfort scores morning Lens B**	78.02 78.25	48 48	16.293 17.343	.852	-.191 (p=.849)

5.1.9 Efron Grading Period 1 and Period 2 and Lens A and Lens B

Grading measurements were obtained for lids, conjunctiva, cornea and bulbar conjunctiva consulting the Efron Grading Scales as guidance, using four categories considered to be the most important considering the population and the lenses used in this study (see below and Appendix 11) when participants were fitted for both the first and the second contact lens. These was recorded in an Excel spreadsheet and then ported into SPSS for statistical purposes. This

was done first for Period 1 and Period 2 and then re-ordered for Lens A and Lens B. As external surface eye conditions such as dry eye and participants using eye drops or wipes for dryness or any other surface eye conditions were specifically excluded from this study (as detailed earlier in Table 4 on page 55), most of these gradings were 0 or 1. Therefore the variables derived as the difference between a given grading in each period and the variables derived as the difference between a given grading with each lens type were in most case 0. Therefore, these difference variables did not follow a normal distribution curve and the nonparametric Wilcoxon test for Two-Related-Samples was used for this analysis. The results can be seen in Table 25 and Table 26 below:

Table 25: Results of the Wilcoxon Test for Efron Grading of Palpebral Conjunctiva, Limbal Conjunctiva, Cornea and Bulbar Conjunctiva (Period 1 and Period 2)

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Right Papillary Conjunctivitis Period 1	.12	57	.331	.092	-1.941 (p=.052)
Right Papillary Conjunctivitis Period 2	.04	57	.350		
Left Papillary Conjunctivitis Period 1	.14	57	.350	.727	-.707 (p=.480)
Left Papillary Conjunctivitis Period 2	.16	57	.368		

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Right Conjunctival staining Period 1	.14	57	.350	.727	-.707 (p=.480)
Right Conjunctival Staining Period 2	.12	57	.331		
Left Conjunctival Staining Period 1	.18	57	.384	.565	-.577 (p=.564)
Left Conjunctival Staining Period 2	.19	57	.398		

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Right Corneal Staining Period 1	.09	57	.285		
Right Corneal Staining Period 2	.05	57	.397	.531	-1.000 (p=.317)
Left Corneal Staining Period 1	.09	57	.285	1.000	-.378
Left Corneal Staining Period 2	.07	57	.258		(p=.705)

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Right Conjunctival Redness Period 1	.07	57	.225		-.652
Right Conjunctival Redness Period 2	.05	57	.257	.651	(p=0.514)
Left Conjunctival Redness Period 1	.09	57	.285	1.000	-.378
Left Conjunctival Redness Period 2	.07	57	.257		(p=.705)

Table 26: Results of the Wilcoxon Test for Efron Grading of Palpebral Conjunctiva, Limbal Conjunctiva, Cornea and Bulbar Conjunctiva (Lens A and Lens B)

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Right Papillary Conjunctivitis Lens A	.12	57	.331		-1.941
Right Papillary Conjunctivitis Lens B	.14	57	.350	.092	(p=.052)
Left Papillary Conjunctivitis Lens A	.14	57	.350	.727	-.707
Left Papillary conjunctivitis Lens B	.12	57	.368		(p=.480)

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Right Conjunctival Staining Lens A	.14	57	.350	.525	-.577
Right Conjunctival Staining Lens B	.12	57	.331		(p=.564)
Left Conjunctival Staining Lens A	.16	57	.368	.727	-.707 (p=.480)
Left Conjunctival Staining Lens B	.18	57	.384		

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Right Corneal staining Lens A	.12	57	.331		-1.000
Right Corneal Staining Lens B	.11	57	.310	.531	(p=.317)
Left Corneal Staining Lens A	.14	57	.350	1.000	-.378
Left Corneal Staining Lens B	.12	57	.331		(p=.705)

	Mean	N	Std. Deviation	Exact Sig. (2-tailed)	Z (based on positive ranks)
Right Conjunctival Redness Lens A	.07	57	.225	.607	.605
Right Conjunctival Redness Lens B	.05	57	.257		(p=.545)
Left Conjunctival Redness Lens A	.09	57	.285	1.000	-.378
Left Conjunctival Redness Lens B	.07	57	.257		(p=.705)

5.1.10 Final participant preference

After the second period was completed, 37 participants (64.9%) preferred Lens A and 20 (35.1%) Lens B. It was hypothesised that pupil size might ~~explai~~n have influenced this result because, as explained in Section 4.2 of the thesis, one of the products in this trial typically used a centre distance lens in one eye and a centre near lens in the other, whilst the other lens used a centre near design in each eye. The participants were therefore divided into those with smaller (2.5-4.0mm), medium (4.1-5.4mm) and large (5.5-7mm) pupils.

When pupil size was measured at the appointments when Lens A was worn, there were 10 participants with small and three participants with larger than average pupils. 44 participants had medium sized pupils in this group. When pupil size was measured at the appointments when Lens B was worn, 15 participants had

smaller size pupils and five participants larger than average pupils. 37 participants in this group had medium sized pupils. It is not suggested from these data that lens type was altering pupil size, but rather that natural variation in pupil size on different occasions (even in a consulting room with constant lighting) means that there will inevitably be some differences in pupil size at the visits, when a participant is wearing Lens A or Lens B. Based on the pupil size at the second visit, the interaction between pupil size and lens preference is shown in Table 28.

For the analyses below, those participants (the majority) with medium size pupils are not considered and instead those with small and large pupils are contrasted, as these represent the two extremes.

Table 27: Lens Preference and Pupil Size in Photopic Lighting Conditions (excluding participants with average size pupils)

Photopic Lighting	**Smaller Pupils (2.5-4mm)**	**Larger Pupils (5.5-7mm)**
Prefer Lens A	10 participants	3 participants
Prefer Lens B	15 participants	5 participants

There was no significant relationship between pupil size and lens preference (Chi-square test, p=0.90).

The final objective of this study was to follow lens wearers at three months, six months and again a year after trial completion to find out how many participants were still continuing to wear the multifocal design they had chosen. Out of fifty-seven participants that completed the trial, thirty-six were still wearing the lenses three months after the trial. At six months, thirty-four were still continuing with the multifocal contact lenses and only one additional participant had discontinued another six months later, one year after

the trial ended. Out of these, seventeen wearers wore Lens A, sixteen Lens B. This study concluded that almost 58% of participants were still wearing multifocal contact lenses one year after the study concluded. At nearly 60% of initial participants, this is a considerable number of presbyopes, who consider a multifocal contact lens a valuable alternative to their spectacle correction.

5.2 Summary

This chapter documented in detail the results obtained for the four main variables relevant to this thesis. These statistical results were displayed in figures showing graphs and tables. The existence of a period effect between Period 1 and Period 2, as well as between the re-ordered data for Lens A and Lens B was excluded for all four main variables. The data were explored for frequency and distribution for Period 1 and Period 2 as well as for the re-ordered data Lens A and Lens B. Thereafter, the data for the two secondary variables were explored. Parametric, as well as non-parametric tests were used appropriately where justified and results shown in figures and tables, similar to those displayed for the four main variables.

The following chapter will discuss these results and put the findings in context with previous studies. Lens A and Lens B will be unmasked and the aims of the study discussed, knowing the result of the unmasking. Strengths and shortcomings will be discussed and lead to recommendations for future research to improve future contact lens comparison studies and other research of this nature. Tables 28, 29 and 30 below show a summary of all numerical findings. Colour coded, they display in detailed overview in which areas which lens has surpassed the other (Lens A = blue and Lens B = green).

Table 28: Summary of Results for Lens A and Lens B for the Four Main Variables (Binocular Distance and Near VA, Stereoacuity for Distance and Near and Photopic, Mesopic and Scotopic Contrast Sensitivity)

Variables	Lens A	Lens B	Difference A/B
Binocular photopic distance VA (LogMAR)	-0.0698 LogMAR	-0.0498 LogMAR	0.02 LogMAR
Binocular photopic near VA (LogMAR)	0.1598 LogMAR	0.1614LogMAR	0.0016LogMAR
Stereoacuity at distance (Log Seconds of arc)	1.7482 log"	1.7654 log"	0.0172 log"
Stereoacuity at near (Log Seconds of arc)	1.7267 log"	1.7512 log"	0.0245 log"
Photopic contrast sensitivity (Log units)	1.4456 log	1.4009 log	0.0447 log
Mesopic contrast sensitivity (Log units)	1.2605 log	1.2202 log	0.0403 log
Scotopic contrast sensitivity (Log units)	1.3281 log	1.3018 log	0.0263 log

Table 29: Summary of Results for Lens A and Lens B Comparing Subjective Vision Experience in the Questionnaire Data (Score 1-5)

Variables	Lens A	Lens B	Difference A/B
Subjective distance VA after four weeks	1.4565	1.5690	0.1125
Subjective intermediate VA after four weeks	1.3827	1.2433	0.1394
Subjective near VA over four weeks	2.0383	1.8735	0.1648

Table 30: Summary of Results for Lens A and Lens B Comparing Subjective Vision Experience in the Diary Data (Likert Scale 1-100)

Variables	Lens A	Lens B	Difference A/B
Subjective distance VA morning	79.00	76.98	2.02
Subjective distance VA afternoon	78.83	76.00	2.83
Subjective intermediate VA morning	60.58	66.06	5.48
Subjective intermediate VA afternoon	59.54	64.63	5.09
Subjective near VA morning	73.06	74.48	1.42
Subjective near VA afternoon	71.90	73.15	1.25
Subjective comfort morning	80.17	82.13	1.96
Subjective comfort afternoon	78.02	78.25	0.23

Chapter 6

Discussion

6.0 Summary of findings for the four main variables

The lens performance for Lens A and Lens B was examined for four different outcome variables as described in Chapter 4. This trial investigated how two different lens designs, the Air Optix Aqua Multifocal manufactured by Alcon and the Biofinity Multifocal developed by CooperVision performed during four weeks of individual wear by participants from different age groups, different walks of life and varying experience in contact lens wear. The intention to produce a realistic and robust data set, relevant to community optometric practice was made early on in the design phase. 57 participants completed both periods of lens wear with one week's washout period between the two periods, to make this the largest silicone hydrogel multifocal contact lens comparison study completed to date. At the time of commencement of this trial in 2011, four monthly disposable multifocal silicone hydrogel contact lenses were commercially available in the UK. The Clariti monthly silicone hydrogel multifocal, then marketed by Sauflon Pharmaceuticals was introduced to the UK market shortly afterwards. The discussion will focus on the two different lens designs mentioned above and the impact they had on the results a little later in this chapter. Firstly, the results for the four main variables will be discussed.

6.0.1 Binocular photopic distance VA

This study found no statistically significant difference between Lens A and Lens B for binocular photopic distance VA. An insignificant

difference of 0.02 LogMAR was detected when comparing the distance VA. This equates to one letter in a line on a Thomson distance VA test chart. This value represents no clinically significant difference in distance vision, proving the null hypothesis to be true, showing equally good visual performance for both lenses for distance VA.

6.0.2 Binocular photopic near VA

Lens A and Lens B both performed similarly when near VA was tested. Lens A fared 0.0016 LogMAR better. This represents an extremely small difference between the lens types for near vision performance and is not clinically or statistically significant.

6.0.3 Stereoacuity for distance and near

The same outcome was found for distance and near stereoacuity in this study. Lens A just outperformed Lens B by a small amount in both instances. The differences between the mean results with the two lens types for distance and near stereoacuity were 0.0172 (log)'' and 0.0245 (log)'' respectively. These differences are not statistically significant. This result is somewhat of a surprise, since both lens designs employ different centre zone designs, one being a combination of centre near and centre distance and the other two centre near zones. It might have been predicted that the lens with the combination of centre near and distance zones might not have performed as well on stereoacuity, as this design steals a little of the monovision concept, albeit being a multifocal. In this study, 12 out of the 57 participants (21%) were in the lower age group, below the age of 47, where both lens manufacturers fitting guides suggested fitting two centre distance lenses. Perhaps for this reason, statistically and clinically, it appears that in this instance the lens

design did not have an impact on the outcome, showing similar results for stereoacuity in this study for Lens A and Lens B.

6.0.4 Contrast sensitivity in photopic, mesopic and scotopic lighting conditions

For contrast sensitivity in all three lighting conditions, Lens A outperformed Lens B by the smallest of margins. For photopic CS, the difference between both lenses was measured to be 0.0447 Log CS units, for mesopic 0.0403 Log CS units and for scotopic lighting the difference was measured to be 0.0263 Log CS units. In all three lighting conditions this represents only marginal differences between the two lenses. This reached statistical significance for only one of the three conditions, photopic (t-test: p=0.013, Wilcoxon Signed Ranks test: 0.018). Although statistically significant, the difference between Lens A (1.45 log units) and Lens B (1.40 log units) is unlikely to be clinically significant. As both lens designs employ concentric blended zone designs, both contact lenses performed similarly being subjected to changing light levels and it is surprising that the factor of the different zone designs again did not seem to make a meaningful difference in how these two different lens modalities performed in changing contrasts as one could assume that the change in lens power within the different zones of the lens, i.e.: distance, near and intermediate power variations, would cause varying amounts of distortion if the wearer was subjected to different light levels. This seemed not to be the case on examining the outcome for contrast sensitivity in this study and this is considered further in section 6.3.

6.1 The two secondary variables

6.1.1 Questionnaire results for part 1 of the VF-14 visual function questionnaire

Examining the results for the subjective vision at distance, intermediate and near, the majority of participants preferred Lens A for distance and Lens B for intermediate and near VA. Participants scored their experiences for distance, intermediate and near using a scale from 1-5. The difference between Lens A and Lens B for distance vision was documented as 0.11, for intermediate vision 0.14 and for near vision it was found a little larger at 0.1648. Examining these numbers it becomes evident just how small the difference in performance between the two different lens modalities actually were in this study. No statistical or clinical difference can be derived from this first part of the VF-14 visual function questionnaire, looking at the subjective interpretation of participant's experiences.

6.1.2 Questionnaire results for part 2 of the VF-14 visual function questionnaire

The second part of the VF-14 visual function questionnaire consisted of a box where comments about the participant's experience that they felt were not covered by the questions asked in part 1 or in the diaries could be addressed, if they felt the need to do so. After close inspection of these comments, it became evident that common concerns were raised time after time. It was decided to divide these comments into six different groups, dependent on the issues raised. These six groups were distance vision, intermediate vision, near vision, insertion and removal, comfort and a section called 'other' comments. Interesting results emerged when looking at positive and negative comments. For distance vision, equal amounts of positive

comments were raised for Lens A and Lens B. For intermediate vision, Lens A scored more than Lens B and for near vision more participants gave positive comments favoring Lens B. Both insertion and removal and comfort were rated more positively in favour of Lens A, whereas roughly the same amount of 'other' positive comments was raised for either lens, mentioning the lens tints or material properties for example.

A slightly different picture emerged for the negative comments. More participants made negative comments for Lens B than Lens A concerning distance vision, whereas for intermediate vision both scored the same. The two areas with most negative comments were near vision and comfort of the lenses. More participants mentioned negative experiences for near vision for Lens A, whereas Lens B seemed less comfortable, according to the number of comments. Only a few 'other' comments were raised in this section. Participants gave positive comments for Lens A and B, but only negative comments were made for Lens A.

Statistically the Wilcoxon test for Two-Related-Samples was used to carry out a comprehensive analysis of comments. This showed no statistically significant differences between Lens A and Lens B. However, it can be argued that the frequency of comments for certain tasks, such as the high number of negative comments for near vision or comfort were relevant. This study showed encouraging results for both lenses regarding distance vision quality, which implied participant satisfaction when driving for example. This would encourage a contact wearer to tolerate the lens on the eye for many hours during the day, which would be the desired outcome for wearers, fitters and manufacturers alike. However, poor quality of near vision would discourage continued contact lens wear and prompt a wearer in the extreme situation to take the lenses out and

change to other forms of visual correction to perform these tasks (eg.: spectacles) or to 'top up' with additional reading glasses worn with the contact lenses. Equally, the same scenario would occur if the contact lenses became uncomfortable on the eyes during prolonged wear. This is why the decision to use a questionnaire and also a daily diary was an important and justified part of this trial compared to some other previous research that did not employ such investigative tools. It becomes clear that even with the added information gleamed from the questionnaire the differences between both lens types were marginal.

6.1.3 Daily diary data Lens A and Lens B

Here, participants scored their subjective experience for distance, intermediate and near vision as well as the contact lens comfort using a Likert-type scale from 1-100, one being poor and 100 being a good experience. These scores were analysed looking at morning and afternoon sessions for Lens A and Lens B for each participant. Interesting patterns emerged.

Firstly, it can be seen from each of the graphs for the morning and the afternoon sessions that the lenses generally performed similarly for each of those two daily phases. Distance vision scores out of 100% averaged 79 morning and 79 afternoons for Lens A and 77 morning and 76 afternoons for Lens B. For intermediate vision, the scores were slightly lower at 61 morning and 60 afternoons for Lens A and 66 morning and 65 afternoons for Lens B. Near vision scores measured higher at 73 morning and 72 afternoons for Lens A and 74 morning and 73 afternoons for Lens B. This pattern repeated itself again for comfort scores. These were high with 80 morning and 78 afternoons for Lens A and 82 morning and 78 afternoons for Lens B.
One of the reasons why it was decided to have a morning and

afternoon section completed each day when designing the daily diary was that both lens types were made from a silicone hydrogel material. At the time of the commencement of this trial in 2011, this relatively innovative material to the UK was hailed as one that would bring about improvements to make contact lenses more comfortable for users compared to ordinary hydrogel materials. According to the manufacturers, both lenses used in this trial have characteristics, which although slightly different for each of the two products, were claimed to improve wettability. A great number of currently available monthly disposable multifocal contact lenses (in 2017) are made from silicone hydrogel material, although there are some signs that companies are reverting to hydrogel materials for some new multifocal contact lenses, like the One Day Acuvue lens. This study aimed to test claims that high level of comfort can be obtained with the two tested silicone hydrogel products. The trial has shown that both contact lenses performed equally well for comfort, both in the mornings and afternoons.

Another interesting finding is that each of the two lens types performed similarly for each of the four categories when looking at their general scores. For distance vision the scores were placed between 50 and 100 showing participants were generally happy with their subjective distance vision. The scores for both intermediate and near vision were found to be more variable amongst participants measuring between 20-100 for intermediate and near vision. Results for Lens A and Lens B showed the same tendencies amongst participants. This particular point in the results showed that both multifocal designs performed more consistently for distance vision tasks than when the lenses were used at a closer visual range, i.e.: at a desk with a computer for intermediate vision or for reading small print when participants had to rate their subjective vision

experience. Both, Lens A and Lens B were fitted on participants of varying age and variety of all addition powers available.

Overall, looking at the statistical analysis of the diary data, this study found no statistically or clinically relevant differences between the performance of Lens A and Lens B, merely small variations discussed in detail in the results chapter. The diary data, however, helped to understand some of the issues with which soft multifocal lens wearers struggle whilst the lenses are worn. It is clear that it is not only important in a comparison trial of this kind to examine VA with such lens designs in a quantitative way. The quality of vision a wearer experiences is also an important factor in whether a person will continue wearing a multifocal contact lens design in place of their spectacle correction or any other mode of contact lens wear. This information would not have been available if the questionnaire and the diary had not been included in the study design.

6.1.4 Participant preferences

In the current research, forty-three participants (75%) felt that multifocal contact lenses are a good alternative to other presbyopic vision corrections at the end of the second wearing period. One year after completion of this trial, 58% of those participants were still wearing their chosen monthly disposable lens option. This high percentage is in contrast to Gispets et al. (2011), where 78% of participants decided to continue contact lens wear, but when followed up six months after the trial ended, only one participant was still wearing multifocal lenses on a daily basis. Their study reports insufficient quality of vision as the main reason as to why participants discontinued with multifocal contact lenses. In the current research, cost and insufficient clarity for near vision tasks were cited as the main reasons why participants returned to spectacle wear, single vision distance contact lenses with near vision

spectacles worn in addition for close vision tasks or gas permeable lens options.

6.2 Unmasking Lens A and Lens B

6.2.1 Procedure followed when unmasking Lens A and Lens B

To finally unmask for the researcher and put the results into context with the two lens designs, an optometrist independent and not involved with the practical aspect of this lens trial broke the masked code.

6.2.2 Identification of Lens A and Lens B in this study

It was discovered that ***Lens A used in this trial was the Air Optix Multifocal produced by Alcon and Lens B was the Biofinity Multifocal manufactured by Cooper Vision.***

6.3 Consideration of trial results in context of the design of the two lens types

Both contact lenses used in this trial rely on a central circular zone, around which concentric zones are positioned to vary the optical power across the lens. The edge of the lens has a small carrier, insignificant to the wearer's prescription, designed to lie smoothly against the conjunctival surface of the eye, providing a comfortable edge. The Air Optix Aqua Multifocal is fitted as a centre near design for the right and left eye, whereas the Biofinity Multifocal employs one centre near lens for the participant's non-dominant eye and a centre distance lens for their dominant eye. In pre-presbyopes and wearers with an addition power below +1.50 the manufacturer's guideline for this lens specifies to use two distance centre lenses.

Both lens types are simultaneous vision multifocal contact lenses.

Statistically as well as clinically, the results of the current research suggest that although there are differences in the lens designs, this did not make a difference to the outcome for any of the four variables, distance, intermediate and near VA, as well as the lens comfort. The contrast sensitivity was marginally better under photopic lighting conditions with the Air Optix Aqua design ($p=0.013$), but this did not reach statistical significance for the contrast sensitivity measurements under mesopic and scotopic conditions. With the Air Optix Aqua design, all participants wore contact lenses with centre-near design in both eyes, whereas with the Biofinity Multifocal, some wore centre-near in one eye and a centre-distance in the other. Participants in this latter group might be expected to perform better for distance contrast sensitivity under the photopic conditions, which would generate smaller pupils. Therefore the actual photopic contrast sensitivity findings are paradoxical and it seems likely that these are a chance finding.

Some marginal differences were noted, when looking at the subjective results from the participant's questionnaires and diaries. Although these differences were very small and did not reach statistical significance, it is interesting to see that the design that seemed more popular with wearers was the one which employs the same zone design for each of the wearer's eyes making the researcher inclined to argue that some participants prefer it when both eyes are subjected to the same transition between zones and therefore achieving better visual balance overall. These findings are also reflected in the outcome of the daily diaries for distance vision in this trial. Participants preferred the Air Optix design again here and are also supported by the outcome of question 2, asked after the trial. When participants were asked which of the two contact

lenses they preferred, thirty-seven (64.9%) participants chose Lens A, the Air Optix Aqua Multifocal.

Very interestingly, participants preferred the Biofinity Multifocal when evaluating intermediate and near vision. Again, these results were marginal. Nevertheless it is interesting that the design that resembles the monovision concept was deemed most successful for near vision. It could perhaps be speculated that this might be because the zone design of the Biofinity Multifocal employing a centre distance and a center near lens at the same time means that the area covered for center near and intermediate zones is wider overall than in the binocular center near zone design of the Air Optix Aqua Multifocal. In fact the available area of the Biofinity lens spreads from the center of the lens in the non-dominant eye through both middle zones in either eye for intermediate to the outside near zone in the lens in the dominant eye, making the whole diameter of the prescription zone of the lenses (considered as a pair) covered for near vision. Then again, this should equally be a positive finding for the distance VA as the reversal of the zones happens with the Biofinity Multifocal, but this was not the case in this study.

6.4 Discussion of this comparison study in reference to earlier research trials

When designing this comparison study, it was evident that all relevant similar trials had been conducted recruiting relatively few participants, although several employed similar crossover design (Richdale et al., 2006, Gupta et al., 2009). Participants in previous research papers vary between very small numbers of 8, 10 in pilot studies or 16 participants (Kirschen et al., 1999) to highest numbers at 35, 38 and 50 participants respectively (Sivardeen et al., 2016, Richdale et al., 2006, Woods et al., 2015) This was very surprising, as

it was clear from the sample size calculation in Chapter 4, section 1 (page 59) that most of these studies were underpowered. Pinēro et al. (2015) also suggested that their study's "*preliminary results should be confirmed in studies with larger samples*". It was therefore reassuring and satisfying that the present research involved considerably more participants than these earlier studies. 62 participants were recruited, of which 57 finished both periods of the trial, fulfilling statistical requirements for a true crossover design, compared to a parallel group study, giving the results greater statistical power.

The type of recruits taking part in previous studies was also of interest. All studies described in Chapter 2 investigated presbyopic contact lens designs, yet some recruited normal sighted or pre-presbyopic participants, which seemed surprising given the intended population for these lenses and the outcome variables (Sanders et al., 2008, Vasudevan, 2014). In the present research a large variety of presbyopic participants averaging 52.9 years of age, some as young as 40, some as old as 60 were recruited. The group in this study represented a cross section of presbyopic participants interested in multifocal contact lens designs commonly seen in community optometric practice. This cross section did also more adequately address the influence of differing near addition powers on outcome variables, especially on participants' near vision tasks as they became older and required stronger near addition powers. Sanders et al. previously investigated this, however only using normally sighted recruits.

Another interesting observation was the time period previous studies employed for each of the wearing periods. Both lenses used in the current research were monthly disposable contact lenses. It seemed most appropriate to trial each lens for the entire span of their clinical life, hence making each period last for four weeks. The research team wanted to ensure that lens performance was

assessed by wearers using the silicone hydrogel initially fresh and new but also towards the end of the anticipated life of a pair of monthly disposable lenses, as manufacturer fitting guidelines stipulated. This would give a true reflection of the lens performance and is strength of this study. Previous studies by Richdale et al. (2006), Gupta et al. (2009) and Sivardeen et al. (2016) also conducted their monthly disposable studies in this way. However, other studies employed a reduced wearing time, representing a shortcoming in these studies (Kirschen et al., 1999, Gispets, 2011), Woods et al., 2015).

It was decided to design this crossover trial with a significant washout period between both intervals of lens wear. When assessing the statistical reasoning of Wellek and Blettner it was felt that this was very important to avoid bias while participants were wearing the second contact lens. Only three of the more recent previous studies mentioned a washout period in their design. Gispets et al. reported a 48-hour rest period between each of two lens designs, which were only worn for fourteen days in each period, whereas Pinēro et al. (2015) and Woods et al. (2015) employed a washout period of seven days between each of three lens modalities, again only worn for two weeks before the investigation started. As described in Chapter 2, a washout period of one week seemed appropriate while evaluating silicone hydrogel contact lenses, as the recovery of the cornea is established a mere twelve hours after contact lens removal (Rho et al., 2014). Studies without a washout period, however, could be perceived as carrying bias in the second period of lens wear, where the participant would be used to wearing the contact lens modality, the handling and the feeling of the lenses on the eyes, making judgment on subtle differences between lenses biased and more difficult for them.

Several previous studies investigating contact lenses for presbyopia employed diaries or questionnaire tools. It is evident from the

results of this trial that the differences between contact lens designs found in quantitative analysis of clinical outcomes like VA can be very small and often show no clinical or statistically significant difference between lenses. This study supports such findings. It has been argued that the use of questionnaire tools has become necessary in vision related studies, as more emphasis has been put on visual functioning or vision-related quality of life (de Boer, 2004). Richdale et al. investigated the subjective findings with the National Eye Institute Refractive Error Quality of Life Instrument questionnaire tool as early as 2006. In 2009, Gupta et al. described a standardised questionnaire employing satisfaction scales in their study and in 2016 Sivardeen et al. utilised the National Eye Institute Refractive Error Quality of Life Near Vision Questionnaire.

Over the years, it has emerged that visual acuity on its own may not capture all important aspects of vision function from the patient's perspective (Massof and Rubin, 2001) giving the three studies mentioned above more credibility and making their methodology more robust. The present research therefore included a questionnaire and a daily diary. When considering which questionnaire would be most appropriate and also most informative for the specific variables this study investigated, it was decided that both the questionnaires mentioned above would not lead to all the desired answers for the variables this trial investigated. Although the National Eye Institute tools are adaptable and validated, they are often long and time consuming for participants. Therefore, the VF-14 visual function questionnaire was used. This tool is versatile and only has fourteen questions. With the added free text box at the end of the questionnaire comprehensive relevant results were collected.

Only one other previous research paper mentioned the use of a diary. Although the specific format is not known, it was interesting to find that this was the most recent study from 2016 (Sivardeen et al., 2016). It is clear from the daily collection of data in this study that

subtle differences in lens performance became more evident throughout the four-week wearing period documented. Every day of lens wear that participants encountered could be documented in this way, producing an almost complete picture of their experience. It could be argued that comparison studies of any type of contact lenses should employ such tools to produce robust research of this kind.

6.5 Strengths and limitations

Strength of the current research lies in the methodology of this comparison trial. The study was conducted under rigorous conditions to maintain the double blind masking for researcher and participants. This ensured a minimum of bias towards one or the other lens type. Both contact lenses were examined over the entire length of four weeks of their predicted disposable life to ensure all measurements taken and subjective experiences were recorded under best and worst conditions. A considerable washout period was implemented, which ensured that the bias towards the lens tested in the second period of the trial was kept to a minimum and a period effect avoided. The large number of participants who completed this trial gives this comparison study greater statistical power and consolidates findings previous researchers predicted in smaller trials. The current research examined both quantitative aspects of vision as well as using subjective tools to document participant's experiences while wearing contact lenses producing comprehensive results, confirming that both are needed in this type of research. During the five years of this trial, other silicone hydrogel multifocal contact lenses have been introduced to the market. These have not been included in the comparison. A limitation of this trial might be the fact that a single researcher conducted the research similar to a single centre study. Although repeated measurements taken by one and

the same person could be perceived as strength due to high repeatability, this could equally be construed as a limitation, if the quality of performance by a single person were of poor quality.

6.6 Recommendations for future research trials

Only limited emphasis was given to the aspect of pupil diameter in the current study. It would be interesting to conduct a sizable multifocal contact lens study to investigate how pupil diameter influences multifocal contact lens wear as presbyopia and near vision addition power increase and the pupil diameter changes. This trial clearly showed only very subtle differences in the performance of these lenses that were not statistically or clinically significant.

Similar sizable trials of this kind are needed to compare the Air Optix Aqua and the Biofinity Multifocal with other more recently introduced silicone hydrogel multifocal contact lenses now on the market, as these were not included in the current research. To date comparative trials with significant numbers have not been published relating to these new multifocal lenses.

6.7 Summary

This chapter discussed findings of the four main and two secondary variables in detail. Participants' preferences were discussed and the identity of the two lens types unmasked. The current research was discussed in the context of previous research trials and strengths and limitations investigated. Recommendations were made for interesting future research studies of this kind. The last chapter will draw conclusions based on the outcomes of the current research.

Chapter 7

Conclusion

The current research compared the Air Optix Aqua Multifocal with the Biofinity Multifocal silicone hydrogel monthly contact lenses. It explored four main and two secondary variables. The study concluded that for binocular photopic distance VA, binocular photopic near VA, stereoacuity at distance and near and contrast sensitivity in mesopic and scotopic lighting conditions there were no statistically significant differences between the two different designs of disposable multifocal lenses. The photopic distance contrast sensitivity was marginally better with Air Optix Aqua than Biofinity, but the magnitude of the difference was so small that it is doubtful to be of clinical significance and most likely a chance finding. Participants' subjective feedback indicated good binocular photopic distance visual performance for both lens types. For binocular photopic intermediate and near VA the scores were more variable in this trial. Marginal but not clinically or statistically significant differences were found between both lenses using the VF-14 visual function questionnaire and the daily diary.

It was concluded that for a comparison study of this kind it is an advantage not only to collect numerical data, but also to employ qualitative tools that draw on and report participants' real life experiences while wearing multifocal contact lenses. A considerable number of participants chose to continue multifocal contact lens wear with both lens types proving equally popular. The current research showed that a large number of presbyopes perceive multifocal soft contact lenses as a viable alternative to spectacles with nearly 60% still across a variety of age groups continuing with their chosen lenses one year after completion of this trial. These findings are in contrast to research with earlier designs, which found continuation with multifocal lenses dropped drastically in numbers after the trial period had ended. Findings of this study support

claims that the presbyopic market presents a valuable opportunity for lens manufacturers and contact lens practitioners for expansion in the future.

This comparison trial also consolidates product knowledge for contact lens fitters and optometrists, who will be confronted with a rising number of presbyopes seeking alternatives to their spectacle wear to correct their failing vision. Professionals will now have more than one lens product to choose from as both, the Air Optix Multifocal and the Biofinity Multifocal have been shown to be equally successful for visual acuity and comfort. As global populations increase, grow older and a rise in myopia is reported across the world, this trial has shown with higher statistical power than in outcomes of previous studies that disposable multifocal contact lenses are perceived as a valued alternative vision correction.

Several additional silicone hydrogel and hydrogel disposable multifocal contact lenses have been introduced to the UK since the start of the current research and the research design used in this study is recommended for further trials with these products to add more products to practitioners' choices and scientifically consolidate performance of these new contact lens products. Different materials are being used in an attempt to solve various problems facing wearers of these contact lens modalities.

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Appendices

Appendix 1

Recruitment Letter
Ashleigh Sight Care
255 Portswood Road
Southampton
SO17 2NG

Southampton, 5th September 2012

Dear Patient,

I am writing to you to bring a research project to your attention, which will shortly be commencing at our practice. As you may be aware, I am currently studying for my Doctorate of Optometry.
My research for the doctoral thesis is a comparison study of two silicone hydrogel multifocal contact lenses. Multifocal contact lenses, which have a distance and near part incorporated in one lens, are an exciting but relatively new way of correcting both, distance and near vision in patients over the age of forty. Some newer products are now manufactured from silicone hydrogel to deal with the problems of dry eyes in patients more effectively.
I will be conducting a comparison study at our practice, comparing two such multifocal contact lenses made by two different manufacturers and I am inviting you to consider, if you would be interested in taking part in this study.
I will be fitting selected patients with one type of monthly disposable multifocal silicone hydrogel lenses, which the participants will be wearing for one month. Then, after a rest period of two weeks, the same patient will wear a second multifocal contact lens by a different manufacturer, also for the period of one month. I will be looking at vision achieved with these contact lenses for distance and near and at how well both eyes work together with these lenses in place. Furthermore, satisfaction and comfort while wearing the lenses will be of interest. Several fitting sessions, as well as aftercare appointments, will be attended by the participating patients at regular intervals throughout the ten week period. Each patient taking part in this study will also be asked to fill in short questionnaires about comfort and satisfaction with these lenses. For the purpose of conducting this trial in tight scientifically valid conditions, my husband and I will both be involved in the fitting procedure.
All our chair time, the actual contact lens trial, the trial contact lenses and the solutions will be given to participating patients free of charge. Your involvement would be to attend the appointments and to try to wear the lenses, although you will not be asked to

wear any contact lenses that you find uncomfortable or unclear. We will not be able to fund travel expenses.
I would be grateful, if you would consider, if you want to be involved in this trial. If you have never tried contact lenses before, this might be an ideal opportunity to try them without any cost involvement on your part. Please, contact the practice and let us know, if you are interested on 023-8055-0431.

Thank you for your interest in advance

Claudia Ashleigh

Appendix 2

Patient Information Sheet

I would like to invite you to take part in our research study. Before you decide, I would like you to understand why I am doing this research and what it would involve for you. I will go through this information sheet with you and answer any questions you might have.

The purpose of this study

People over the age of 40 years often need multifocal (e.g. varifocal) glasses or contact lenses to enable them to see clearly in the distance and to read. Most of these people wear glasses, but multifocal contact lenses are also available. Some modern soft contact lenses are made of an advanced material (silicone hydrogel), which is designed to be comfortable for long periods of wear. Recently, multifocal contact lenses have become available in this material. The purpose of my research is to compare two different multifocal contact lens designs made from this type of material.

Why have you been invited?

This study will involve forty patients between 40-60 years of age. Participants need to have healthy eyes and to not be using any eye drops. Our records indicate that you might fit these criteria.

It is up to you, whether you wish to join this study. We will describe the study and go through this information sheet. If you agree to take part, we will then ask you to sign a consent form. You are free to withdraw at any time, without giving a reason. This would not affect the standard of care you receive.

What will happen, should you decide that you want to be part of this trial?

The contact lenses that we are evaluating should not be worn overnight when you are asleep, but are worn during waking hours for one month and will then need replacing. Each participant will be fitted with a pair of contact lenses supplied by one manufacturer and will be asked to wear these for one month. After this first month, participants will resort back to their existing spectacle or contact lens prescription for a wash out period of one week. They will then be fitted with a pair of lenses from the second manufacturer and asked to wear these for a further month. While you are wearing the contact lenses, you will be asked to complete diaries and questionnaires detailing how you are getting on with the contact lenses. Like any contact lens wearer, if you have problems with any

of the contact lenses at any time, you should remove them and if the problem persists contact your contact lens practitioner. Assuming that there are no problems, you will be asked to wear these contact lenses for at least six hours per day.

Clinical Assessments:

Before you will be fitted with these contact lenses, I will examine both of your eyes with a slit amp microscope, to ensure both eyes are healthy. This will involve taking a good look at both eyelids. I will also establish your prescription as a base for the contact lens powers needed and stain your eyes with a dye called Fluorescein, to establish that the front of your eyes and the tear film are both healthy, before the lenses are fitted. At the end of each wearing period, we will ask you to attend Ashleigh Sight Care for a contact lens aftercare. At this appointment, I will assess your vision to discover how the contact lenses are performing. I will also check the fit of the contact lenses and the health of the front of your eyes again at this point.

Will there be any costs for you during this trial

There will be no costs involved, other than the travelling expenses for attending the appointments.
All fitting procedures and contact lens fitting time, as well as the contact lenses and solutions given to you during the course of this study will be made available to you free of charge. If you wish to continue with the contact lens wear of either type of contact lens at the end of the research, you will be issued with a prescription to enable you to obtain the contact lenses. Only the trial lenses for the research will be supplied free of charge. If you wish to continue wearing contact lenses when the trial has finished, you will need to meet the costs of replacement lenses, solutions and aftercare.

Are there any disadvantages to you by taking part in this trial?

You will need to attend the practice on several occasions (minimum of four sessions) for this research trial and we are unable to reimburse your travelling expenses. Contact lens wear involves a very small risk of eye infections, which occur in about four per 10,000 contact lens wearers per year. The contact lenses that are being used in this research are not known to be associated with a higher than normal risk of infection. They should, however, not be worn when swimming or under the shower to minimise the risk. Like any contact lens wearer, you will be taught how to detect the signs of infection (sore or red eye or blurred vision) and what you should do, if this occurs. You will be given written information on this.

Confidentiality:

All information collected during this trial will be confidential and only shared with researchers involved. No names and dates of birth will be used. Participants will be known by an identification number and their age and gender.

Ethical Issues:

Applications to the Institute of Optometry and London South Bank University ethics committees will have to be submitted and passed before this research could commence. Ethical, legal and data protection procedures will be followed, as demanded by the optometry professional body and the university. If there should be issues or complaints that cannot be resolved with the research team, you are free to contact the Chair of the University Research Ethics Committee: the contact details for Professor Joan Curzio are curiziojl@lsbu.ac.uk.
In the event that new relevant information becomes available, your optometrist will tell you about this and discuss possible changes or developments relevant for the running of the project.

What will happen, if you don't finish the study?
If for any reason you wish to stop the trial at any stage, you are free to do so. Your continued eye care at this practice will not in any way be affected by your participation, or decision not to participate in this research. No costs for lenses, solutions or chair time will be incurred, should you not finish the trial.

Appendix 3

Advice for Driving in your Multifocal Contact Lenses

Most people find multifocal contact lenses helpful for driving at day and night, since they make it easier to view the car instruments as well as distant objects like road signs. However, some people notice seeing **glare** and **haloes** around lights, when wearing the lenses.

Therefore, it is advisable, to be a passenger in a car, before you start driving in these contact lenses yourself, especially at night-time and in poor visibility.

The minimum driving standard in Great Britain advises that the driver has to satisfy him/herself that he/she can see the number plate from 20.5 metres away. No consulting room test exactly predicts the legal number plate vision test, so it is advisable to test this out wearing the contact lenses, before you start driving.

If you have any concerns about your safety for driving when wearing these contact lenses, then please don't wear them for driving, but instead consult your eye care practitioner.

Appendix 4

How to Detect Signs of an Eye Infection

Eye infections:

- Initially, usually only affect one eye at a time
- Can cause: Redness, painful eyes
  Swollen or flaky eyelids
  Discharge or watery eyes
  Blurry vision and light sensitivity

Unlike allergic reactions:

- Usually affect both eyes
- Can cause: Itchy and watery eyes

If you do think that you have an eye infection, it is important that you contact the optometrist as soon as possible on the numbers given to you or alternatively, contact your GP. In particular, if you experience any pain or redness that gets worse a few hours after removing the contact lenses, then please contact the optometrist immediately or, if you cannot reach an optometrist at Ashleigh Sight Care, consult Southampton General Hospital Eye Casualty on 023 8063 4288 or 023 8079 6592, asking to be seen by the duty ophthalmologist.

Appendix 5

Form for Informed Consent

A Comparison of Performance and Patient Acceptance of Two Multifocal Contact Lenses

Researcher: Mrs. Claudia Ashleigh

	Please tick and initial each item!
I confirm that I have read and understand the information sheet dated / / for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.	-----/-----
I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my medical care or legal rights being affected.	-----/-----
I understand that relevant information about my records and data collected may be looked at by researchers involved in the above study. I give permission to these researchers to have access to this information.	-----/-----
I agree to take part in the above study.	-----/-----

Name of the patient	**Date**	**Signature**
Name of the researcher/ person taking consent	**Date**	**Signature**

Appendix 6

VF-14 QOL Questionnaire for Multifocal Contact Lens Research

Because of your vision, how much difficulty do you have with the following activities?

Tick the box that best describes how much difficulty you have when wearing the multifocal contact lenses. If you do not perform the activity for reasons unrelated to your vision, circle "n/a"

Activity		None	A little	Moderate	Great deal	Unable to do
1. Reading small print, such as medicine bottle labels, a telephone book, or food labels	n/a					
2. Reading a newspaper or a book	n/a					
3. Reading a large-print book or large-print newspaper or numbers on a telephone	n/a					
4. Recognizing people when they are close to you	n/a					
5. Seeing steps, stairs or curbs	n/a					
6. Reading traffic signs, street signs or store signs	n/a					
7. Doing fine handwork like sewing, knitting, crocheting, carpentry	n/a					
8. Writing checks or filling out forms	n/a					
9. Playing games such as bingo, dominos, card games, or mahjong	n/a					
10. Taking part in sports like bowling, handball, tennis, golf	n/a					
11. Cooking	n/a					
12. Watching television	n/a					
13. Driving during the day	n/a					
14. Driving at night	n/a					

Please add any additional comments that you may have about your experience with the contact lenses that you have been wearing for the last 3-4 weeks. We are particularly interested in any comments that may not have been covered by the options given in your daily diaries or in this questionnaire. If necessary, please continue overleaf.

Appendix 7

The Daily Diary

Day:_____ Date:_____

Please tick activities that you have carried out for at least an hour this morning:

driving ☐ television ☐ shopping ☐ exercise ☐
reading ☐ computers ☐ restaurant ☐ cooking ☐

Please indicate how well you think the contact lenses have performed for distance vision (e.g., driving, television, looking down the street, looking out a window):

very poor slightly poor fairly good very good

Please indicate how well you think the contact lenses have performed for near vision (e.g., reading, writing, looking at prices in shops):

very poor slightly poor fairly good very good

Please indicate how well you think the contact lenses have performed for intermediate vision (e.g., computers, cooking, eating):

very poor slightly poor fairly good very good

Please indicate how comfortable the lenses have been during the morning:

very poor slightly poor fairly good very good

Complete at lunchtime

Please tick activities that you have carried out for at least an hour this afternoon:

driving ☐ television ☐ shopping ☐ exercise ☐
reading ☐ computers ☐ restaurant ☐ cooking ☐

Please indicate how well you think the contact lenses have performed for distance vision (e.g., driving, television, looking down the street, looking out a window):

very poor slightly poor fairly good very good

Please indicate how well you think the contact lenses have performed for near vision (e.g., reading, writing, looking at prices in shops):

very poor slightly poor fairly good very good

Please indicate how well you think the contact lenses have performed for intermediate vision (e.g., computers, cooking, eating):

very poor slightly poor fairly good very good

Please indicate how comfortable the lenses have been during the morning:

very poor slightly poor fairly good very good

Complete in evening

MULTIFOCAL CONTACT LENS RESEARCH

Daily diary

Participant details (to be entered by the researcher):

Name:_____ Research number:_____

This booklet is for the week beginning:

Day:_____ Date:_____

Instructions

Thank you for participating in this research. The purpose of this booklet is to provide you with a rapid, easy to use, diary in which you can enter your experience with your contact lenses. This booklet consists of the present page, which is for instructions, and then 7 further pages, one for each day of the week.

Please try to remember to complete this diary every lunchtime and every evening, even if you have not worn your contact lenses. Half a page of the diary is for each morning and half for each afternoon. If you forget to complete the diary then please leave this half page blank. It should take about a minute to complete.

Many of the questions in this booklet can be answered by placing a vertical line through the horizontal line, as illustrated below:

Example question: Do you find Party Political Broadcasts:

very boring slightly boring slightly interesting very interesting

(in this example, the question was answered by drawing a vertical line nearest to the "very boring" end. This answer suggests that the respondent finds Party Political Broadcasts to be quite boring).

Appendix 8

Table 22: Severity Ratings of Subjective Scores in Questionnaire for Lens A and Lens B (◎ = good, better best score ⊡ = bad, worse and worst score (-

Participant No	DV Lens A	Int V Lens A	NV Lens A	Insertion Removal Lens A	Comfort Lens A	Other Lens A	DV Lens B	Int V Lens B	NV Lens B	Insertion Removal Lens B	Comfort Lens B	Other Lens B
1/10805					-3							
2/19549		3			3	-2	3				3	
3/10356			-1	3	-1	-2			-1	2	2	
4/8770							-1		2			
5/14290					-3				-2		-2	
6/8152								-2	-3	-2		
7/3699			-2						-2		-1	
8/450		-2										
9/8252				-3			3	3	3		-1	
10/8936		3					-1		3	-2		
11/8945											3	2
12/75											-3	
13/6550			-1							-1		
14/8779	1	1	1						-1			
15/8218			-2				-3			-2		
16/6695												
17/9265	3	3	3		-1							
18/7769												
19/8964			-3		-2							
20/20922												
21/2703							-1					
22/739												
23/1786												
24/1090												
25/9266	-1				3		-1		-1			
26/6892											-1	
27/8901	-1		-1				-1		-1		-2	
28/9387	3	3	-1			3			-1			

29/9386												
30/767				3	3				2			
31/8708												
32/8701												
33/3328												
34/2095												
35/9267												
36/16991			-2		2				-2			
37/20937					-3							
38/13003	-1	-1							1		3	
39/2720	-2			3	3			-2			-3	
40/1641			-3				-2				-2	
41/2093	-2				2			-2				
42/6093												
43/16545												
44/6687					-3				3		1	
45/6051												
46/16125					-1		-3		-2		2	
47/6892												
48/5608												
49/4564			-2	3	-1		2	2	2		-1	
50/1074		-1										
51/371			1					-1				
52/6802	-2		-1		3		1	3	3		-2	
53/4430									-2			
54/4829		-2	-1				-1		-1			
55/4309		-2	-2				-1	-1	-1			
56/6793					-2				-2			
57/5503			-1		3						-3	
58/5573				-1								
59/7063												
60/2376												
61/5838												
62/7310		-1	-1		-2		-1	-1				

Average of positive scores	**2.33**	**2.66**	**1.66**	**3**	**2.63**	**3**	**2.25**	**2.67**	**2,5**	**2**	**2.33**	**2**
Average of negative scores (-)	**1.5**	**1.5**	**1.6**	**2**	**2**	**2**	**1.45**	**1.5**	**1.57**	**1.75**	**1.91**	**0**

Appendix 9

A Comparison of Performance and Patient Acceptance of Two Multifocal Contact Lenses (UREC number 1216)

Replies to REC Comments

Comment 1

Question 5 (b) relates to safety. There is an acknowledgment of the risk of infection in using the lenses. However, as this is a new "generation" of contact lens material, should there also be a consideration as to allergies, which may arise in participants and how this will be dealt with. There is reference to participants returning to the opticians if there are any issues, but this needs to be made more explicit regarding allergic reaction to the new materials.

Reply 1

We now realise that our use of the phrase "new generation" could be misinterpreted since silicone hydrogel materials, although the latest innovation in soft lens materials, have been commercially available in the UK since 1999 in the form of single vision contact lenses. Bausch & Lomb introduced first generation silicone hydrogel multifocal soft contact lenses to the UK in 2006 (Gupta et al., 2009). The two contact lenses we would like to use for this trial are second generation multifocal silicone hydrogel lenses, which use similar materials to the first generation lenses but have improved optical design. Since the materials have been used for some years and allergies have not emerged as an issue, we think that this is very unlikely. Nonetheless, we have made two changes to the documentation:

1. We have changed "new generation" to "latest generation" throughout.

2. Section 5b has been changed to:
   "This trial involves fitting participants with soft contact lenses. Contact lenses need to be handled in a hygienic manner to minimise the risk for eye infections. The usual clinical procedures will be followed for fitting contact lenses and for instructing participants how to care for and handle their contact lenses. The fittings will be carried out with new, sterile contact lenses and the manufacturer's seals on the lens containers will not be broken until the time of the fitting. A contact lens will not be used on more than one patient and manufacturer's recommendations for lens disinfection will be followed. Allergies with modern contact lenses are rare, but the patient information sheet includes the usual advice to instruct patients about the action they should take if they

experience any problems, including those that could result from allergies. These instructions are: 'Like any contact lens wearer, if you have problems with any of the contact lenses at any time, you should remove them and if the problem persists contact your contact lens practitioner on the telephone numbers given to you, including the out of hours service number for the optometrist.'"

Comment 2
Also, in 5b, risk/discomfort associated with intrusion on personal space/bodily contact also needs to be addressed.

Reply 2
We have inserted the following additional text in Section 5b:
"The usual clinical procedures will be followed when the researcher applies contact lenses to a participant for the first time. The researcher will explain that they are going to gently hold the eyelids open and apply the lens to the eye. The participant will be warned that the lens will feel cold and wet and will make them want to blink but that they should not feel discomfort. They will be told that discomfort indicates the need to re-rinse a lens and if discomfort is felt then the practitioner will remove the lens immediately. The participant will be asked, if they are happy for the researcher to now apply the contact lens and the researcher will only proceed, if the participant agrees. It should be noted that it is commonplace for optometrists to hold patient's eyelids open during eye examinations (e.g., when looking inside the eye).
Modern soft contact lenses are comfortable, but tuition is required for wearers to become familiar with applying and removing these. The usual procedures for training will be followed in accordance with guidelines of the College of Optometrists on 'Fitting of Contact Lenses'. The member of practice staff, who carries out contact lens tuition is trained and experienced and patients are given (and participants in this research are given) as many tuition appointments and as much time as they require to safely master the skills required for handling contact lenses. At the tuition, participants will be required to demonstrate that they can apply and remove the lenses successfully and safely at least three times, before they are allowed to take their contact lenses away and commence wear.

Comment 3
Question 5(d) refers to "private, healthy individuals" – it is unclear whether this is in general health terms or simply eye health.

Reply 3
This term relates to the participant's general as well as their eye health. A thorough 'symptoms and history' examination will be

performed by the researcher at the time of the interview. Questions therein will clarify, if the individuals are suitable for this contact lens trial by enquiring about their ocular health and history as well as their general health and history. For example, questions will identify problems like the dry eye syndrome or other corneal surface compromise (eg.: glaucoma, arthritic conditions, Sjoergen's syndrome, keratoconus, corneal ulceration and scarring).
We have altered the text in the section to the following:
'People will only be included in the trial, if they are private patients at the practice, who have healthy eyes and are also generally healthy individuals between 40 and 60 years of age.'

Comment 4
Please, clarify what pre-screening will take place/will have taken place to ensure that the individuals, who are new contact lens wearers, are suitable for contact lenses?

Reply 4
A thorough eye examination will be performed on each individual, prior to the trial. Here, as is customary in all community optometric practices, the participant's corneas, eye lids and ocular tear film will be examined under magnification using a slit lamp bio-microscope with Fluorescein dye. Should there be any doubt that it would be harmful to the participant to fit them with contact lenses, these individuals will be exempt from the trial.
We have inserted the following sentence in the design section of the proposal:
'The participant's corneas, eye lids and ocular tear film will be examined under magnification using a slit lamp bio-microscope with Fluorescein. (Gasson and Morris, 2010)'

Comment 5
Question 6 refers to data being stored for 5 years – is this from the end of the study or from the point of collection? Also need to stipulate what will happen after 5 years.

Reply 5
Once all research data has been collected, it will be stored for a period of five years from the end of the research. At the end of this period, all paper records will be shredded. All computerized data will be erased after this time.
We have inserted the following wording in the anonymity section of the document:
'Once all research data has been collected, it will be stored for a period of five years. At the end of this period, all paper records will be shredded. All computerized data will be erased after this time.

Comment 6
Question 7(f) of the application form refers to the ability of the participants to purchase the lenses at a reduced cost after the study. This is not stated anywhere else and has not been quantified. The patient information sheet also does not make this clear, but states that the cost of purchasing replacement lenses, etc, have to be met by the patient.

Reply 6
We thank the REC members for highlighting this inconsistency. We had originally intended to offer a small discount (e.g.: 10%), but we subsequently realized that this could introduce complications. For example, once a fitting is completed the law requires contact lens practitioners to issue a contact lens prescription, which does not have to be filled at that practice (e.g.: contact lenses could be bought on the internet, as long as the prescription is in date). Therefore, we have deleted mention of the discount and instead now state: 'At the end of the research participants who have met the criteria (Gasson and Morris, 2010) for a successful contact lens fitting, will be issued with a contact lens prescription for the lens type that gives the best performance. They will be entitled, like any other contact lens wearer, to use this prescription to obtain contact lenses from any supplier within the lifetime of the prescription.

Comment 7
Is the research compromised by using a mixture of individuals who are already contact lens wearers and those who are new to it, given the possibility of "adjustment" time?

Reply 7
We have thought very carefully about this issue. We hope that our research findings will be relevant to typical community optometric practices, like the practice in which the research will take place. In these practices, multifocal contact lenses are typically fitted to some patients, who are new to contact lens wear (neophytes) and also patients, who have been wearing single vision contact lenses in the past. For our results to be relevant to these practices, we feel that it is important to have a mixture of neophytes and existing wearers.
In fact, modern soft contact lenses are so comfortable that new wearers usually find them completely comfortable within a few minutes of the first insertion. Typically, patients wear their lenses comfortably all day within 2-3 days of the fitting. The challenge with multifocal contact lenses is achieving good visual performance and the adaptation time for this is likely to be the same for neophytes and existing wearers.

Our decision to include both, neophytes and existing wearers is in accordance with the procedure in some previous research on multifocal contact lenses. (Richdale et al. (2006), Gupta et al. (2009))

Comment 8
2-4 weeks is allocated for adapting to the new lenses. Will the difference in time of a minimum of two weeks and a maximum of four weeks have an impact on the outcome variables?

Reply 8
We think that two weeks will be enough, but as a precaution we have changed this to 'typically 3-4 weeks'. In any event, we will record both the interval from the fitting to the follow-up appointment and will estimate the number of hours that the lenses have been worn at the time of the follow-up appointment. This estimation will be based on the number of days they have been worn and the participant's report of the average number of hours worn per day (which is always recorded after aftercare checks). In the data analysis we will check that both these variables are not significantly different for each lens type and in the unlikely event that it is the key findings will be checked whilst controlling for this variable.

Comment 9
Is an eye examination in the previous year to the study recent enough to determine good eye health for this age group?

Reply 9
The accepted recall time for an eye examination for this age group, is two years. It is thought that eye health as well as a spectacle prescription for this age will not change significantly within this time period. Therefore, we feel that an eye examination, performed in the previous year to the study will be good enough and safe to determine good eye health for this age group.

Comment 10
Environmental factors – will there be any screening out of those whose roles bring them in contact with water/go swimming or participate in other activities, which increase the risk of infection etc?

Reply 10
General advice given to patients in contact lens care, states that re-usable soft contact lenses should not be worn swimming in the water or when under the shower. The same instructions will be given to participants, when getting advice for the use of these silicone hydrogel contact lenses. It will become clear in the symptoms and

history section at the beginning of the interview, if a participant is taking part in any activity subjecting them to increased risk of infection and any such cases will be cautioned not to wear their contact lenses during the hazardous activity. If this is not possible, of if compliance with this instruction is doubted, the individual will not be included in the research (or fitted with contact lenses) in accordance with usual clinical practice (Gasson and Morris, (2010).

Comment 11
No sample of the diary to be recorded has yet been provided nor the first and second monthly questionnaires referred to.

Reply 11
Attached to this email are the copies of both, the proposed daily diary booklet and a copy of the questionnaire mentioned in the revised ethics proposal.
Both, the diary and questionnaire tools are shown as we would like to use them in the research. We are proposing to pilot the questionnaire and diary on a small number of people, once ethical approval has been granted and before the start of the research. This way, we ensure that only a reasonable time is asked of each participant, to fill these tools in.

Final comments about the patient information sheet and recruitment letter: Reply 12
Both documents have been fully revised to add the requested information and both have been reviewed for language issues to make them more 'user friendly'.
The details for the complaints procedure have also been added.
The written information sheet about 'how to detect signs of infection' has been added as a separate document.
As the ethics panel asked numerous questions around contact lens safety, a link to a published, generally accepted and comprehensive guide to contact lens safety has been added to this submission below. This can be found on http://www.webmd.com/fda/focussing-on-contact-lens-safety?page=2 for further information, should this be needed.

Reference List
GASSON, A. & MORRIS, J. (2010) The Contact Lens Manual, a practical guide to fitting, 4th Edition
GUPTA, N., NAROO S.A., WOLFFSOHN, J.S.(2009) Visual comparison of multifocal contact lens to monovision. *Optom Vis Sci,* 86, E98-105
RICHDALE, K., MITCHELL, G.L. & ZADNIK, K. (2006) Comparison of multifocal and monovision soft contact lens correction in patients with low-astigmatic presbyopia. *Optom Vis Sci*, 83,

Appendix 10

Go straight to content.

NHS
Health Research Authority

MRC Medical Research Council

Do I need NHS REC approval?

To print your result with title and IRAS Project ID please enter your details below:

Title of your research:

A Double Masked Randomised Crossover Trial of two Second Generation Silicone Hydrogel Multifocal Contact Lenses

IRAS Project ID (if available):

Your answers to the following questions indicate that **you do not need NHS REC approval for sites in England.** However, **you may need other approvals.**

You have answered ***'YES'*** to: Is your study research?

You answered ***'NO'*** to all of these questions:

Question Set 1

- Is your study a clinical trial of an investigational medicinal product?
- Is your study one or more of the following: A non-CE marked medical device, or a device which has been modified or is being used outside of its CE mark intended purpose, and the study is conducted by or with the support of the manufacturer or another commercial company (including university spin-out company) to provide data for CE marking purposes?
- Does your study involve exposure to any ionising radiation?
- Does your study involve the processing of disclosable protected information on the Register of the Human Fertilisation and Embryology Authority by researchers, without consent?
- Is your study a clinical trial involving the participation

of practising midwives?

Question Set 2

- Will your study involve research participants identified from, or because of their past or present use of services (adult and children's healthcare within the NHS and adult social care), for which the UK health departments are responsible (including services provided under contract with the private or voluntary sectors), including participants recruited through these services as healthy controls?
- Will your research involve collection of tissue or information from any users of these services (adult and children's healthcare within the NHS and adult social care)? This may include users who have died within the last 100 years.
- Will your research involve the use of previously collected tissue or information from which the research team could identify individual past or present users of these services (adult and children's healthcare within the NHS and adult social care), either directly from that tissue or information, or from its combination with other tissue or information likely to come into their possession?
- Will your research involve research participants identified because of their status as relatives or carers of past or present users of these services (adult and children's healthcare within the NHS and adult social care)?

Question Set 3

- Will your research involve the storage of relevant material from the living or deceased on premises in the UK, but not Scotland, without an appropriate licence from the Human Tissue Authority (HTA)? This includes storage of imported material.
- Will your research involve storage or use of relevant material from the living, collected on or after 1st September 2006, and the research is not within the terms of consent from the donors, and the research does not come under another NHS REC approval?
- Will your research involve the analysis of DNA from bodily material, collected on or after 1st September 2006, and this analysis is not within the terms of consent for research from the donor?

Question Set 4

- Will your research involve at any stage intrusive procedures with adults who lack capacity to consent for themselves, including participants retained in study following the loss of capacity?
- Is your research health-related and involving prisoners?

- Does your research involve xenotransplantation?
- Is your research a social care project funded by the Department of Health?

If your research extends beyond **England** find out if you need NHS REC approval by selecting the *'OTHER UK COUNTRIES'* button below.

OTHER UK COUNTRIES

If, after visiting all relevant UK countries, this decision tool suggests that you do not require NHS REC approval follow this link for final confirmation and further information.

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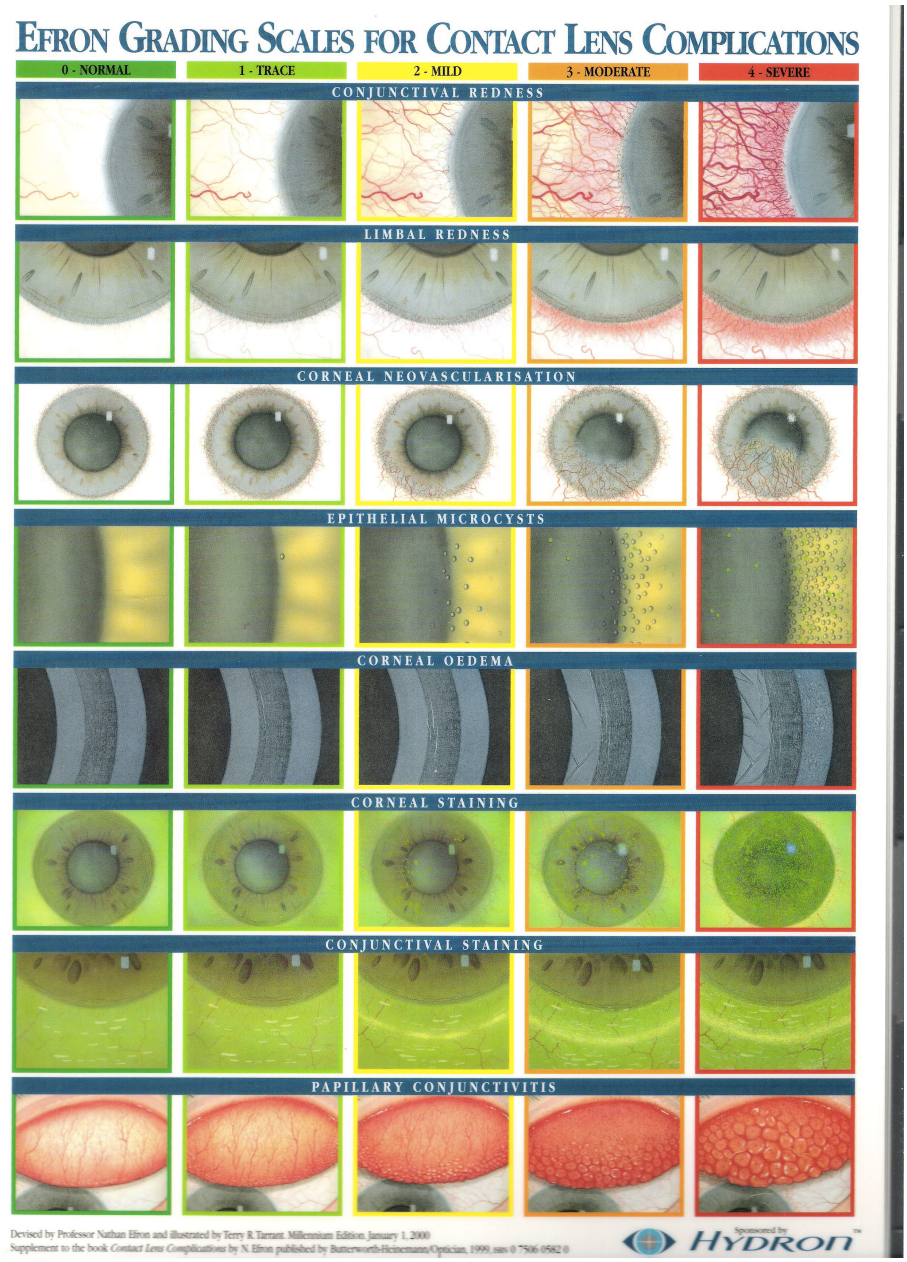
NOTE: If using Internet Explorer please use browser print function.

Appendix 11


EFRON GRADING SCALES FOR CONTACT LENS COMPLICATIONS
0 - NORMAL
1 - TRACE
2 - MILD
3 - MODERATE
4 - SEVERE
CONJUNCTIVAL REDNESS
LIMBAL REDNESS
CORNEAL NEOVASCULARISATION
EPITHELIAL MICROCYSTS
CORNEAL OEDEMA
CORNEAL STAINING
CONJUNCTIVAL STAINING
PAPILLARY CONJUNCTIVITIS
Devised by Professor Nathan Efron and illustrated by Terry R Tarrant. Millennium Edition January 1, 2000
Supplement to the book Contact Lens Complications by N. Efron published by Butterworth-Heinemann/Optician, 1999. isbn 0 7506 0582 0
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