The Role of Stereopsis in Microsurgical Performance on the EYESi Ophthalmic Surgical Simulator

by

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Abstract

Purpose: There remains a lack of objective evidence on whether stereopsis is necessary for an ophthalmic surgical career. It is also unclear if high grade stereoacuity correlates with better surgical performance. The present study attempts to address this question by comparing the simulated surgical performance of subjects with different levels of stereoacuity using a virtual reality (VR) intraocular surgical simulator (EYESi, VRmagic Holding AG, Mannheim, Germany).

Methods: Subjects were tested based on their stereoacuity level and stratified in 3 age-matched groups: normal stereo (60 seconds of arcs or better), subnormal stereo (worse than 60 seconds of arc), and patients with no measurable stereoacuity in the clinical setting. 11 subjects in each group to make a total of 33 subjects with no previous surgical experience were recruited from IWK Health Centre, Halifax, NS from March to August 2018. Subjects performed 3 attempts on a standardized microsurgical module on the EYESi VR simulator. Mixed repeated measure ANOVA was used for statistical analysis.

Results: There was no significant main effect of the stereo-group that the participants belonged to on their scores *[F (2, 28) = 0.21, p=0.81],* or on the time needed to complete the task *[F (2, 28) = 0.04, p=0.96],* or on the odometer value *[F (2, 28) = 0.45, p=0.64]* or on the amount of injury to the cornea *[F (2, 28) = 0.56, p=0.57]* or to the lens *[F (2, 28) = 0.50, p=0.61].*

Conclusion: This study showed that the simulated microsurgical performance on the EYESI intraocular surgical simulator of individuals with reduced and absent stereoacuity were statistically indistinguishable from those with normal stereoacuity. Caution is recommended when advocating high level of stereoacuity as a requirement for admission to residency training programs in ophthalmology as there is still no definite evidence that stereopsis is necessary to achieve satisfactory skills in ophthalmic microsurgery.

List of Abbreviations Used

ANCOVA	Analysis of Covariance
BEO	Both Eyes Open
BSV	Binocular Single Vision
DVD	Dissociated Vertical Deviation
E	Esophoria
EMMean	Estimated Marginal Mean
ET	Esotropia
ETDRS	Early Treatment Diabetic Retinopathy Study
H/O	History Of
LE	Left Eye
OU	Both Eyes
RE	Right Eye
SB	Stereo-Blind group
SN	Normal Stereopsis group
SR	Reduced Stereopsis group
TNO	Toegepast Natuurwetenschappelijk Onderzoek (Netherlands Organization for Applied Scientific Research)
VA	Visual acuity
X	Exophoria
X(T)	Intermittent Exotropia
XT	Exotropia

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Chapter I

Introduction

In animals, it is easy to understand the need for two eyes on either side of the head moving independently so each has a completely different field of view. Humans, on the other hand, have two forward-facing eyes with overlapping visual fields thus greatly dismissing this purpose. However, this overlap is important because it allows for binocular single vision and the use of stereopsis (Waqar *et al*., 2012).

Binocular single vision (BSV) describes the ability to combine the two retinal images, one from each eye, into a single percept (von Noorden & Campos, 2002). BSV can be broken down into three levels; simultaneous perception, fusion, and stereopsis (Duke-Elder & Wybar, 1973). Simultaneous perception describes the ability to perceive two retinal images, whereas fusion describes the ability to cortically blend these two retinal images. Stereopsis is considered the highest level of binocular single vision and describes the ability to cortically blend two slightly disparate retinal images into a single image that conveys relative depth information i.e. the depth of an object in relation to the point of regard (von Noorden & Campos, 2002).

1.1: Normal Stereopsis

Stereopsis was first described in 1838 by Charles Wheatstone, the inventor of the stereoscope, and as mentioned above, is a visual experience that allows the perception of the natural three-dimensional world during binocular viewing. Stereopsis

results from the integration of two slightly dissimilar retinal images, which requires a degree of horizontal retinal disparity within Panum's area (Bishop, 1990).

For stereopsis to develop normally, the individual's visual system must be comprised of two eyes with equal and normal vision; must be transmitting images to the brain via the two retinae which are similar in size, colour and brightness; and, must be visually aligned such that there is retinal correspondence between the two eyes (von Noorden & Campos, 2002). The brain also need to be able to accurately interpret the images from both eyes with no neurological insult along the pathway preventing that.

In the retina, the fovea has high spatial resolution power, and as a result, even if the images formed by the two eyes are slightly different, a single image is perceived and thus detailed high stereopsis is possible. While in the peripheral retina, as its receiving unit is large, only a large disparity of the images can be perceived, and its stereopsis is thus decreased (Lee & Koo, 2005). This precision of stereoscopic depth perception is referred to as 'stereoacuity', and is typically quantified in terms of seconds of arc of retinal disparity. Stereoacuity tests are routinely applied clinically and aim at determining the smallest amount of recognizable retinal disparity in seconds of arc (Hahn et al., 2010).

Since disparity detection requires good vision in each eye, stereopsis is not present at birth but develops rapidly following the improvement in visual acuity with appropriate stimulation. Stereopsis has been reported to develop in early infancy between 3 and 5 months of age (Birch, 1993) and adults levels are not achieved until around 5-7 years (Fielder & Moseley, 1996). Stereopsis also changes with aging. A study

by Lee and Koo (2005) found that both near and distance stereopsis decreased as age increased, particularly in those older than 50 years. Although the exact mechanism of the decrease of stereopsis with age is not fully understood, several reports said that it could be attributed to various neurological factors linked to the general deterioration of cerebral function (Lee & Koo, 2005; Cohn & Lasley, 1985). Another report by Sadun and Bassi (1990) suggests that the loss of stereopsis may be due to the selective loss of retinal ganglion cells and Muller cells, rather than due to a defect in cerebral function. Stereopsis is not only limited by age but there are distance limitations as well. Stereopsis is present up to a distance of 500 m and improves at closer distance until limited by accommodation (Fielder & Moseley, 1996).

1.2: Abnormal Stereopsis

About 2% of asymptomatic Adults with no other disorder of binocular function have no stereopsis, i.e. stereo-blind (Fielder & Moseley, 1996). As mentioned earlier, stereopsis continues to improve during childhood up to the age of approximately 10 years in some individuals (Read, 2015). This long period of plasticity implies that binocular single vision remains vulnerable to disruption until later in development; for example, the onset of accommodative esotropia in toddlerhood can profoundly and permanently disrupt stereopsis (Birch, 2003).

Decreased stereopsis can occur as a result of deficient binocular functions in a range of disorders such as anisometropia, visual deprivation, amblyopia and strabismus (Waqar et al., 2012). Hubel and Wiesel's experiment in 1965 with visually immature

kittens either by means of an induced strabismus or alternating monocular occlusion gave insight into how the neural cells of the striate cortex are affected by the visual information from the optic nerves. Their investigation led to the conclusion that ocular dominance columns within the striate cortex are organized by where the visual input is coming from, ranging from solely contralateral and monocular to solely ipsilateral and monocular. Furthermore, in the visual system of adult cats whose binocular development was not interrupted there are more "binocularly driven" cells (Hubel & Wiesel, 1965).

Subsequent investigations have clearly established that strabismus in early life prevents the normal development of binocular sensory neurons in visual cortex (Crawford & von Noorden, 1979). Infantile esotropia, defined as a large-angle inward deviation that becomes constant before 6 months of age, has a particularly disruptive effect on stereopsis. Among children whose eyes were surgically aligned after the age of 24 months, only 12% achieved any stereo vision, although this increased to 74% among children aligned before 6 months of age (Birch, Fawcett, & Stager, 2000). It was suggested by the authors that the poorer outcome of surgery after 6 months does not reflect the closure of a sensitive period, but simply the brain's longer exposure to misaligned visual input. Therefore, early alignment, not just early surgery, is paramount as timely correction of strabismus can lead to better outcomes in terms of stereopsis. However, although early surgery does restore some stereopsis, measured stereoacuity is by no means normal (Read, 2015; Fielder & Moseley, 1996).

Many children with accommodative esotropia also have abnormal stereoacuity even after undergoing re-establishment of stable alignment by optical correction and/or surgery. In a prospective cohort of 79 children with accommodative esotropia followed up for 4 to 11 years, only 18% had normal Randot stereoacuity results at their most recent visit. The remaining children had subnormal (28%) stereoacuity, nil (39%) stereoacuity or could not be assessed because they either had large manifest deviation (10%) or had deep amblyopia (5%) that precluded stereoacuity testing (Birch, 2003).

Clinicians commonly report no stereopsis in strabismic subjects with larger angle of manifest deviation, while other patients show various levels of stereoacuity in keeping with the size and control of their deviation, age of onset and the stability of the angle of their strabismus. A particular group of interest shows gross stereopsis, even though presenting signs of abnormal binocular function. These have been described as microstrabismics (Lang), monofixators (Parks), or stereoblind (von Noorden).

According to his clinical experience, Parks (1968) considered three grades of stereoacuity: 400 seconds of arc or greater classified as peripheral binocularity, 80-200 seconds of arc corresponding to macular binocularity, and 60 seconds of arc or less representing a foveal binocularity. It is generally accepted that normal individuals can detect 40 seconds of arc of retinal image disparity, rarely as little as 20 seconds.

1.3: Monocular Cues

While binocular stereopsis is the only direct tool of our visual system to give depth perception, various monocular clues can provide an indirect measurement (Westheimer, 1994). Some of these monocular depth cues are illustrated in figure 1-1.

'Relative size' describes the process of retinal image size allowing us to estimate distance based on our past and present experience and familiarity with similar objects; for example, as a car drives away, its retinal image becomes smaller and smaller. This is interpreted as the car going further and further away.

'Interposition' or occlusion occurs when there is object overlapping. The overlapped object is considered further away. 'Linear perspective' refers to the perception of distance for the visual objects which subtend a smaller visual angle on the retina than others closer; for example, truly parallel lines appear to converge with increasing distance; this is typical of roads, railway lines and electric wires.

'Aerial perspective' uses the relative differences in colors of objects viewed at various distances; due to the scattering of blue light in the atmosphere, distant objects appear bluer, giving distant mountains their bluish haze (Waqar et al, 2012). The contrasts of objects also provide clues to their distance. Because the scattering of light blurs the outlines of an object, the degraded image of a distant object will be a clue to its position in space relative to the observer.

Similarly, highlights and shadows can provide information about an object's dimensions and depth. Another phenomenon of monocular depth clues is 'movement parallax'. When we move our head from side to side, objects at different distances move

in the same direction but at different relative speeds. Closer objects appear to move faster than further objects (von Noorden & Campos, 2002); an effect widely used and amplified in wide-screen digitally created movies.

Interestingly, most of these cues were originally discovered and used by renaissance artists to a great extent and only later studied by psychologists. The understanding of linear perspective, in particular, by the artists of the mid-fifteenth century had a dramatic effect on the evolution of visual arts in Europe, as exemplified by 'The Flagellation of Christ' by Piero della Francesca, Florence (figure 1-2), and by Jan van Eyck's 'The Arnolfini Portrait' (figure 1-3), Netherland ("30,000 Years of Art", Phaidon Press, London, 2007).

It is important to note that these monocular clues are psychological in nature and are learned skills based on life experiences. Thus, they can be improved with training, but are also prone to illusion (Wright, Gooch & Hadley, 2013). In 1960, Psychologists Eleanor Gibson and Richard Walk conducted the famous "visual cliff" experiment to study depth perception in infants. They were interested to know if infant's ability to perceive depth is a learned or an innate behavior. They studied 36 infants between the ages of six and 14 months, all of whom could crawl. The infants were placed one at a time on a visual cliff. The visual cliff involves an apparent, but not actual drop from one surface to another. It was created using a big glass table that was raised about a foot off the floor. Half of the glass table had a checker pattern underneath in order to create the appearance of a 'shallow side'. In order to create a 'deep side,' a checker pattern was created on the floor; this side is the visual cliff (figure

1-4). Even though the glass table extends all the way across, the placement of the checker pattern on the floor creates the illusion of a sudden drop-off. It appears that there are two visual cues play the decisive role in depth perception here; ‘relative size’ in which the checker pattern on the deep side distance decreases the size and spacing of the pattern elements projected on the retina. The other cue is "motion parallax," that causes the pattern elements on the shallow side to move more rapidly across the field of vision.

The infants were placed on the center board one by one. The mother of each child would call the child from the deep side and the shallow side consecutively. Researchers looked to see if the infant would cross the deep side and crawl to the mother, or if the infant would crawl away from its mother toward the shallow side. It was assumed if the child was reluctant to crawl to the mother, he or she was able to perceive depth, believing that the transparent space was an actual cliff.

Gibson and Walk found that nine of the infants did not move off the center board. All of the 27 infants who did move crossed into the shallow side when their mothers called them from the shallow side. When their mother called from the deep side, only three of the infants crawled off the visual cliff toward their mother. The remaining 24 children either crawled to the shallow side or cried because they could not cross the visual cliff and make it to their mother. The infants knew the glass was solid by patting it, but still did not cross. Gibson and walk concluded that the ability to perceive depth emerges sometime around the age that an infant begins to crawl. This experiment

does not prove that the human infant's perception and avoidance of the cliff are innate (Gibson & Walk, 1960).

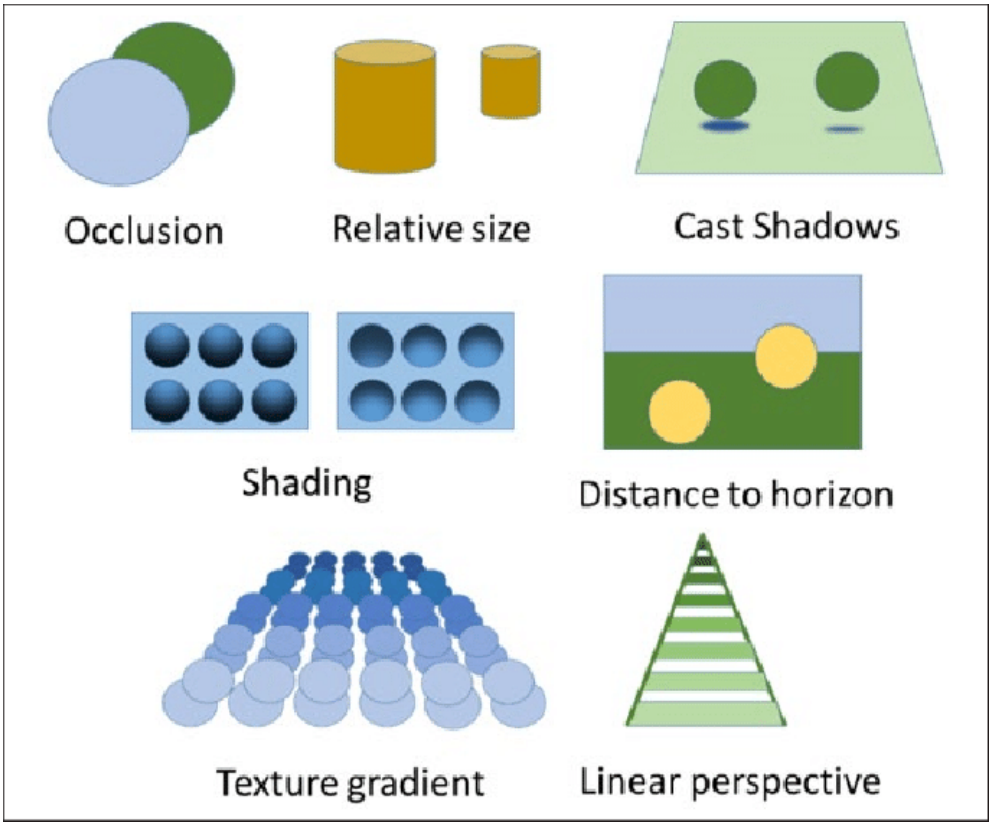


Figure 1- 1: Illustration of the basic monocular depth cues.
Retrieved from Bogdanova, R., Boulanger, P., & Zheng, B. (2016). Depth Perception of Surgeons in Minimally Invasive Surgery. Surgical Innovation, 23(5), 515-524.

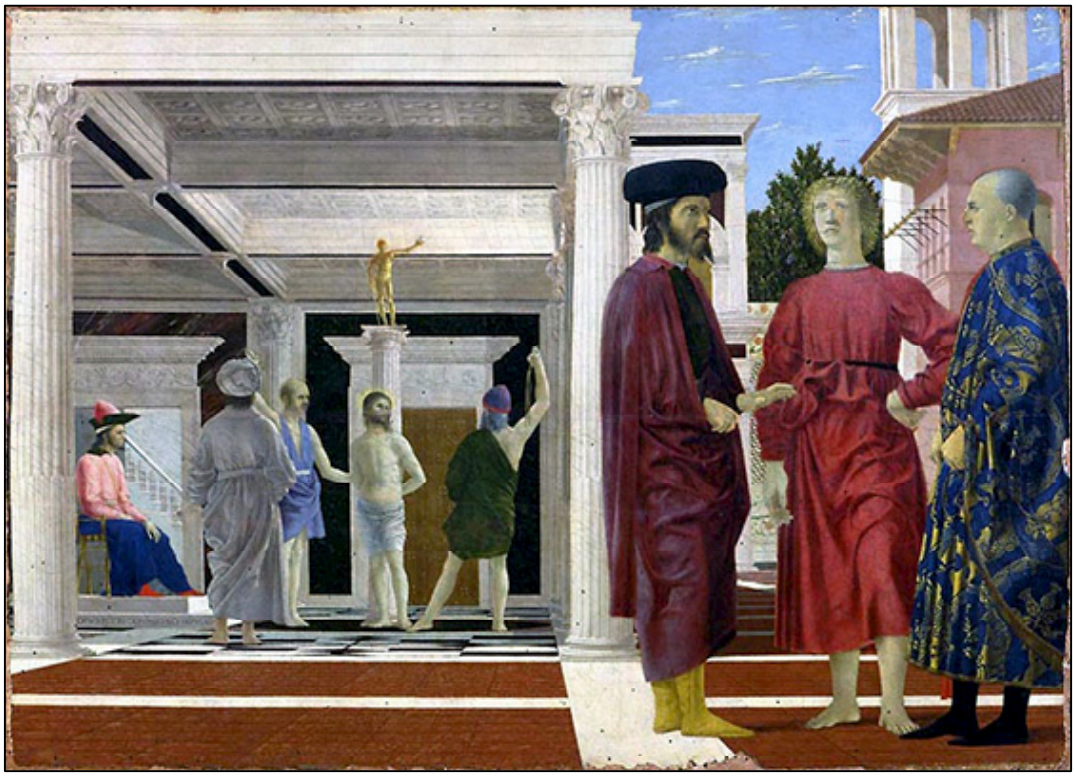


Figure 1- 2: 'Flagellation of Christ' by Piero della Francesca.
Retrieved from Christine Zappella, "Piero della Francesca, Flagellation of Christ," in Smarthistory, August 9, 2015, accessed February 13, 2019, https://smarthistory.org/piero-della-francescas-flagellation-of-christ/.

Figure 1- 3: 'Arnolfini Portrait' By Jan van Eyck.
Retrieved from Lane Eagles, "The question of pregnancy in Jan van Eyck's Arnolfini Portrait," in Smarthistory, August 26, 2018, accessed February 13, 2019, https://smarthistory.org/arnolfini-pregnancy/.

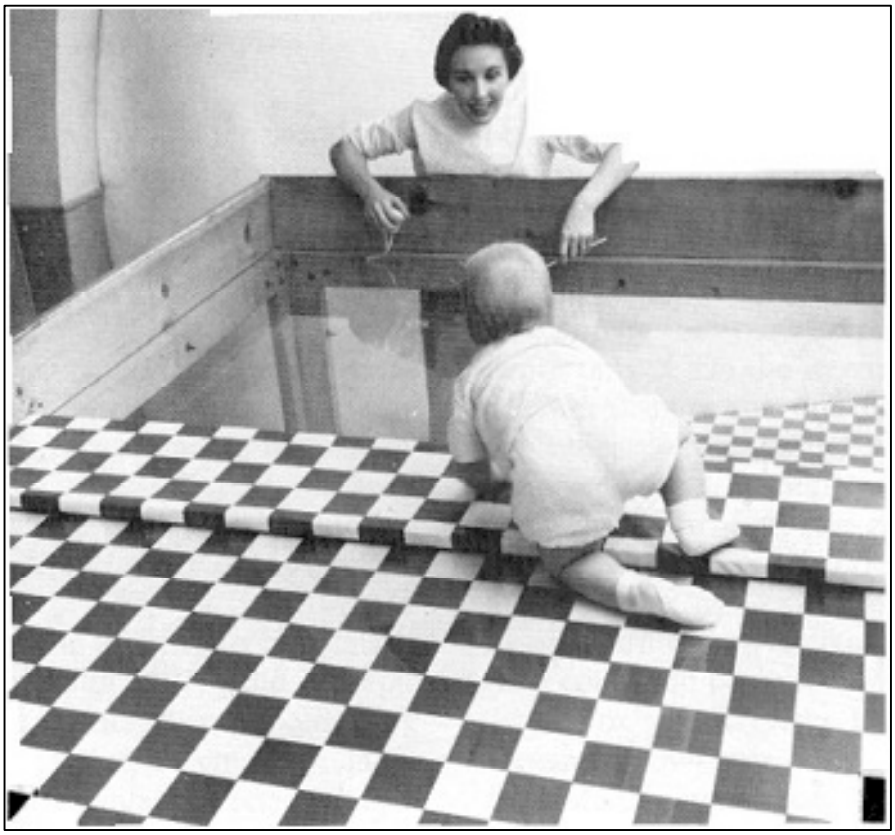


Figure 1- 4: The Visual Cliff Experiment. A mother calling her child from across the deep side of the visual cliff.
Retrieved from Gibson, E. J., & Walk, R. D. (1960). The "visual cliff." Scientific American, 202, 67–71.

1.4: Functional Significance of Stereopsis

Despite the enormous research effort into the basis of stereopsis that dates back over a century, very little was known about its functional benefits. This imbalance is also evident in the standard clinical texts, which extensively cover the basis of binocular single vision but contain little or nothing on its functional aspects (Fielder & Moseley, 1996). However, since the 1990s more researchers have started to evaluate the functional relevance of stereopsis. Even so, clinical studies investigating the functional consequences of reduced stereopsis remain very few. There also has been no distinction between the loss of stereopsis later in life, or temporarily for study purpose, and those who have never had it.

Traditionally, strabismus surgery was classified as a cosmetic procedure, but evidence clearly demonstrates that correcting the deviation has a significant impact on a patient in many aspects of life, especially the psychosocial ones (O'Connor & Tidbury, 2018). The effects of decisions regarding management in childhood are far reaching, impacting on career opportunities and quality of life. However, it is still challenging to isolate the impact from the lack of stereopsis from the impact of the appearance of strabismus.

Stereopsis provides fast and easy access to accurate visual information on depth in our surroundings. “By reducing the amount of scanning necessary to extract spatial information, stereopsis facilitates comprehension of complex visual experiences“ (Fielder & Moseley, 1996).

Stereopsis has been linked to better reading ability (Kulp & Schmidt, 2002) perhaps because both stereopsis and reading require precise control of eye movements (Read, 2015). Many strabismic individuals have abnormal eye movements characterized by saccade dysconjugacy that might adversely affect their reading abilities (Grant & Moseley, 2011).

Given the presence of monocular cues and the distance limitations of stereopsis, one can understand why individuals with training can perform without much trouble in everyday life even when this high form of depth perception is lacking. In a study looking at the influence of depth perception on automobile driving performance, investigators found that stereopsis had a positive effect only in dynamic situations at intermediate distances; for example, driving through a slalom course, while other more routine driving tasks were unaffected (Bauer *et al*, 2001).

Since disparity information is greater at near distances, it is expected that fine motor skill tasks would be affected by a lack of stereopsis. Relatively few studies have focused on comparing individuals with various levels of stereoacuity in tasks that require complex motor skills such as threading beads, posting coins into a coin box and catching a ball. What has been reported to date has focused on children with strabismus, adults with childhood-onset strabismus or longstanding monocular vision loss, and adults with normal stereo-acuity placed temporarily under artificial monocular conditions (Webber, Wood, Gole, & Bown, 2008; Caputo et al, 2007; Hrisos et al, 2006). These studies fail to directly correlate the reduced motor skills to reduced or deficient stereoacuity. Webber and associates (2008) reported that strabismus has the greatest negative influence on

the performance of fine motor skills. However, after multivariate analysis with multiple regression model that takes into account the inter-correlation between strabismus and stereopsis, the influence of the level of stereoacuity was not found to be significant.

The study of Caputo and associates (2007) on children who had undergone surgery for congenital esotropia showed postoperative improvements in motor performance but it did not correlate with measured improvements in stereoacuity. Therefore, it remains unclear whether improvement in motor skills reflects stereopsis specifically or some other aspect of binocular vision.

Analysis of the kinematics of the hand movements by Piano and O'Connor (2013) demonstrate that in visually-guided reaching and grasping tasks, the hand aperture is wider and inaccurate, taking longer overall to reach the target but in particular slowing in the final approach. However, the relationship between stereoacuity and motor skills was not linear, with the absence of stereoacuity having a much greater impact, suggesting the presence of some stereopsis is better than none and is nevertheless functional. It is worth noting that all participants of this study had normal stereoacuity initially and underwent an induced degrading of binocular visual function by monocular blur using convex spherical lenses. Therefore, their performance may differ from individuals with long-standing absence of stereopsis who may have adapted to their loss by using monocular cues. The use of convex lenses also alters the images sizes and therefore, can affect some of the monocular cues such as the relative size.

On the other hand, it has been reported that the development and use of compensatory cues for depth perception in people with weak stereopsis are insufficient

to deal with interception tasks (like catching a tennis ball) under high temporal constraints (ball moving at high speed) and that this disadvantage cannot be fully attenuated by specific and intensive training (Mazyn *et al*, 2007; Mazyn *et al*, 2004). It has been suggested that the level of adaptation to the absence of stereopsis is task dependent. O'Connor and colleagues (2010) reported that their subjects with nil stereoacuity performed some motor tasks better than those subjects with normal stereoacuity who were temporarily rendered stereoblind by monocular occlusion. However, when the task difficulty increased (placing large beads on a large needle compared to placing small beads on a finer needle), the reduction in performance associated with a lack of stereoacuity increased with increasing task difficulty.

The effect of losing stereopsis extend beyond hand movements. It was found that adaptations to changes in terrain (e.g., steps) are significantly less accurate without stereopsis both in normally sighted subjects viewing monocularly, and in subjects with amblyopia and reduced stereoacuity or absent stereopsis (Buckley *et al.*, 2010; Helbostad, Vereijken, Hesseberg, & Sletvold, 2009).

Beside the relationship of stereopsis with visuomotor control, stereopsis is clinically known to be linked to long-term stability of ocular alignment. Birch and colleagues (2004) studied children who underwent surgery for infantile esotropia, resulting in stable alignment within 4 prism diopters by 2 years of age. Children who had no stereo vision postoperatively were 3.6 times more likely to need repeat surgery later in childhood. Out of 60 children with accommodative esotropia who received successful optical correction to within 4 prism dioptres by age 4, those who had no stereo vision

following alignment were 17 times more likely to need surgery later (Birch, Fawcett & Stager,2002).

1.5: Professional Requirements

A number of professions apply visual standards to prospective employees. These professions include but not limited to; aircraft pilots, fire-fighters, military personnel, police officers, and train operators. Clearly having good visual acuity and the ability to discriminate colours are important for the practising members of these professions in order to properly perform the assigned tasks and to maintain public safety. Meanwhile, having stereoacuity visual requirement for certain professions could potentially discriminate against individuals with physical disabilities without good evidence.

The value of stereopsis for pilots of aircraft for example has yet to be clarified. It has been argued for a long time that stereoscopic vision aids greatly in judging distances and making good landings, and therefore avoidance of crashes (Wright *et al.*, 2013). However, in a retrospective study of attrition rates from US Air Force Undergraduate Pilot Training, the absence of stereopsis was not found to be a significant factor. The authors suggested that stereopsis does not correlate with flying ability and in most situations monocular cues suffice (Snyder & Lezotte, 1993). This could be explained by the fact that many of a pilot's tasks are beyond the range of distances that provide useful stereoscopic information.

Just as there is poor agreement on the usefulness of stereopsis for pilots, there is similar disagreement by international aviation governing bodies on what level of stereopsis is required to be considered "fit to fly". The US Air Force requires any aircrew

involved in controlling or clearing the aircraft, out to 200 meters, to demonstrate 25 seconds of arc (although 60 seconds of arc can be considered if the condition is stable). The US Navy standard is 40 seconds of arc for aircrew in control of the craft with no allowance for waiver, while the US Army requires 40 seconds of arc for all aircrew, regardless of crew position (Wright *et al.*, 2013). Conversely, the Canadian Air Force does not specify a level of stereoacuity but candidates must not have diplopia or the risk of developing it during the course of a prolonged or difficult flight, and heterophorias may not exceed specified measurements (Government of Canada, Canadian Aviation Regulations, 2017).

The Royal Canadian Mounted Police used to require a level of stereoacuity to be at least 100 seconds of arc measured by Titmus stereotest (Hovis, 2016). However, their binocular vision criteria have changed recently and now only require indicating the presence of strabismus or constant diplopia and the risk of experiencing diplopia when tired or in an environment with reduced visual cues or greater visual strain or stress (Royal Canadian Mounted Police, 2017).

On the contrary, there are no binocular vision standards for surgeons, including ophthalmologists in many countries. There has been a debate within ophthalmology on whether stereoacuity should be a pre-requisite for admission to ophthalmology training. Wong and colleagues (2010) sent a questionnaire to 907 UK ophthalmologists asking them if they think there is a need for such visual standards. Only 186 responded, therefore, the results must be taken with caution given the low response rate. The results showed that 80% of respondents felt a visual standard should apply to junior

doctors seeking entry into ophthalmology training programs. Of those ophthalmologists who said a visual standard should apply, 97% felt distance visual acuity standards should be applied, and 94% stated that stereoacuity standards should be set. In addition, the authors approached the national ophthalmic bodies in several countries asking whether they applied visual standards to ophthalmology. Twenty countries (Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Japan, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, UK, and USA) have no visual standard, either for those entering into the training programme or for practising ophthalmologists. The Czech Republic requires its ophthalmologists to have binocular vision to perform ophthalmic surgery (Wong *et al*., 2010), while in the Netherlands, doctors wishing to enter ophthalmology training are tested for stereopsis and are required to have stereoacuity of 240 seconds of arc or better (Nibourg *et al.*, 2015).

In 2008, Andrew Elliott conducted a literature review on behalf of the professional subcommittee of the Royal College of Ophthalmologists UK and concluded: “Despite an intuitive feeling to the contrary, there is no definite evidence that stereopsis is necessary to achieve satisfactory skills in ophthalmic surgery”. He further commented that excellent manual dexterity and adaptation to non-stereoscopic depth clues may be compensatory.

Chapter II

Literature Review

Surgery is a visually demanding profession requiring fine judgement of distances and depth. As discussed earlier in the introduction, the brain is capable of using several mechanisms to judge depth, one of which is stereopsis. Very few studies have outlined the role of stereopsis in surgical performance and their results are somewhat contradictory indeed. Murdoch and associates (1991) compared groups with normal, reduced, and absent stereo-acuity in an instrument assessing manual dexterity. The test task used involved passing a metal loop along a winding wire with points being deducted for failure to keep the loop from contacting the wire. The authors found poorer performance in the group with absent stereo-acuity and increased variation in results among the group with reduced stereo-acuity. However, someone might question if passing a loop along a bendy wire captures all the skills required for intraocular surgery.

Barry and associates (2009) described the better performance of a control group compared with a strabismic study group in a laparoscopic training device and postulated that this was directly related to the level of stereoacuity of each subject. However, there was significant overlap between groups and several participants with strabismus performed better than the mean of the control group. None of their strabismic participants had measurable stereopsis using Randot circles.

In laparoscopy, the images are captured by a single lens and are seen on a 2-dimensional monitor. Therefore, laparoscopes do not present binocular disparity and

surgeons have to rely only on 2-dimennsional cues for estimating depth in the operative field. This was confirmed by a study by Shah and colleagues (2003) who reported that experienced surgeons have shown greater adaptation to non-stereoscopic environment than medical students in a task using a laparoscopic simulator.

Dentistry is another speciality that requires good judgement of depth particularly for cavity preparation. Dimitrijevic and colleagues (2011) found no statistical relationship between stereoacuity (using the TNO test) and depth estimation in 163 dentistry students and 20 experienced dentists. In this study students were grouped together according to the year of training. Interestingly, students with no experience in pre-clinical operative dentistry performed significantly worse at depth estimation than dentistry students and experienced dentists. In 2001, Forgie and colleagues measured the stereoacuity of 46 dentists practicing in Scotland using the TNO stereotest. The results showed that the stereoacuity followed a Gaussian distribution ranging from poor (480 seconds of arc) to good (15 seconds of arc). The study identified three out of the 46 practicing dentists (10% of participants) with no stereoacuity detected by TNO test. These findings suggest that deficiency in stereopsis is not a hindrance to career progression in dentistry. This is not surprising as most dentists learn to master working with monocular depth cues when they use a mirror to view the operative side during their clinical practice.

On the contrary, microsurgery, which is gaining increasing acceptance in many surgical disciplines, offers a detailed stereoscopic viewing using the operating room microscope. Therefore, the demand of stereopsis in microsurgery could be higher.

Grober and associates (2003) assessed the effect of stereopsis on microsurgical performance in a suturing task of a group of surgical residents. This investigation failed to find a significant association between the level of stereoacuity and microsurgical performance. Stereoacuity was measured with a non-standard technique and individual stereoacuity scores were not provided in this study.

In ophthalmic microsurgery specifically, surgery is technically different from laparoscopic surgeries or dentistry as the ability to combine detailed visual information with fine manual dexterity with greater precision is extremely important. It has been argued that good vision, and in particular, good stereo-vision, ought to be a requirement for practicing as a surgeon; a premise used by many training programs to require a detailed visual function assessment before admission. However, opinion remains divided on this matter. Biddle and associates (2014) evaluated the stereopsis in practicing surgeons of different specialities, including neurosurgery (8), ophthalmology (8), ENT surgery (8), pediatric surgery (7), obstetric/gynecological surgery (7), general surgery (6), oral and maxillo-facial surgery (6), plastic/dermatological surgery (5), orthopedic surgery (5), trauma surgery (3), colorectal surgery (2) and renal/transplant surgery (1). The authors found that most surgeons have high-grade stereoacuity, defined as scoring 60 seconds of arc or better, while around 20% did not. However, the study did not correlate the levels of stereoacuity with surgical ability.

2.1: Significance of the Study

The role of stereopsis for intraocular surgery would be difficult to ascertain in a live operative theatre setting without compromising patient safety. However, surgical

simulators are now universally used in surgical residency training, including ophthalmic microsurgery. These simulations allow surgeons in training to become familiar with the principles behind the procedures they will be performing and help develop the motor skills required for safe skill transfer to the patients. Newer Virtual Reality (VR) simulators provide the most realistic platform. Using the EYESi™ (VRmagic, Mannheim, Germany) VR simulator for ophthalmic intra-ocular surgery, the role of stereopsis in surgical performance can be investigated. At Dalhousie, ophthalmology residents are required to achieve a certain proficiency level on the EYESi simulator in order to be able to perform cataract surgeries in the real operative theatre setting.

Previous studies have identified a benefit to having some stereoscopic vision for tasks performed under EYESi surgery simulation. Waqar and colleagues (2012) investigated the performance of junior doctors with normal stereo-acuity, first binocularly and then monocularly to simulate an acute loss of their stereopsis. There was a significant decrease in surgical performance when the subjects became monocular. While this study demonstrated the effect of an acute loss of stereopsis, people with long standing stereo-deficiency generally become adapted to various monocular cues to judge depth, and thus might perform better than in the Waqar experiment. Sachdeva and Traboulsi (2011) on the other hand, examined subjects with a lifelong deficiency or complete absence of stereo-acuity and found them performing consistently worse than normal controls. However, they did not distinguish between individuals with reduced and absent stereo. They also included subjects with causes of stereoacuity deficit such as complete unilateral blindness and nystagmus; such

situations obviously introduce confounding factors. Moreover, looking at the improvement of performance scores between consecutive attempts, their study showed no difference between the study and control groups.

Another report in 2015, by Nibourg and colleagues, evaluated the time needed for stereo-sufficient and stereo-deficient groups to perform a microsurgical task on the EYESi simulator and a bead stringing task under an operating microscope. The subjects with sufficient stereoacuity performed both surgical tasks faster than the stereo-deficient subjects. Nevertheless, their criterion of a stereo-sufficient group to achieve 240 seconds of arc or better (assessed with the TNO stereo test) included subjects with normal and reduced stereoacuity. Therefore, it remains unclear if subjects with reduced stereoacuity (i.e. between 240 and 60 seconds) would perform similar to or worse than subjects with normal stereoacuity (60 seconds or better).

2.2: Purpose of the Study

There remains a lack of evidence about what level of stereopsis is necessary for a surgical career. This study proposes to examine more closely the possible relationship between the levels of stereoacuity and performance in ophthalmic surgery by applying strict inclusion and exclusion criteria of the participating subjects. This will include individuals with normal and various levels of subnormal stereoacuity, as well as stereo-blind subjects.

The aim of this study is to examine the relationship between the level of stereoacuity and microsurgical performance in ophthalmic surgery. Selvander and Åsman (2011) reported that intraocular surgical performance correlated with

stereoacuity level, with a decrease in performance appearing with minor stereoacuity defects. The effect on surgical performance became more pronounced as stereoacuity worsened. In light of their findings, we expect subjects with reduced stereoacuity to do poorly initially in the simulated surgical task.

2.3: Hypothesis

It is unclear what level of stereoacuity is necessary to achieve normal levels of surgical performance. We hypothesized that there is a statistically significant difference in surgical performance between individuals with normal and abnormal stereopsis. We expect the performance of individuals with normal stereopsis to be better (i.e. higher total score and less injury to the surrounding tissues) and faster (i.e. smaller odometer values and shorter time) than those with deficient stereopsis of any level, including its complete absence. We set out to test this hypothesis using the VRMagic EYESi Ophthalmic surgical Simulator.

2.3.1: Null Hypothesis

In this study, the null hypothesis was that there would not be a statistically significant difference in the surgical performance scores on the EYESi surgical simulator among the different stereo-groups.

2.4: Research Questions

1. Is microsurgical performance of subjects with reduced stereopsis similar or worse than those with normal stereopsis?
2. Does better stereoacuity correlate with better surgical dexterity?

3. What is the minimum level of stereoacuity (threshold) required for microsurgical performance comparable to that which is achieved with normal stereopsis?

Chapter III

Methodology

3.1: Research Design

This study is a quasi-experimental trial with three groups. Subjects were assigned based on their stereoacuity level into three groups: stereo-blind (SB), reduced stereopsis (SR), and normal stereopsis (SN).

3.1.1: Rationale for the chosen methods

For a research to be deemed experimental, it has to involve randomization, a control group and manipulation of the independent variable (Depoy & Gitlin, 1998). Because subjects in this study could not be randomly assigned to normal, reduced, or absent stereoacuity groups, the design is not a true experiment. To mitigate against this limitation, subjects were matched for age in all the three groups in order to make the groups as homogenous as possible. A control group with normal stereoacuity was included and manipulation of the independent variable by including participants of any level of stereoacuity was used in order to fulfill two of the three requirements of a true experimental design.

3.2: Study Sample

A total of 33 participants were recruited into this study; 11 participants in the reduced stereopsis group, 11 participants in the stereo-blind group and 11 controls with normal stereoacuity.

Subjects were matched for age in all the groups and their age had to fall within the range between 10-65 years. Age matching means that the age of any participant in a group was within one year of the matched subjects in the other groups. The decision of age matching was made in order to control for the effect of age on the development of fine motor skills. Moreover, subjects under the age of 10 were excluded from the current study because the immature prehensile movements of children in their first decade of life differ from those of adults, (Kuhtz-Buschbeck *et al.*, 1998; Smyth *et al*., 2004). Adults older than 65 years were also excluded since their motor skills have been shown to be slower and less accurate compared to young adults (Voelcker-Rehage, 2008).

We chose not to match the participants of this study for sex because previous studies have shown no statistically significant difference in surgical performance of men and women on The EYESi microsurgical simulator (Sachdeva & Traboulsi, 2011; Selvander & Åsman, 2011). We also decided not to match the participants for handedness based on the systematic review of Louridas *et al.* (2016) to predict surgical trainees' future technical aptitude that failed to identify a significant association between handedness and surgical performance.

3.2.1: Sample size determination

The IWK research consulting scientist, Dr. Jill Hatchette, had been consulted specifically with regards to an acceptable sample size. The results from Murdoch *et al*. study (1991) were used to calculate sample size. The mean scores of their normal and reduced stereoacuity groups were used for calculation (alpha level of 0.05 and 80%

power). A group size of ten (10 subjects per group) was estimated to be sufficient to detect performance differences (total of 30 subjects). However, because previous studies did not use the same inclusion and exclusion criteria as the present study, there is some uncertainty about this estimate.

3.2.2: Inclusion criteria

The inclusion criteria for each group are as follow:

Inclusion criteria – normal stereopsis group (SN)

- Stereoacuity of 60 seconds of arc or better on Original Randot stereotest
- Best-corrected distance visual acuity of 6/12 or better in each eye on the ETDRS chart

Inclusion criteria – reduced stereopsis group (SR)

- Measurable stereoacuity by Randot or Titmus stereotest but worse than 60 seconds of arc on Randot
- Best-corrected visual acuity of 6/12 or better in at least one eye and with both eyes open

Inclusion criteria – stereo-blind group (SB)

- No measurable stereoacuity by Randot and Titmus stereotest
- Best-corrected visual acuity of 6/12 or better in at least one eye and with both eyes open

A stereo-acuity of 60 seconds of arc or better represents a bi-foveal binocularity (Parks, 1968) and is unachievable in microtropic patients. Reduced and absent stereopsis in the SR and SB groups was confirmed by ocular history to be longstanding

and not recently acquired. Visual acuity of 6/12 or better is typically considered normal vision by North American standards (Maberley et al., 2006) and is the minimal vision necessary to achieve a stereoacuity score of 60 seconds of arc (Donzis, Rappazzo, Burde, & Gordon, 1983), thus it is chosen here as the cutoff. No acuity criteria were set for the other, potentially poorer-seeing eye, because it is often reduced in those with deficient or absent stereoacuity and that visual acuity of the better seeing eye predicts VA under binocular conditions. Additionally, binocular visual acuity will be tested to confirm the presence of good vision when both eyes are open.

3.2.3: Exclusion Criteria – for the three groups

Patients were excluded based on the following criteria:

- Any diplopia
- Nystagmus
- Any ocular movement limitation or abnormality
- Presence of ocular disease such as glaucoma, cataract, uveitis, retinal disease, or any optically uncorrectable accommodative defect
- Recent intraocular or periocular surgery (within the preceding 60 days)
- Presence of neurological illness or tremor
- Presence of movement disorder
- Presence of musculoskeletal disorder or injury
- Inability to sit at the simulator equipment
- Inability to complete the pre-test familiarization task
- Prior microsurgical experience

- Age younger than 10 years or older than 65 years
- Lack of self-consent ability

All inclusion and exclusion criteria were confirmed after the individual gave informed consent, but before performing the simulated surgical task. Participants were screened for some of the exclusion criteria via a participant self-questionnaire (Appendix A) by asking them to indicate if the answer is "yes" to any of a series of screening questions. They were not required to specify which item(s) made them ineligible. To confirm the absence of the remaining exclusion criteria, a full orthoptic evaluation was performed.

Subjects were also asked to complete the Waterloo Handedness Questionnaire (Appendix B) to determine their dominant hand in preparation for the surgical simulation task.

In addition, subjects were asked if they play videogames and the number of hours they spend playing videogames per week. This information was considered as a covariate in the analysis of the collected data as several studies showed that previous video gaming experience is associated with higher baseline performance in laparoscopic simulator surgical skills (Chalhoub *et al.*, 2016; Louridas *et al.*, 2016).

3.2.4: Recruitment of Subjects

Two methods of recruitment were employed: (i) screening of potential subjects from the patient population of the Eye Clinic, IWK Health Centre and (ii) verbal networking. Staff orthoptists at the IWK Health Centre Eye Care Clinic in Halifax, Nova

Scotia were informed about the study and given a list of the study's inclusion and exclusion criteria to seek for potential subjects in their patient population. In addition, lists of booked patients in the orthoptic and eye clinics were screened by the principal investigator one month in advance for potential participants. Identification of suitable participants did not require any additional testing during the patient's regularly scheduled examination. Patients who meet the criteria were invited to participate in the study by sending them a letter containing information about the study and the informed consent earlier before their next scheduled appointment. They were later contacted by phone one day before their appointment and if they expressed interest to participate, the principal investigator arranged to meet them and recruit them at the same day of their scheduled appointment.

Friends and colleagues recruited through verbal networking were informed of the study and asked to contact the principal investigator if they expressed interest in participating.

3.3: Experimental Procedure

3.3.1: Orthoptic Evaluation

All participants underwent full orthoptic evaluation performed by a certified orthoptist prior to the simulated surgical task. The evaluation included distance and near visual acuity testing using the Good-Lite ETDRS visual acuity chart and Sloan letter near vision card (Good Lite, Elgin, IL, USA) as well as the assessment of ocular alignment by cover test. If ocular deviation was observed, it was quantified using alternate prism

cover test and if the measured deviation was greater than 10 prism diopters, a simultaneous prism cover test was performed too. All participants were confirmed to have full extraocular movement by testing their motility following a muscle light in both the horizontal and vertical directions.

Stereoacuity Testing: Stereoacuity was quantified using four tests; The "Original" Randot® stereotest (SO-006, Stereo Optical, Chicago, IL, USA), previously known as Randot® Special Edition (fig. 3-1A), is in a booklet format and presents a distribution of random dots constructed using vectographic material with polarized spectacles. The tasks include shape recognition, and forced choice animal and circle tasks. The 8 sets of circles range in disparity from 400 to 20 seconds of arc. They are arranged in a diamond pattern with four potential choices, similar to the Titmus stereotest, but are completely constructed with random dots. The test is concluded when the subject can no longer note any "depth" to the target or the subject makes two consecutive errors. This stereo test was chosen because it has been proven to have minimal monocular clues (Hahn *et al*., 2010) and because of the optical dissociation of binocular viewing caused by the polarized glasses. These are dichoptic viewing conditions, as are those of the EYESi surgical simulation system used in this study. Subjects unable to correctly identify the circle with largest disparity (400 seconds of arc) will be asked to identify at least four of the five stereoscopic shapes in the same test (600 seconds of arc). The criteria of identifying four of the five shapes for a positive response was chosen based on the findings of Hahn *et al*. (2010) that this section has an absolute value of binocular

stereopsis of 600 seconds i.e. could not be obtained monocularly, if 4 out of 5 are achieved.

Subjects' stereoacuity was also assessed using the "Original" Stereo Fly stereotest (SO-001, Stereo Optical, Chicago, IL, USA) commonly known as Titmus stereotest (fig. 3-1B). The test involves a vectograph card in booklet form and a pair of polarized glasses that dissociate the eyes optically. Presented in the booklet are contoured stereoscopic patterns representing a housefly (3552 seconds of arc), three rows of animals (400 to 100 seconds of arc), and nine sets of four circles arranged in a diamond (800 to 40 seconds of arc). The Titmus test was used carefully in this study because the animal and circle targets could induce false responses due to the monocular clues of the test (Archer, 1988; Clarke & Noel, 1990; Hahn *et al*., 2010). To further confirm that a positive response to the fly is not one of monocular clues, the horizontal disparity is eliminated by turning the plate 90 degrees and by asking the subject to report on the apparent change. To confirm that circles are seen stereoscopically, participants are asked if the chosen circle is displaced upward or laterally instead of being seen in depth. This Stereotest was chosen despite the presence of monocular clues because it is the most widely used stereotest to qualify applicants to particular professions with stereovision requirements. In addition, this test allows the examiner to detect gross stereopsis as it measures as low as 3000 seconds of arc while performing Randot stereotest alone would have limited the additional information gained by stereoacuity testing with larger threshold measures.

Because the two aforementioned stereotests are near tests while the microscopic viewing system in the EYESi surgical simulation is optically set for distance in order to keep the accommodation of the operating surgeon relaxed, we decided to perform one additional distance stereotest in order to confirm the presence of stereopsis at distance in participants with detectable stereopsis. We opted to test for distance stereoacuity using the DISTANCE Randot test® (SO-015, Stereo Optical, Chicago, IL, USA). This is a Polaroid vectographic random dot test designed to evaluate four levels of disparity (400, 200, 100 and 60 seconds of arc). It is composed of one book containing shapes; circle, triangle, square, and star, two shapes at each of the four disparities viewed using polaroid glasses at distance fixation of 3 meters (fig. 3-1C). At each disparity level the subject must correctly identify both of the two test shapes. The smallest disparity at which the subject is able to identify both of the two shapes is recorded as the stereoacuity at distance.

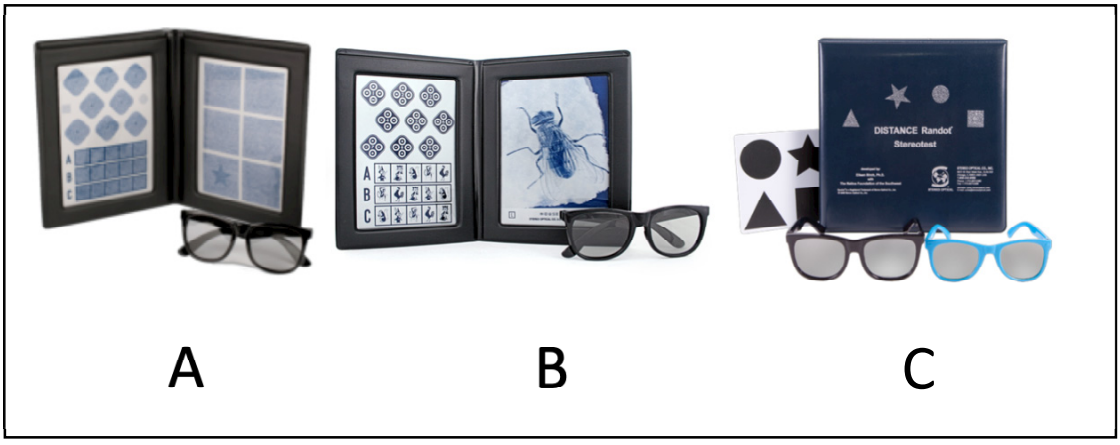


Figure 3- 1: The stereotests used in this experiment; A- Original Randot®stereotest (SO-006), B- Original Stereo Fly stereotest (SO-001), C- DISTANCE Randot test® (SO-015).
From Stereo Optical, Chicago, IL, USA, 2018 (https://www.stereooptical.com/products/stereotests-color-tests/). Copyright [2018] by Stereo Optical Company Inc.

Subjects with evidence of stereovision were further assessed on synoptophore® (Haag-Streit, Harlow, UK) using the stereo slide (fig.3-2) in order to confirm the presence of stereovision under dichoptic conditions similar to those of the EYESi surgical simulator. This viewing condition is completely dissociative and any participant who becomes diplopic in the synoptophore would be excluded from the study. Both the horizontal and vertical angles in addition to torsional controls in the synoptophore were set at zero, i.e. not correcting any ocular misalignment, when testing the subjects' stereovision using the synoptophore.

Only the stereoacuity scores from Randot and Titmus stereotests were used for the inclusion criteria because those are the tests commonly available at the optometrist/ophthalmologist's office. They are the ones more likely to be used to examine the stereoacuity of the potential candidates to residency training programs in ophthalmology. Whereas the synoptophore and distance Randot stereotest are usually only available at an orthoptic clinic. In addition, Randot and Titmus stereotests are the stereotests most commonly used in the previous reported literature making it more consistent to compare our results to those previous studies.

Worth4Dot test (Lombart Instrument, Norfolk, VA, USA) and Bagolini striated lenses (Good Lite, Elgin, IL, USA) were conducted as well to further confirm the subjects' binocular sensory status and to rule out any participants with diplopia.

Figure 3- 2: The Synoptophore Stereo-slide used in this experiment

3.3.2: Pre-test Familiarization Session

In order to confirm good manual dexterity and to familiarize participants with the surgical task they are about to perform, an artificial eye (Phillips Studios, Bristol, UK) was used. The primary investigator created a tiny opening on the side of the eye at the level of the limbus and inserted five rubber spheres inside the artificial eye. The artificial eye was provided to the participants together with a small probe-like instrument (fig.3-3) and were asked to perform a task similar to the one to be performed in the EYESi surgical simulator with both eyes open and without magnification. In this task, the participant was asked to touch five objects placed at different depths by the tip of the instrument inserted inside the artificial eye. The task is completed when all the five objects were touched and a maximum time of 5 minutes was given to achieve this goal. An instructional video was shown to the participants before conducting the task. This

session also allowed the investigators to assess if participants are capable to efficiently and cautiously handle the instrument used inside the model eye of the EYESi. The familiarity session was standardized, and performed without any dichoptically dissociating optical device or magnification. This session was done at the same day immediately before the surgical simulation task.

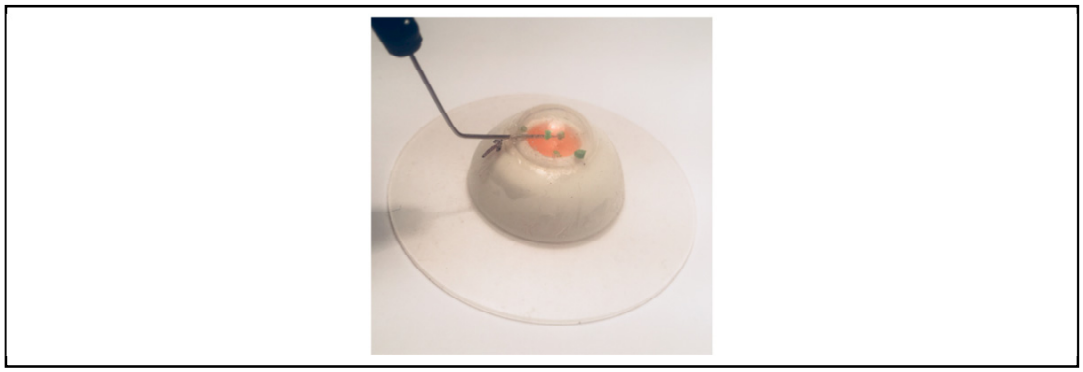


Figure 3- 3: The Pre-test Familiarization Session

3.3.3: Surgical Simulator Task

The EYESi ophthalmic surgical simulator (VRmagic, Mannheim, Germany) available at the Simulation Laboratory of the Departments of Surgery and Ophthalmology, Dalhousie University was used (fig.3-4 A). This simulator provides both cataract and vitreoretinal surgery simulations in a three-dimensional virtual environment. It consists of a model head mounted under a microscope that provides a virtual stereoscopic view of an eye lying under the operating microscope. Probes inserted into the electronic eye can virtually emulate different intraocular instruments. The simulator is loaded with various modules such as anti-tremor, grasping forceps, capsulorhexis and phacoemulsification. Each module has several levels of proficiency.

Each module is reproducible, providing identical tasks and objective measures of performance.

The Navigation training module was used in this experiment. The size, shape and anteroposterior location of objects visualized within the anterior chamber vary according to the module's difficulty level (ranging from one to three). Level two was used in this experiment. Spheres in this level vary in size and depth within the anterior chamber. During the task, subjects manipulated a handheld probe, controlled by the subject's dominant hand, with its tip inserted into the anterior segment of the artificial eye. Subjects used the handheld probe to touch twelve target spheres of variable size (0.4 – 0.6 mm) lying at different depths in the anterior chamber. The challenge was to be able to efficiently maneuver the tip of the probe in the anterior chamber and hold it still in each sphere until the sphere turned green. The task was completed when all the red spheres were turned to green (Fig. 3-4 B)

At the end of each task, the simulator generates a performance summary with a total possible score that can vary from 0 to 100. The simulator awards positive points for the percentage of the task completed. It then subtracts from this for reduced efficiency and errors such as excessive time taken, corneal injuries, lens injuries, distance travelled by the instrument within the anterior chamber (odometer), operating without red reflex (movements of the eye), non-horizontal insertion of the instrument and out-of-focus interactions. These scores correlate with the experience of intraocular surgery indicating construct validity (Solverson *et al.*, 2009; Selvander & Åsman, 2011).

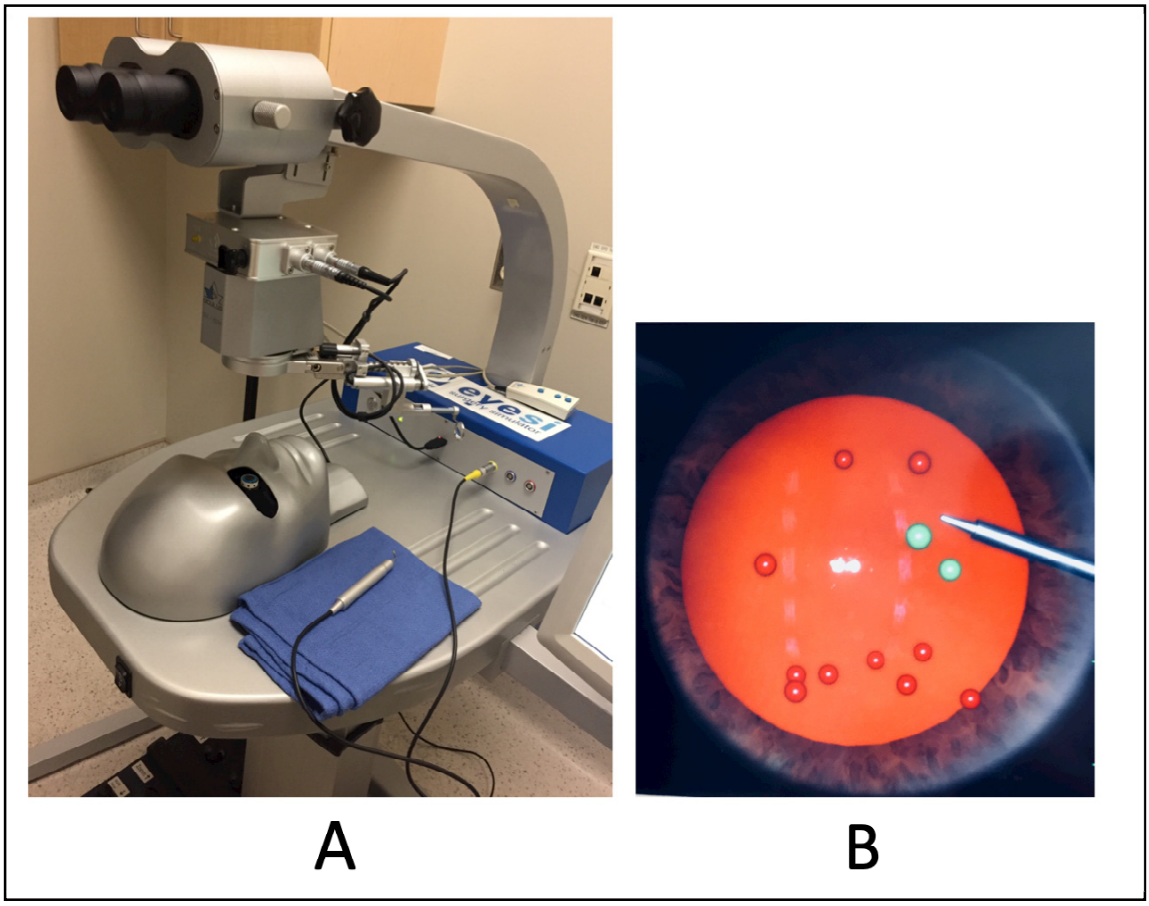


Figure 3- 4: A- The EYESi surgical simulator used in this study, B- Navigation training module (level 2)

Each subject received a basic orientation in machine setup including microscope adjustment, focusing, seating and positioning by the principal investigator. Participants who needed glasses to correct their vision were wearing their glasses for the surgical simulator task. An instructional video incorporated in the simulator system was shown before conducting the assigned task. Subjects were also given a familiarization period of 5 minutes on the EYESi in which they were asked to perform one attempt on the same level of the navigation module in order to become familiar with the task and instrument

handling to minimize the effect of initial improvement in novice participants. Scores of this attempt were not recorded.

Subjects were given up to 5 minutes to attempt the completion of one trial. Three consecutive trials were conducted with 1-minute rest between trials. It has been shown in previous studies that improvement in scores of novice participants reached a relative plateau around the third iteration and started to decrease after the fifth iterations (Solverson *et al.*, 2009; Selvander & Åsman, 2011) that could be attributed to increased fatigue, hence the decision of three trials in addition to the initial unscored familiarization trial. The time limit of maximum 5 minutes per trial was chosen based on the findings of Selvander and Åsman study (2011) in which they used the same navigation module but a more difficult level (level three), the majority of their inexperienced participants were able to complete the task in less than 5 minutes (range 1-7 minutes).

During the rest period, all subjects were asked to put their hands and eyes off the simulator, stand up and walk few steps while doing relaxing finger movements (flexions, extensions and finger joining in rapid successions with moments of immobility).

Subjects were asked whether they see the microscopic view stereoscopically or flat after the adjustment of the microscope and before starting the familiarization session on the EYESi and again at the end of each trial and their response was noted. A flat response means that the participant is suppressing and has lost stereoscopic vision.

The primary investigator also watched their live performance on the simulator's monitor and any utilization of monocular clues was noted.

3.3.4: Outcomes Parameters

The parameters recorded for each attempt were: total score, total time, corneal area injured, lens area injured and odometer measurement.

3.4: Ethical Consideration

Prior to the initiation of this study, ethical review was sought from the IWK Health Centre Research Ethical Board (REB) (Appendix C). Free and informed consent was obtained from all participants by the principal investigator. All subjects did have an opportunity to review the consent form and ask any questions concerning the study. Once written authorization was obtained, subjects were enrolled in the study. They had the free ability to decide not to take part in the study and to withdraw from the study at any time. They were assured that this will not affect the care they receive from the IWK Health Centre in any way.

With minimal if any physical risks to participants in this study, the main ethical consideration was maintenance of participant anonymity. Each participant was informed that the data collected will be reported anonymously. Raw data and results are not identifiable to any particular participant. All participant identification codes and records were on secured electronic files in a locked office. Only the primary investigator (Hanouf Alkharashi) and supervisor (Dr. R. LaRoche) have access to these records.

Fatigue was another consideration in this study since the total time to complete all the tasks was estimated to be two hours. Participants were required to be attentive during the surgical task. To combat potential fatigue, participants were offered breaks during testing and the option to complete the surgical simulation task in another visit.

3.4.1: Harms

All of the tests for this research project have been demonstrated to be safe and are used routinely in the clinical setting of an ocular motility clinic. They are part of the standard of care in Canada. No medicines or eye drops were used. There were no expected harms from participation. There was no anticipated risks due to the non-invasive nature of the tests and tasks.

3.4.2: Benefits

Participating in this study gave an opportunity to naive participants to explore ocular microsurgery. Participant with a potential interest in a career in microsurgery further explore this interest.

Knowledge gained from this study will help to better understand how people with reduced and no stereopsis function for certain fine motor tasks. The importance of stereopsis for intraocular surgery is difficult to ascertain in a live theatre operative settings without compromising patient safety. Virtual reality simulation is a safe alternative. This study may help to determine if there is a necessity to specify a certain level of stereoacuity requirements for admission to ophthalmology residency program. Moreover, knowing a critical threshold of stereoacuity that is needed for microsurgical efficiency would help better counsel potentially good surgeons with subnormal

stereopsis. This is also useful to individuals with little or no stereopsis who want to know how their condition can affect their career options.

3.5: Statistical Analysis

For each dependent outcome, mixed factorial analysis of covariance (ANCOVA) was used with the following factors: (1) repeated measures factor of trials (T_1, T_2, T_3), and (2) between-subjects' variables (groups: SN, SR, SB) and (3) covarying for the participant's age and the number of hours per week of video gaming. Significance was based on an alpha level of 0.05. Data analysis was performed using SPSS Statistics (v25, IBM).

Chapter IV

Results

A total of thirty-three (33) participants were enrolled in this study; 11 participants in each group. Participants were within one year of age difference with their matched subjects in the other groups. The mean age of participants was 24.6 years, with a range of 13 to 42 years. There were 26 females and 7 males. Of the 33 participants, only three were left handed (2 stereo-blinds and 1 with normal stereoacuity).

Binocular best-corrected visual acuity in all participants was 6/6 except for one who had 6/7.5. All of the participants in the SN group had a stereoacuity of 20 seconds of arc on the Original Randot stereotest. None in the SB group had any measurable stereoacuity and all had suppression at distance and near. Stereoacuity in the SR group and the main orthoptic clinical findings in the three groups are summarized below in table 4.1. No subjects were excluded due to diplopia experienced on synoptophore, Worth4Dot or Bagolini.

For the dependent variables in the form of the EYESi simulator outcomes, mixed factorial ANCOVA analysis was used for each outcome considering the following:

- repeated measures analysis for within-subjects variables (Trials: T1, T2, T3)
- between-subjects factor (stereo-groups: SN, SR, SB)
- covariates: assigned to be age of participant and the number of hours/week of video gaming

P-value less than 0.05 was considered statistically significant. The EYESi outcomes for all participants are summarized in table 4.2.

CODE	Age (yrs)	Sex	Near Randot	Titmus	Synoptophore	Distance Randot	RVA (6/)	LVA (6/)	VA BEO (6/)	Diagnosis
Stereo-blind Group (SB)										
SB1	24	M	0	0	—	0	6	12	6	Residual consecutive XT, Basic Type
SB2	33	F	0	0	—	0	6	7.5	6	Consecutive XT, basic type, H/O infantile ET
SB3	26	F	0	0	—	0	6	12	6	Residual consecutive XT, basic type, Left hypertrpia, DVD, anispmetropia
SB4	14	F	0	0	—	0	6	6	6	Residual ET, basic type, A-pattern
SB5	41	F	0	0	—	0	6	6	6	Residual ET, basic type, Right hypertropia
SB6	33	F	0	0	—	0	7.5	6	6	Consecutive XT, basic type, RhypoT
SB7	23	F	0	0	—	0	7.5	6	6	Consecutive XT, basic type, RhypoT
SB8	13	F	0	0	—	0	CF	6	6	Right Hypertropia, microcornea RE
SB9	30	M	0	0	—	0	6	7.5	6	Residual XT, basic type
SB10	16	F	0	0	—	0	7.5	6	6	Partially accommodative ET, basic type
SB11	16	F	0	0	—	0	4.8	48	6	XT, basic type, Left Hypertropia, amblyopia LE
Reduced Stereo Group (SR)										
SR1	24	F	200	200	0	100	6	6	6	Residual ET at 6m, X at 1/3m, Myopia OU
SR2	32	F	400	50	Partial	200	6	6	6	Residual E, convergence excess, microstrabismus RE, Myopi OU
SR3	25	F	200	140	0	200	6	6	6	Small E, basic type, microstrabismus
SR4	15	F	600	400	Partial	0	6	6	6	Residual ET, basic type, microstrabismus RE
SR5	41	F	0	800	Partial	0	9.6	6	6	Partially accommodative ET, basic type, microtropia RE
SR6	32	M	0	400	complete	0	7.5	6	6	ET, basic type, microtropia RE
SR7	25	M	600	50	Partial	0	6	7.5	6	Exophoria, basic type, microstrabismus LE, anisometropia
SR8	14	F	400	50	0	100	6	6	6	Congenital CN IV RE, X (T), basic type with good control, asymptomatic.
SR9	30	M	0	200	Partial	0	9.6	15	7.5	Consecutive E, basic type, left hyperphoria, Myopia OU, H/O X(T)
SR10	16	F	0	3552	0	0	6	15	6	Partially accommodative ET, consecutive XT to hyperopic Rx at 6m
SR11	17	M	400	400	0	400	7.5	6	6	X(T) basic type with good control
Normal Stereo Group (SN)										
SN1	25	F	20	40	complete	60	6	6	6	orthophoria
SN2	32	F	20	40	complete	60	6	7.5	6	orthophoria
SN3	26	F	20	40	complete	100	6	7.5	6	orthophoria
SN4	15	F	20	50	complete	60	6	7.5	6	Residual esophoria, basic type
SN5	42	F	20	40	complete	100	6	6	6	orthophoria
SN6	33	F	20	40	complete	60	6	6	6	orthophoria
SN7	23	F	20	40	complete	60	6	6	6	orthophoria
SN8	14	F	20	40	complete	60	6	6	6	orthophoria
SN9	30	F	20	40	complete	60	6	6	6	orthophoria
SN10	16	F	20	40	complete	60	6	6	6	orthophoria
SN11	17	M	20	40	complete	60	6	6	6	orthophoria

Table 4. 1: *Summary of Orthoptic Findings. All stereoacuity results are in seconds of arc except for synoptophore that was graded as none"0", partial, complete, or was not performed "—". Underlined SR codes are participants who reported sudden loss of stereopsis on EYESi simulator. H/O is short for 'history of'.*

CODE	Score T1	Score T2	Score T3	Time T1	Time T2	Time T3	Odom T1	Odom T2	Odom T3	Cornea T1	Cornea T2	Cornea T3	Lens T1	Lens T2	lens T3	Videogaming (hrs/wk)
Stereo-blind Group (SB)																
SB1	**11**	**62**	**83**	**300**	**181**	**76**	**269**	**166**	**75.4**	**0.63**	**0**	**0**	**0.018**	**0**	**0**	9
SB2	**55**	**63**	**80**	**160**	**105**	**95**	**203**	**109**	**89.7**	**0**	**0**	**0**	**0.93**	**0**	**0**	0
SB3	**30**	**87**	**88**	**96**	**65**	**49.5**	**133**	**91.6**	**74.4**	**1.6**	**0**	**0**	**0**	**0**	**0**	0
SB4	**0**	**83**	**81**	**197**	**60**	**76**	**371**	**63.7**	**72.9**	**8.1**	**0**	**0**	**2.9**	**0**	**0**	1
SB5	**12**	**40**	**48**	**144**	**185**	**138**	**145**	**161**	**147**	**1.7**	**0.29**	**0.086**	**0**	**0**	**0**	0
SB6	**76**	**83**	**64**	**79.7**	**61**	**71**	**88.9**	**78.5**	**110**	**0**	**0**	**0**	**0**	**0**	**0**	0
SB7	**85**	**90**	**66**	**59**	**63.5**	**86.5**	**76.6**	**82.6**	**108**	**0**	**0**	**0**	**0**	**0**	**0**	0
SB8	**52**	**0**	**55**	**198.3**	**299.9**	**141**	**258**	**418**	**185**	**0**	**3.1**	**0**	**0.36**	**0**	**0**	0.5
SB9	**61**	**68**	**82**	**96.7**	**87.3**	**71**	**111**	**98.3**	**81.4**	**0**	**0**	**0**	**0**	**0**	**0.29**	0
SB10	**20**	**50**	**48**	**300**	**217**	**216**	**232**	**181**	**168**	**0.14**	**0**	**0.6**	**0.65**	**0**	**0**	0
SB11	**62**	**72**	**82**	**156**	**102.5**	**95**	**144**	**110**	**90.4**	**0**	**0**	**0**	**0**	**0**	**0**	0
Reduced Stereo Group (SR)																
SR1	**77**	**79**	**80**	**88**	**95**	**84**	**90.4**	**77.3**	**77.3**	**0**	**0**	**0**	**0**	**0**	**0**	0
SR2	**67**	**60**	**77**	**108**	**83**	**98**	**99.2**	**89**	**81**	**0**	**0.51**	**0**	**0**	**0**	**0**	0
SR3	33	35	51	298	123	213	413	139	270	0.51	0.92	0	0.25	0.036	0	0
SR4	**83**	**88**	**91**	**86**	**58**	**67**	**90.2**	**51.2**	**65.9**	**0**	**0**	**0**	**0**	**0**	**0**	9
SR5	78	21	18	105	216	300	81.6	168	173	0	1.1	0	0	1.3	0	0
SR6	29	36	39	171	172	99	174	186	83.9	0.94	0	1.5	0	0	0	1
SR7	**92**	**92**	**85**	**82**	**91**	**97**	**75.6**	**78.4**	**79.7**	**0**	**0**	**0**	**0.036**	**0**	**0**	10
SR8	**75**	**77**	**93**	**86**	**60**	**65.**	**102**	**92.8**	**74**	**0.23**	**0.14**	**0**	**0**	**0**	**0**	4
SR9	**74**	**52**	**83**	**112**	**190**	**103**	**91.1**	**146**	**63.2**	**0**	**0**	**0**	**0**	**0**	**0**	10
SR10	**43**	**37**	**61**	**212**	**137**	**121**	**170**	**136**	**111**	**0**	**0.71**	**0**	**0**	**0**	**0**	1
SR11	74	79	75	74	41	50	106	90.8	90	0	0	0	0	0	0	13
Normal Stereo Group (SN)																
SN1	72	85	92	95	85	51	105	85.00	61.4	0	0	0	0	0	0	2
SN2	0	57	77	145	101	79	240	140	103	2.9	0	0	0	0.036	0	0
SN3	93	98	92	65	46	47	80.2	51.7	52.9	0	0	0	0	0	0	41
SN4	46	53	55	232	173.7	141	252	154	125	0.14	0	0	0	0	0	0
SN5	0	61	54	196	139	146.5	227	116	151	6	0	0	0	0.054	0	4
SN6	42	59	91	180	145	63	178	137	66.4	0.43	0	0	0	0	0	0
SN7	**57**	**76**	**74**	**98.4**	**74**	**68**	**126**	**93.6**	**97.2**	**0**	**0**	**0**	**0**	**0**	**0**	0
SN8	0	66	91	247	168	106	137	102	75.7	3.5	0	0	0	0	0	5
SN9	53	76	85	155	109	104	153	84.2	92.2	0	0	0	0.97	1.1	0	0
SN10	56	57	61	118	136	125	159	127	110	0	0	0	0	0	0	6
SN11	75	58	71	78	135	103.5	86.5	113	116	0	0	0	0	0	0	42

Table 4. 2: *Summary of the EYESi Outcomes. Total Scores were out of a scale of 100 point, time in seconds, odom= odometer in mm, cornea= corneal area injured in mm2, Lens= lens area injured in mm2. T1= first trial, T2=second trial, T3=third trial. Numbers in bold represent participants' scores who used monocular clues during the surgical task as observed by the principal investigator. Underlined SR codes are participants who experienced sudden loss of stereopsis on EYESi*

4.1: Total Score

The total score is a performance score between 0 and 100 calculated by the EYESi. This score is generated based on different performance variables tracked and scored by the simulator such as operating out of focus or without red reflex, non-horizontal instrument insertion and removal, target remaining objects, speed and efficiency of movement, ability to avoid the lens, zonular fibers, iris and cornea.

Mauchly's test of sphericity showed a significant outcome (*W=0.659, p=0.004*) indicating that data have violated the assumption of sphericity. Sphericity refers to the condition where the variances of the differences between all possible pairs of within-subject conditions are equal. Sphericity is an important assumption in repeated measures ANOVA; therefore, appropriate adjustments were made when interpreting repeated measures effect.

There was no statistically significant main effect for repeated trials *[F (1.49, 41.7) = 3.17, p=0.066],* meaning that participants' scores did not differ statistically over trials. However, there was a significant interaction of trials and stereo-group *[F (2.98, .41.7) = 3.31, p=0.03].* This interaction suggests that the performance of some groups did actually change over trials. As illustrated in figure 4.1, the reduced stereo group (SR) started with a high score from the first trial and remained at the same level until the third trial, unlike the stereo-blind (SB) and the stereo-normal (SN) groups that scored lower at first trial and then improved gradually over trials. No other significant interactions were found.

Contrary to our initial prediction, a between-subjects analysis revealed that there was no significant main effect of the stereo-group to which the participants belonged on their scores *[F (2, 28) = 0.21, p=0.81]* (Table 4.3). There were also non-significant main effects of age of participants *[F (1, 28) = 0.62, p=0.44]* nor the frequency of playing videogames *[F (1, 28) = 3.52, p=0.07].*

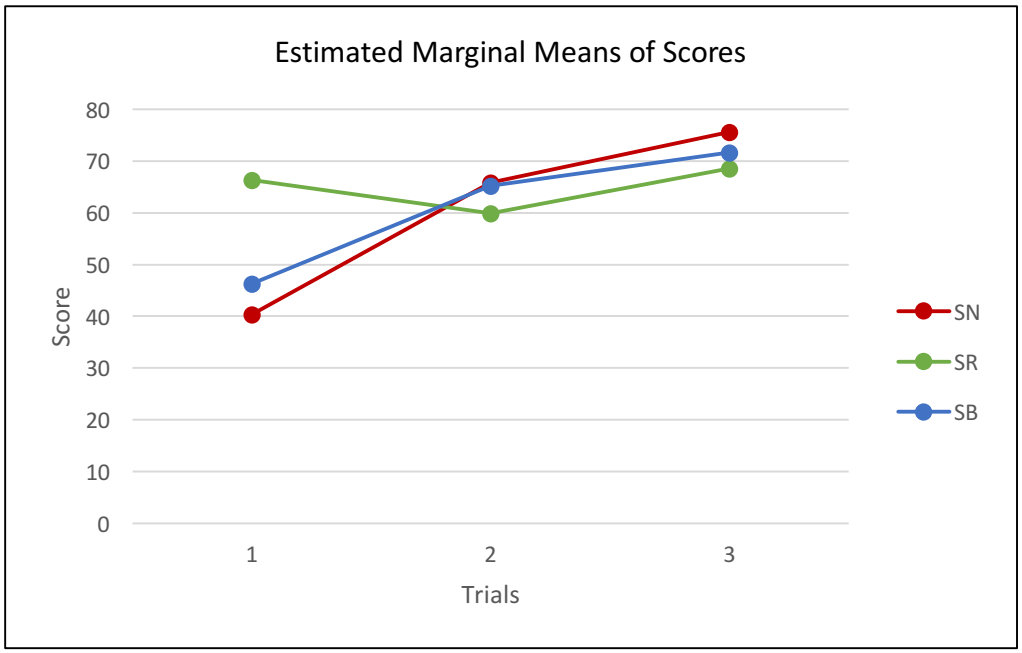


Figure 4. 1: *Linear Plot of EMMean Scores over Trials. A significant interaction was found between trials*group (p<.05). The SR group remained at the same level of scores over trials, unlike the other two groups that scored lower at first and improved over trials. SB: Stereo-blind group, SN: stereo-normal group, SR: stereo-reduced group. EMMeans: Estimated Marginal Means that takes into account covariates and between-subjects variable and are adjusted for repeated measures.*

Group	Mean Scores	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
SB	61.044*	5.355	50.075	72.013
SN	60.568*	5.390	49.527	71.609
SR	64.934*	5.206	54.270	75.598

Table 4. 3: *Mean scores for stereo-groups. (* Covariates appearing in the model are evaluated at the following values: AGE = 24.64, hrs/wk = 4.803.)*

4.2: Time

Mauchly's test was not significant (*W=0.91, p=0.29*) meaning that the condition of sphericity for repeated-measures ANOVA has been met and no corrections were required.

As expected, there was a statistically significant main effect for repeated trials on the time needed to complete the surgical task *[F (2, 56) = 6.66, p=0.003].* The interaction between trials and stereo-group was not statistically significant *[F (4, 56) = 1.23, p=0.31],* meaning that all participants became faster with repeated trials regardless of their stereo-group (figure 4.2).

Again, between-subjects analysis failed to show any significant main effect of the stereo-group on the time needed to complete the task *[F (2, 28) = 0.04, p=0.96] (Table 4.4).* No other significant main effects or interactions were found.

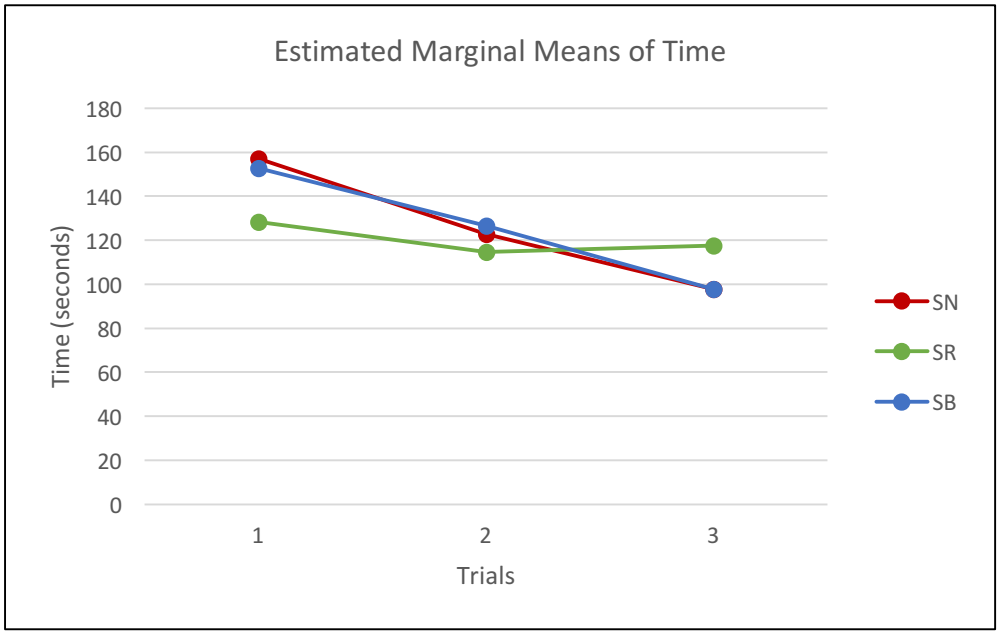


Figure 4. 2: *Linear plot of EMMean time needed to complete the task versus trials. A significant main effect of repeated trials was found meaning that all three groups became faster. Although visually the SR group can look as if there is no improvement, the Trial*Group interaction was not significant.*

Group	Mean Time (secs)	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
SB	125.690*	16.377	92.143	159.236
SN	125.963*	16.485	92.195	159.730
SR	120.135*	15.922	87.520	152.750

Table 4. 4: *Mean time needed to complete the surgical task for each stereo-groups. (* Covariates appearing in the model are evaluated at the following values: AGE = 24.64, hrs/wk = 4.803.)*

4.3: Odometer

Mauchly's test showed a significant outcome (*W=0.767, p=0.028*) indicating a violation of the assumption of sphericity. For that reason, appropriate adjustments were made when interpreting repeated measures effect.

A significant main effect for repeated trials on the probe-travelled distance within the eye was found *[F (1.6, 45.4) = 4.31, p=0.026]* regardless of the stereo-group the participant belonged to as no significant interaction between trials and stereo-group was found *[F (3.2, 45.4) = 0.69, p=0.571]* (figure 4.3).

There was no significant main effect of the stereo-group *[F (2, 28) = 0.45, p=0.64]* from between-subjects analysis. This analysis also showed no significance of age and videogaming. Table 4.5 shows the mean odometer values of the stereo-groups.

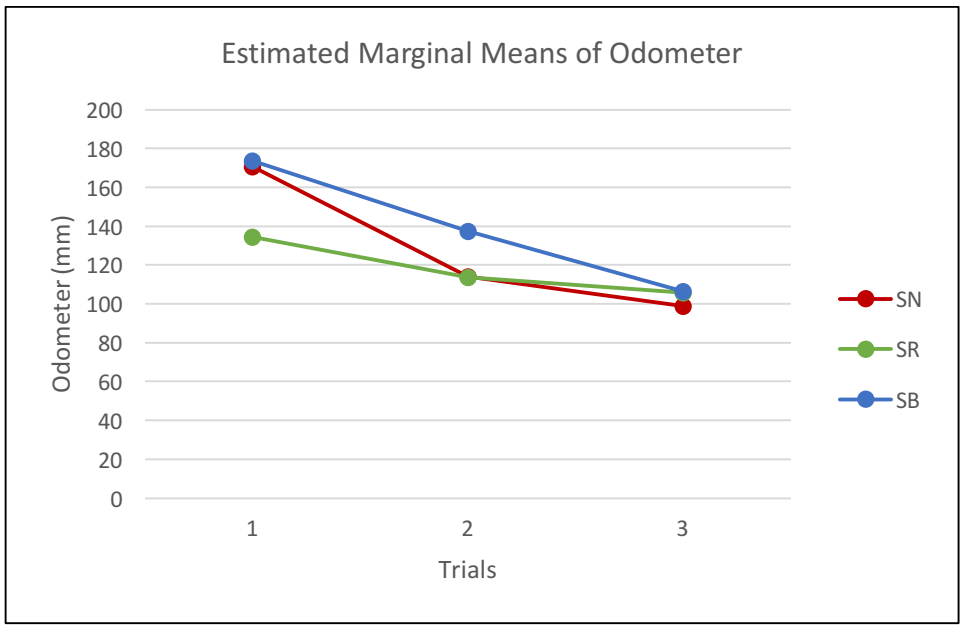


Figure 4. 3: *Linear plot of EMMean odometer over trials. A significant main effect of repeated trials was found regardless of the stereo-group.*

Group	Mean Odometer (mm)	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
SB	139.246*	16.011	106.449	172.042
SN	127.831*	16.116	94.818	160.844
SR	118.014*	15.566	86.128	149.900

Table 4. 5: *Mean odometer values for each stereo-groups. (* Covariates appearing in the model are evaluated at the following values: AGE = 24.64, hrs/wk = 4.803.)*

4.4: Corneal Area Injured

Adjustments were made when interpreting repeated measures effect because Mauchly's test of sphericity was significant (*W=0.315, p=0.000*).

There was no statistically significant main effect for repeated trials *[F (1.2, 33.2) = 0.27, p=0.647]* and no significant interaction between trials and stereo-group *[F (2.4, 33.2) = 1.27, p=0.297].* In other words, the participants performance in term of avoiding

injury to the cornea did not change statistically over trials in all the three stereo-groups (figure 4.4).

Taking between-subjects analysis into account, there was no significant main effect of the stereo-group *[F (2, 28) = 0.56, p=0.57]* or age *[F (1, 28) = 0.14, p=0.90]* or videogaming *[F (1, 28) = 0.85, p=0.36].* Table 4.6 shows the mean values of injured cornea of the three groups.

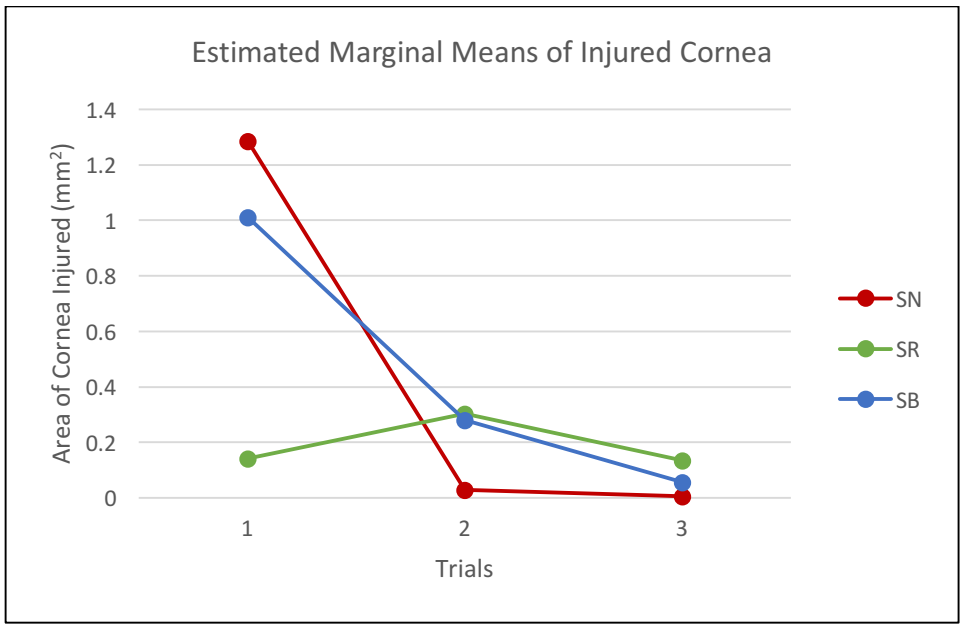


Figure 4. 4: *Linear plot of injured corneal area versus trials. Even though the plot seems to show a difference between the groups or over trials, statistically, there was no significant main effects of stereo-group or repeated trials.*

Group	Mean injured corneal area (mm2)	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
SB	0.450*	0.199	0.043	0.857
SN	0.440*	0.200	0.031	0.850
SR	0.194*	0.193	0.000	0.590

Table 4. 6*: Mean injured corneal area for stereo-groups. (* Covariates appearing in the model are evaluated at the following values: AGE = 24.64, hrs/wk = 4.803.)*

4.5: Lens Area Injured

Mauchly's test of sphericity was significant (*W=0.607, p=0.001*) and appropriate adjustments were made when interpreting repeated measures effect.

Unlike the corneal area injured, there was a statistically significant main effect for repeated trials on participants performance to avoid injuring the lens *[F (1.4, 40.2) = 3.70, p=0.047]* this effect did not differ among stereo-groups since the interaction between trial and groups was not statistically significant *[F (2.9, 40.2) = 1.9, p=0.147]* as illustrated in figure 4.5.

Between-subjects analysis failed to show any significant main effect of the stereo-group *[F (2, 28) = 0.50, p=0.61]* (Table 4.7).

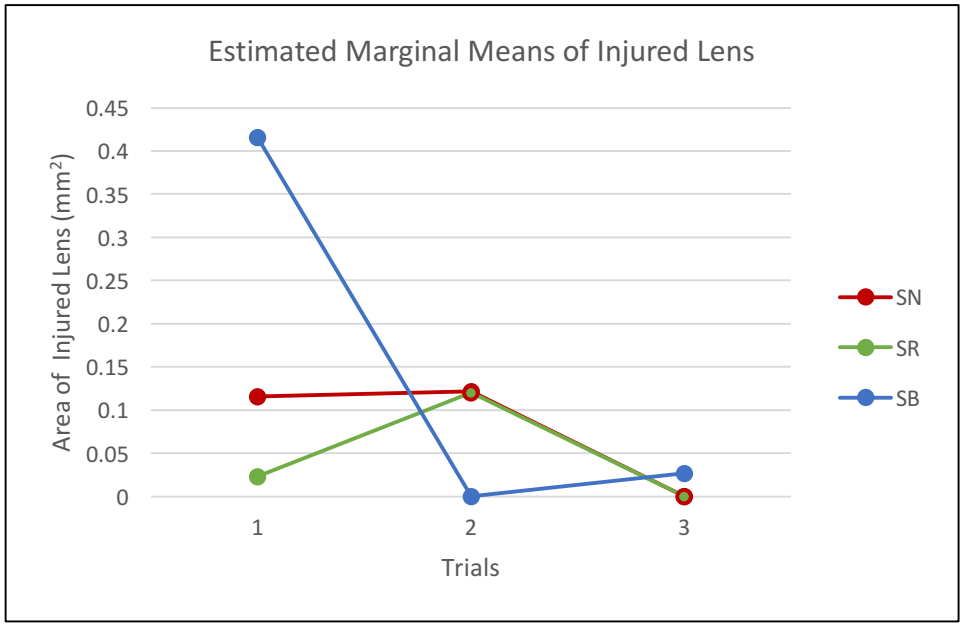


Figure 4. 5*: Linear plot of injured lens area versus trials. Although the SB group in the plot seems to show more improvement in performance, statistically, there was no significant main effects of stereo-group.*

Group	Mean injured Lens area (mm2)	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
SB	0.144*	0.096	0.001	0.286
SN	0.079*	0.070	0.000	0.222
SR	0.048*	0.068	0.000	0.186

Table 4. 7: *Mean injured lens area for stereo-groups. (* Covariates appearing in the model are evaluated at the following values: AGE = 24.64, hrs/wk = 4.803.)*

4.6: The Reduced Stereo Subgroups Comparison

Five out of the eleven participants in the reduced stereo group reported seeing the spheres as flat while performing the surgical task on the EYESi surgical simulator (underlined SR codes in table 4.1 and table 4.2). This suggests that they had lost their stereopsis and suppressed the weaker eye. Those participants either reported seeing the targets initially in depth and then lost that depth perception over trials or reported seeing the targets as flat targets from the beginning. In order to inspect if this sudden loss of stereopsis has had any influence on their surgical performance, we decided to do further analyses using repeated measures ANOVA for the SR group only and assigned two new subgroups as a between-subjects variable, where subgroup A included all SR participants who maintained their stereopsis on the EYESi (6 participants) and subgroup B included the SR participants who lost their stereopsis (5 participants).

Analysis of the interaction between trials and subgroup failed to show any statistical significance in their total score *[F (2, 18) = 1.415, p=0.269]*, the time needed to perform the task *[F (2, 18) = 1.17, p=0.332]*, the odometer *[F (2, 18) = 1.414, p=0.269]*,

or the amount of injury to the cornea *[F (1.1, 10.2) = 0.95, p=0.366]* or the lens *[F (1.1, 9.5) = 1.39, p=0.27].* No significant main effect of the subgroup or trials was detected.

Although there was no statistically significant difference between the two subgroups, there seems to be a trend for the subgroup B to exhibit lower surgical performance as shown in figures 4.6 - 4.9.

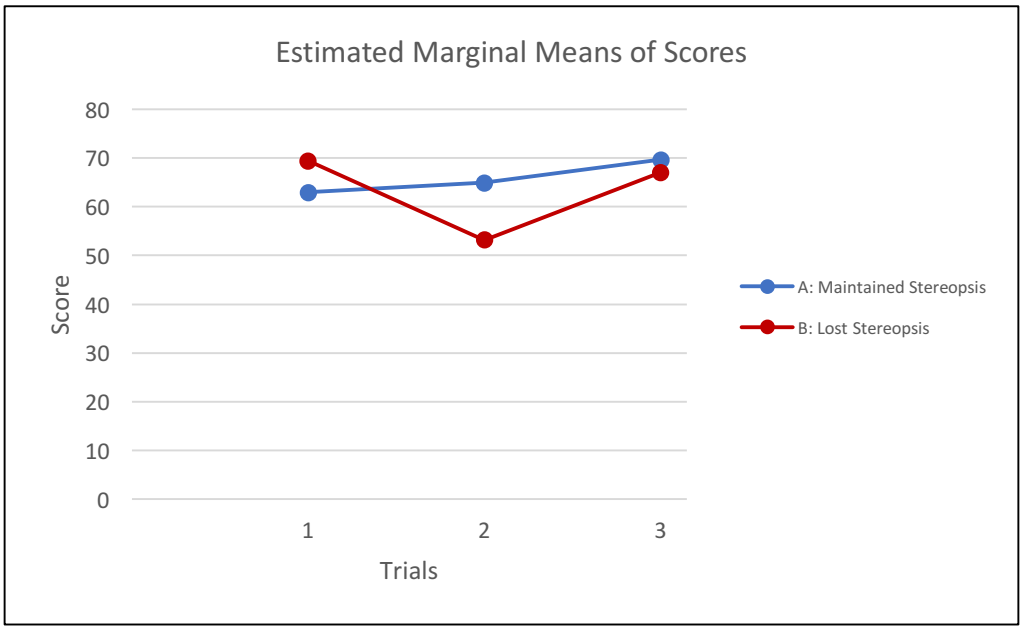


Figure 4. 6: *Linear plot of the scores of the subgroups over trials. Despite not being statistically significant, the plot exhibits a trend of a drop of performance in the second trial of the participants who experienced a sudden loss of stereopsis but were able to regain a high score again in the last trial.*

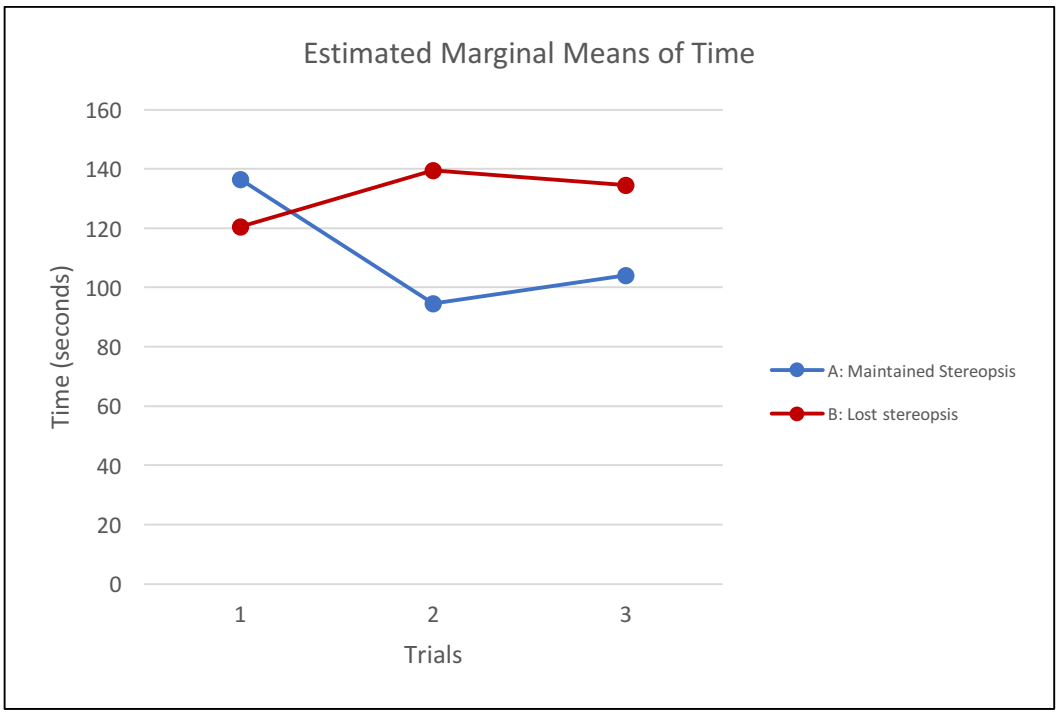


Figure 4. 7*: Linear plot of the time of the subgroups over trials. Although not statistically significant, there appears to be a trend of the subgroup B that lost stereopsis to take longer time to complete the surgical task over trials in contrast to the subgroup A that maintained stereopsis throughout the trials.*

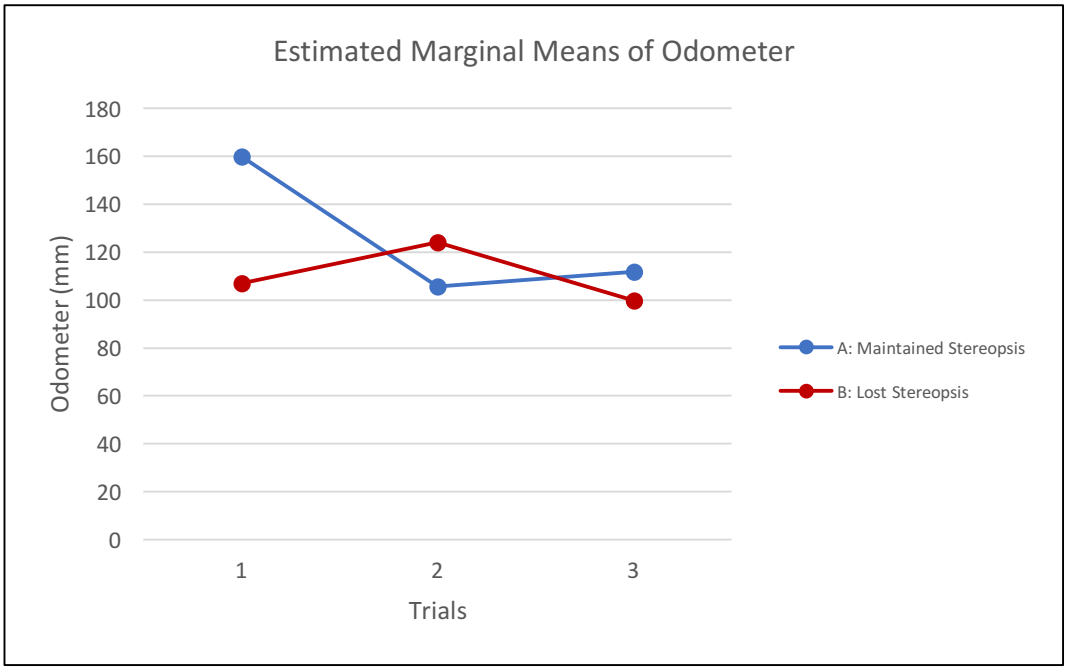
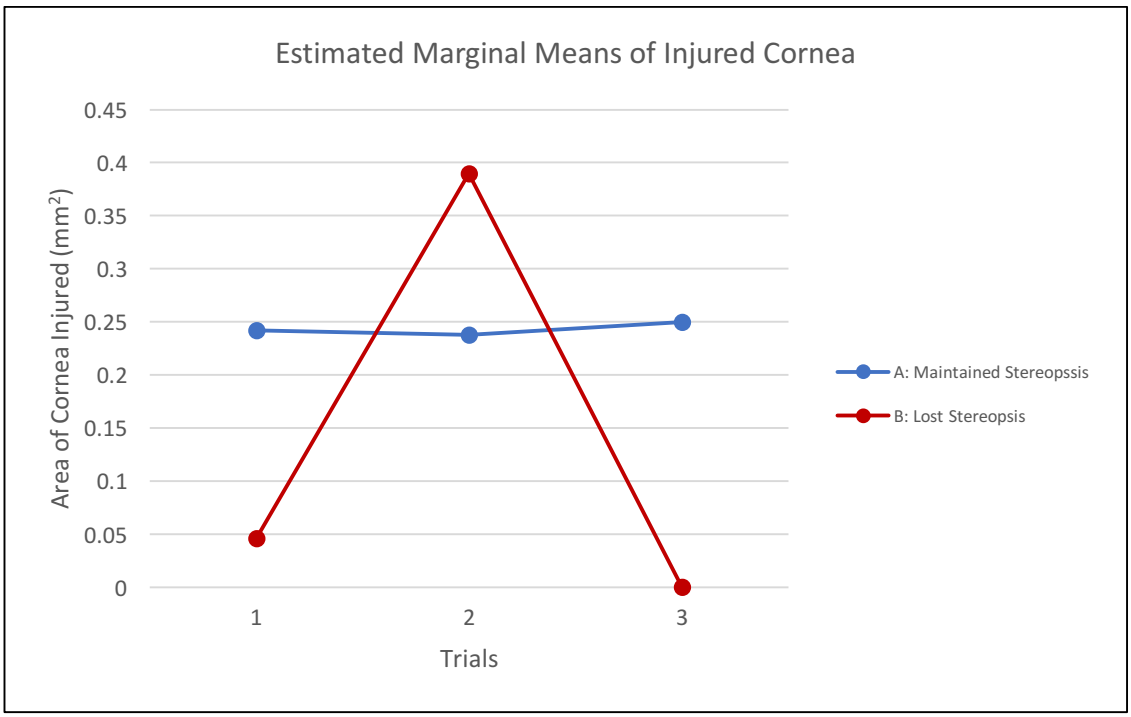


Figure 4. 8*: Linear plot of the odometer of the subgroups over trials. There was a trend, in spite not being statistically significant, of the subgroup A that maintained stereopsis to improve over trials in contrast to the subgroup B.*



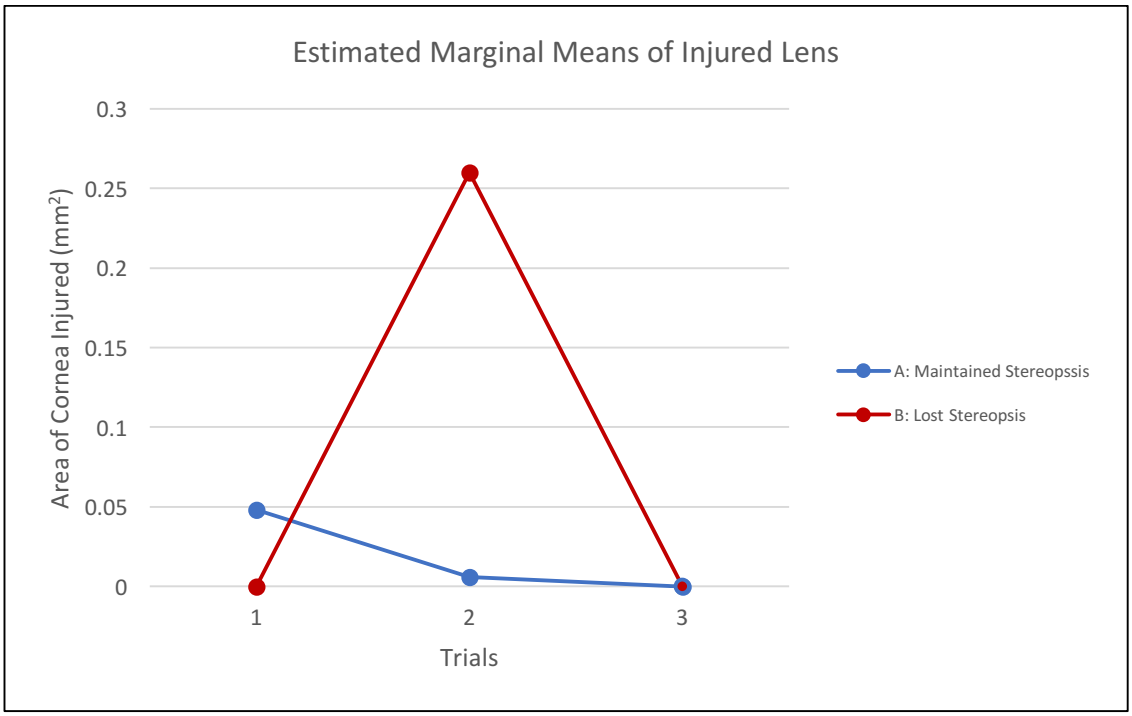


Figure 4. 9: *Linear plot of the injured cornea (top) and injured lens (bottom) of the subgroups. While the difference in performance between the subgroups was not statistically significant, the plot shows a trend of the subgroup B to cause more injuries in the second trial after they lost stereopsis but were able to avoid further injuries in the last trial. In the other hand, the subgroup A appears to maintain a stable performance over trials.*

Chapter V

Discussion

5.1: Summary of Results and Comparative studies

As mentioned in the literature review earlier, there remains a lack of objective evidence on whether stereopsis is necessary for an ophthalmic surgical career. It is unclear if high grade stereoacuity is an indicator of surgical competence. The present study attempted to address this question by comparing the surgical performance of subjects with three different levels of stereoacuity (absent, reduced, and normal) on a microsurgical task using a virtual reality intraocular surgical simulator (EYESi, VRmagic Holding AG, Mannheim, Germany). Overall, this study failed to find any statistical significant difference in the microsurgical performance of the three stereo-groups in terms of total score, time needed, odometer value or the amount of injury to the surrounding tissues.

To our knowledge, this is the first study to look at the microsurgical performance of individuals with reduced stereopsis as a separate group from the stereo-blind and stereo-normal groups. Previous studies in this area have either included those individuals in the deficient stereoacuity group (Sachdeva & Traboulsi, 2011) or in the stereo-sufficient group (Nibourg *et al*, 2015) or were not considered at all (Waqar *et a*l, 2012). This inconsistency with the definition of sufficient or deficient stereopsis has added more uncertainty to the role of stereopsis in microsurgery.

The most striking result to emerge from our data comparison of the three stereo-groups, is that there was no statistical significant effect of the stereo-group that the participants belonged to on their overall simulated microsurgical performance. Our findings were in agreement with the results of Grober and associates (2003) that did not find a significant correlation between stereopsis and microsurgical performance of a suturing task in a group of surgical residents. The results of the current study are also consistent with those of Murdoch and colleagues (1991) in which their reduced stereopsis group performed similarly, but with wider variation, to the controls in an instrument assessing fine manual dexterity.

However, our results differed from the more recently published studies on the same intraocular surgical simulator (EYESi). Selvander and Åsman (2011) reported that the simulator performance score correlated with stereoacuity level on two of three surgical modules used in their study. Their subjects had different level of stereopsis, measured by TNO, but the number of subjects with reduced and absent stereopsis was relatively small (16 out of 70 participants had stereoacuity ranging between 120-480 seconds of arc, 5 participants could not achieve the highest level of 480 seconds of arc). In addition, they found that time with instrument inserted, injured cornea and lens area values did not correlate with the stereoacuity value for any of the surgical modules. These findings are in agreement with ours.

Sachdeva and Traboulsi (2011) reported better performance for individuals with normal stereoacuity than those with deficient stereoacuity. It is worth noting that in their study there were several participants with impaired stereoacuity who actually

performed as well as, or better than, controls. An important difference between our study and their study, however, is that our participants were given time to familiarize themselves with instrument handling and to practice the task prior to data collection. Our participants received a standardized pre-test familiarization session followed by watching an instructional video on the EYESi and finally a practice session on the same level of the navigation training module that was required to perform for the study. All participants of our study and those of Sachdeva and Traboulsi's had no previous surgical experience and were asked to perform a very narrow task in an unfamiliar setting. It seems like the practice period had allowed subjects with impaired stereopsis in the current study to adapt to their condition by learning to exploit monocular cues to depth perception, which may have aided their performance. This could potentially explain why no significant differences were found in the current study.

Although the setting of the surgical simulator has limited the use of some monocular depth clues by constraining the head movements, eliminating shadowing and varying the sphere size, we believe that participants had adopted some strategies to encode the perceived location of the spheres. One strategy that was noted by the principal investigator is utilizing the effect of interposition of the surgical probe and the target sphere for guidance during the microsurgical manipulation. Figure 5.1 displays the approach of subjects who incorporated this monocular cue of interposition to guide them to the exact location of the target sphere. Whenever they missed touching the target sphere, they would keep the probe in the same location and based on how the probe and the sphere were overlapped, they would move the probe either up or down

to touch the sphere. This strategy was noted to be used by all the participants in the SB group and seven participants of the SR group (table 4.2: numbers in bold). None of the participants in the stereo-normal group has employed this strategy except for one participant who was an orthoptic student. The rest of participants with normal stereopsis had a different approach as they moved the probe backward, away from the sphere and tried to reach the sphere again relying on their stereoscopic vision. This poses some questions as to what specific adaptive mechanism are at play and lends itself to further research. Knowing which depth cues individuals with longstanding absent stereoacuity use to perform fine motor tasks could prove useful in the rehabilitation of individuals with a newly acquired loss of stereopsis and also to teach surgeons with deficient stereopsis in residency training programs. Interestingly, the utilization of this adaptive strategy did not cause any statistical significant injury to the surrounding cornea and lens in the current study. Other surgical specialities, however, have to define their margins of errors and whether the use of such monocular cues could cause any potential tissue damage.

The current study also showed that the performance of both the stereo-blind and the stereo-normal groups became better and faster over trials. This finding supports the previous research by Nibourg and colleagues (2015) that showed similar learning curves of their stereo-deficient and stereo-sufficient groups and that stereo-deficiency would not necessarily result in an inability to perform simulated surgical tasks properly.

A somewhat unexpected finding in the current study was that the scores of the reduced stereo-group did not show a similar improvement over trials. Further analysis

of the reduced stereo subgroups, although not reaching statistical significance, did show what seems to be a trend for the subgroup B (which experienced an acute loss of stereopsis on the EYESi) to exhibit lower surgical performance.

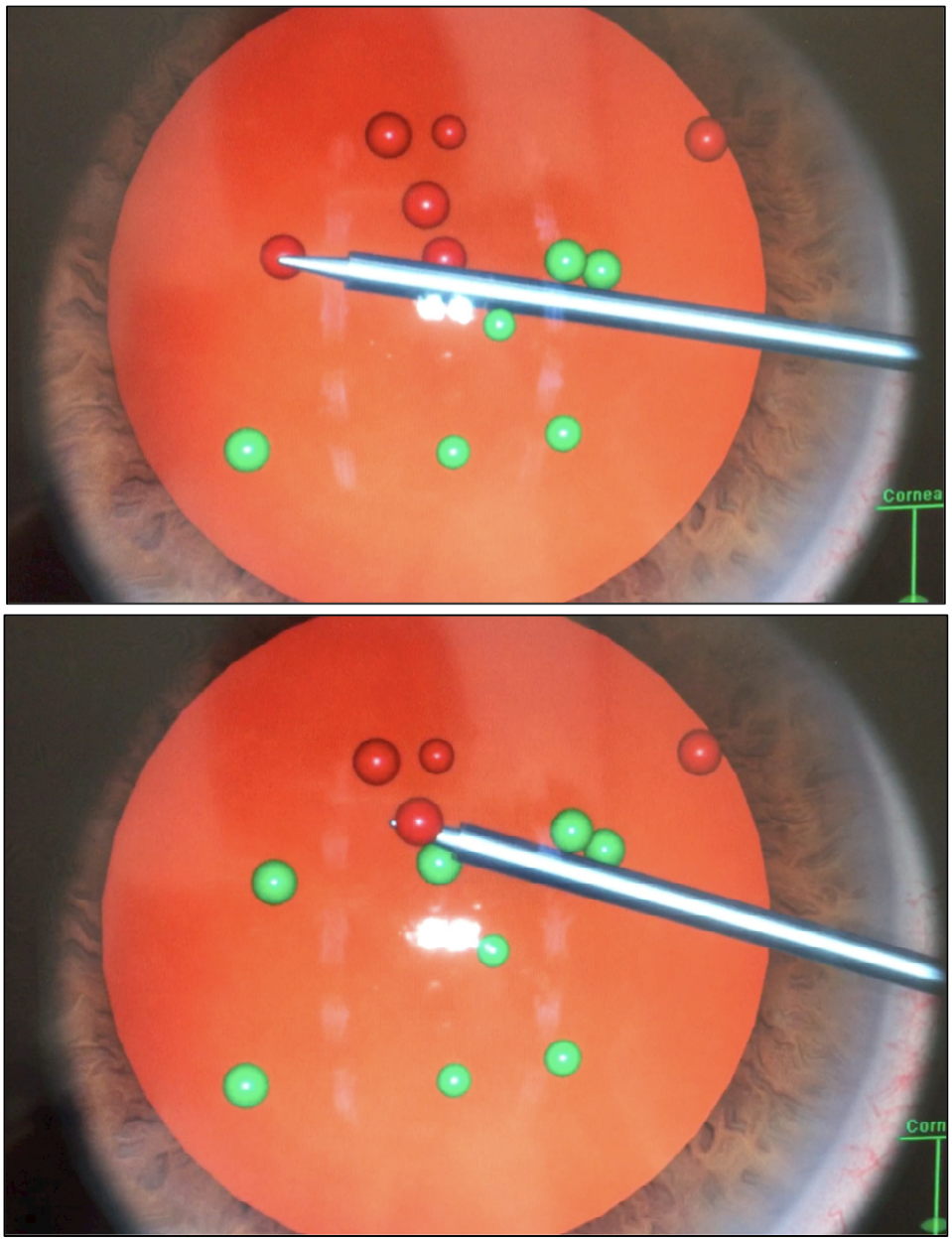


Figure 5. 1: *A strategic approach to judge depth adopted by some participants utilizing the monocular cue 'Interposition'. If the probe overlapped the sphere (top picture), it means the probe is located higher than the sphere and the participant has to move the probe down. If the probe is partially covered by the sphere (bottom picture), this indicates that it is below the sphere and has to be moved up in order to touch it.*

The effect of sudden loss of stereopsis was investigated by Waqar *et al* in 2012. In their study, they asked 30 junior doctors with no previous ophthalmic surgical experience to undertake four attempts of the EYESi level 4 forceps module binocularly and another four monocularly to simulate an acute loss of stereopsis. Significant findings ($p < 0.05$) included a decrease in average total score and increases in average corneal area injured, average lens area injured, and average time taken when the simulation was performed monocularly compared with binocularly. A possible explanation is that individuals with acute loss of binocular depth perception were unable to quickly adapt to their situation and take advantage of available monocular cues. In the current study, it was not possible to reach statistical significance when examining the effect of the sudden loss of stereopsis on the SR subgroup's performance. This could be possibly because the number of participants in the SR group who experienced that effect was too small (5 participants only).

Looking back at the orthoptic evaluation of those five participants, it seems that this sudden loss of stereopsis under the surgical microscope is more likely to occur to individuals with near-distance disparity. More specifically, those whose strabismus was well-controlled at near but manifest at distance. Having a closer look at the different stereotests that were performed on our participants during the orthoptic assessment (table 4.1), it seems that no single test was able to accurately detect which participants are more likely to experience this effect of sudden loss of stereopsis under the operating microscope. Future, larger-scale research efforts may be able to carry out reasonable

sub-group analyses and to try to predict which individuals with reduced stereopsis are more likely to experience this effect.

Another interesting finding in the stereo-reduced group was the discrepancy between the stereoacuity scores between Titmus and near Randot stereoacuity tests of some individuals. Those individuals scored 50 secs of arc on Titmus but their score ranged between 400-600 secs of arc on near Randot. Those participants may be inaccurately considered to have normal stereopsis if the examiner only relied on the Titmus stereotest. One of those participants had also lost stereovision acutely under the EYESi operating microscope. This poor agreement between the two stereoacuity tests is not new and is often noted during the clinical evaluation of patients with binocular single vision disorders such as strabismus or amblyopia. A study by Fawcett & Birch in 2003 evaluated the validity of the Randot and Titmus tests for quantifying stereoacuity in children with known binocular single vision disorders. They found that stereoacuity scores derived using the circles tests showed good agreement with random-dot stereoacuity when stereoacuity was 2.2 log seconds of arc (160 seconds of arc) or better, but they progressively overestimated stereoacuity for poorer random-dot stereoacuity scores.

This disagreement between stereotests did not exist only between Randot and Titmus tests in this study. Participant SR6 for example (table 4.1), had reduced stereoacuity using Titmus stereotest, complete stereopsis on synoptophore, and no detectable stereoacuity on both near and distance Randot stereotest. This again could be because of the underlying principle of testing stereoacuity of each stereotest. While

Randot stereotests utilize random-dots stereograms to test global stereopsis, the other two tests use contour-to-contour principle and test local stereopsis. The testing distance also plays a role in this discrepancy as some are near stereotests while other tests asses distance stereopsis. Another thing to consider about the synoptophore is despite the fact that it is arranged so that the targets are set at optical infinity, proximal convergence exists and is induced by the perceived awareness of nearness of an object (Von Noorden & Campos, 2002). This proximal convergence has possibly caused a change in the size of the angle of strabismus and/or the ability to control the deviation. This awareness of near has possibly played a role on the EYESi surgical simulator as well.

One more issue with stereoacuity testing is the effect of compensatory head posture which could help in achieving better stereoacuity, as was the case for some of our participants. However, we decided to only record the stereoacuity score without any head posture. This decision was made in order to maintain the consistency of our testing protocol and because those individuals would not be able to modify their head posture while using the EYESi operating microscope. This improved effect of compensatory head posture on stereoacuity score is important to consider when testing stereoacuity for applicants to professions with stereoacuity requirements and whether they would be able to hold this head posture while performing their job.

Overall, the findings of this study suggest that stereoacuity testing alone holds no predictive value as it relates to simulated microsurgical ability. A systematic review published in 2016 by Louridas and colleagues was carried out in order to identify

background characteristics and cognitive tests that may predict surgical trainees' future technical aptitude and concluded that:

> "To date, no single test has been shown to reliably predict the technical performance of surgical trainees. Strategies that rely on assessing multiple innate abilities, their interaction, and their relationship with technical skill may ultimately be more likely to serve as reliable predictors of future surgical performance."

Traditional stereoacuity tests rely on visual perception only, which we see now is not necessarily a predictive of surgical competence, at least in a simulated environment. Many factors are involved in hand-eye coordination and stereopsis is only one of them. Therefore, it would be beneficial to incorporate motor function testing into a test for stereoacuity levels. One such test that does exist is the Two Pen test, where patients are asked to line up the tip of their pencil with the tip of the examiner's pencil binocularly and then monocularly (Von Noorden & Campos, 2002). This particular test assesses only gross stereopsis, leaving the door open to the development of a test that measures finer stereoacuity and finer motor actions while still maintaining the principle of combining the stereoacuity testing with dexterity assessment.

A more reasonable approach to assess surgical competence of applicants to ophthalmology training programs was suggested by Waqar and his colleagues (2012). In their paper, they advised potential applicants to undertake stereoacuity testing before applying, and those with deficient stereopsis could have a counselling session with their local college tutor. Those individuals should be offered a chance to undertake a virtual

reality simulated surgery and decide themselves if they feel confident pursuing a microsurgical career.

5.2: Study Limitations

A number of limitations need to be noted regarding the present study. First, participants were accepted in the stereo-blind and stereo-reduced groups regardless of the etiology of their abnormal binocular depth perception. It was difficult to create homogeneous groups when participants could not be randomly assigned to a particular visual status. There are many known and unknown reasons why participants may have reduced or absent stereoacuity; as a consequence, the etiologies of the reduced or absent stereoacuity in participants varied, as was the presence or absence of amblyopia and manifest strabismus. Because the purpose of the study was simply to explore the relationship between abnormal stereoacuity and microsurgical performance, this heterogeneity is in many ways irrelevant as long as the group was homogenous in terms of the level of stereoacuity (absent, reduced or normal). Larger scale studies could divide the abnormal groups into subgroups according to the cause of their binocular deficiency. This would aid perhaps in further identifying and understanding the different adaptation mechanisms and abilities to utilize them in training individuals with a newly acquired loss of stereopsis.

Another limitation of the study was the duration of loss or reduction of stereopsis. Although the reduced and absent stereopsis in the SR and SB groups was confirmed by ocular history to be longstanding, the length of time in which the subjects

lived with their deficient binocular depth perception varied, allowing some a much longer time for adaptation.

The most important limitation, however, lies in the fact that we investigated the microsurgical performance on only one of the surgical simulator tasks that involved touching spheres dispersed at various depths in the anterior chamber using a handheld probe, whereas many more skills are required in real ophthalmic surgery. This simple task was chosen because our subjects were inexperienced in microsurgery and we did not want to introduce a confounding variable by recruiting experienced surgeons, in which their extensive training and experience would influence their performance. The effect of stereopsis on other surgical tasks may differ as well; therefore, findings of this study cannot be generalized to surgeries in different fields.

Despite attempts to prevent confounding experimental factors, we cannot eliminate them all. One is the effect of innate or developed manual dexterity on surgical performance. Since free space fine motor actions are heavily dependent on visual guidance, testing for motor skills cannot be done without visual input. Therefore, measuring and analyzing manual dexterity as a separate covariate is difficult and, hence, not included in this study. However, we did our best to control for this effect by only recruiting subjects with sufficient manual dexterity assessed during the pre-test familiarization session on the artificial eye and by age matching in all the three stereo-groups in order to control for the effect of age on the development of fine motor skills.

Although the frequency of playing videogames did not show a significant main effect on microsurgical performance in the current study, other factors naturally

variable within a group may do. Any kind of activities that require fine motor skills or good hand- eye coordination which the participants regularly take part in may have influenced their motor behavior regardless of their binocular status.

5.3: Conclusion

The current study showed that the microsurgical performance on the EYESi intraocular surgical simulator of individuals with reduced and absent stereoacuity, but good binocular vision, were statistically indistinguishable from those with normal stereoacuity.

These findings add support to the idea that stereopsis may not predict technical aptitude in surgical trainees. Therefore, caution is recommended when advocating the use of stereopsis as a screening tool for admission to residency training programs in ophthalmology as there is still no conclusive evidence that stereopsis is necessary to achieve satisfactory skills in ophthalmic microsurgery. A more reasonable way to counsel junior doctors wishing to embark on a career in ophthalmology may be to combine stereoacuity testing with motor dexterity testing. A trial session on a surgical simulator such as the EYESi could be a good platform for such a combined test.

It is also clear that opportunity for adaptation exists in longstanding loss of stereopsis, and future research could attempt to isolate the contributions of various monocular distance cues to surgical performance and train future surgeons, especially the ones with deficient stereopsis, on utilizing these adaptation skills.

The present results are very encouraging, as they provide the necessary motive and rationale to continue to develop larger-scale research programs that merge motor dexterity and clinical vision science with the ongoing advances in virtual reality simulators.

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Appendix A

Self Questionnaire

If you answer "**YES**" to any of the following questions, you are *not* eligible to participate in this study.

To protect your privacy, you do not need to tell us which of the questions applies to you.

1. Have you ever been diagnosed with any form of ***neurological disorder*** such as: stroke, cerebral palsy, hydrocephalus, epilepsy, seizures, Tourette's syndrome, Parkinson's disease or multiple sclerosis?

2. Have you ever been diagnosed with any form of ***movement disorder*** such as: Huntington's disease, peripheral neuropathy, progressive supranuclear ophthalmoplegia, amyotrophic lateral sclerosis (ALS), myasthenia gravis, muscular dystrophy, hemiplegia, hemiparesis or have uncontrollable hand shaking?

3. Have you ever been diagnosed with any form of ***musculoskeletal disorder*** such as: Carpal Tunnel Syndrome, Tension Neck Syndrome, tendonitis, Epicondylitis, ligament sprain, thoracic outlet compression, digital neuritis or fibromyalgia?

4. Have you ever been diagnosed with any form of ***ocular disorder*** such as nystagmus, glaucoma, cataract, uveitis or retinal disease?

5. Are you a surgeon/surgical resident or have any **surgical experience**?

Appendix B

Waterloo Handedness Questionnaire

Please indicate your hand preference for the following activities by circling the appropriate response:
*If you always (i.e. 95% or more of the time) use one hand to perform the described activity, circle **RA or LA** (for right always or left always). If you usually (i.e. about 75% of the time) use one hand, circle **RU or LU**, as appropriate. If you use both hands equally often, circle **EQ**.*

1. Which hand would you use to spin a top? .....LA LU EQ RU RA
2. With which hand would you hold a paintbrush to paint a wall? .....LA LU EQ RU RA
3. Which hand would you use to pick up a book? .....LA LU EQ RU RA
4. With which hand would you use a spoon to eat soup? .....LA LU EQ RU RA
5. Which hand would you use to flip pancakes? .....LA LU EQ RU RA
6. Which hand would you use to pick up a piece of paper? .....LA LU EQ RU RA
7. Which hand would you use to draw a picture? .....LA LU EQ RU RA
8. Which hand would you use to insert and turn a key in a lock?.....LA LU EQ RU RA
9. Which hand would you use to insert a plug into an electrical outlet? .....LA LU EQ RU RA
10. Which hand would you use to throw a ball?.....LA LU EQ RU RA
11. In which hand would you hold a needle while sewing? .....LA LU EQ RU RA
12. Which hand would you use to turn on a light switch?.....LA LU EQ RU RA
13. With which hand would you use the eraser at the end of a pencil?.....LA LU EQ RU RA
14. Which hand would you use to saw a piece of wood with a hand saw? .....LA LU EQ RU RA
15. Which hand would you use to open a drawer?.....LA LU EQ RU RA
16. Which hand would you turn a doorknob with?.....LA LU EQ RU RA
17. Which hand would you use to hammer a nail?.....LA LU EQ RU RA
18. With which hand would you use a pair of tweezers?.....LA LU EQ RU RA
19. Which hand do you use for writing? .....LA LU EQ RU RA
20. Which hand would you turn the dial of a combination lock with? .....LA LU EQ RU RA

Appendix C

REB Approval Letter

IWK Health Centre
Research

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Approval – Delegated Review
March 08, 2018

Principal Investigator: Miss. Hanouf Alkharashi
Co-Principal Investigator: Dr. G Robert Larcohe
Title: The Role of Stereopsis in Microsurgical Performance on the EYESi Ophthalmic Surgical Simulator
Project #:1023183

On behalf of the IWK Research Ethics Board (IWK-REB) I have reviewed the documents included in this study. I am pleased to confirm the Board's full approval for this research study, effective today.

Best wishes for a successful study.

Yours truly,

Adam Huber
Co-Chair, Research Ethics Board

This approval includes the following study documents:

Document Name	Version Date
Protocol	2018/03/06
Information and Consent Form	2018/03/06
Data Collection Form	2018/01/31
Questionnaire - Handedness	2018/01/31
Questionnaire - Screening	2018/01/31
Script - Introductory Letter	2018/01/31

The Board's approval for this study will expire one year from the date of this letter (March 08, 2019). To ensure continuing approval, submit a Request for Continuing Review to the Board 2 - 4 weeks prior to the renewal date. If approval is not renewed prior to the anniversary date, the Board will close your file and you must cease all study activities immediately. To reactivate a study, you must submit a new Initial Submission (together with the usual fee, if applicable) to the IWK-REB and await notice of re-approval.

Please be sure to notify the Board of any of the following:

- Proposed changes to the initial submission (i.e. new or amended study documents)
- Additional information to be provided to study participants

- Material designed for advertisement or publication with a view to attracting participants
- Serious adverse events experience by local participants
- Unanticipated problems involving risks to participants or others
- Sponsor-provided safety information
- Additional Compensation available to participants
- Upcoming audits/inspections by a sponsor or regulatory authority
- Closure of the study (within 90 days of the event)

Approved studies may be subject to internal audit. Should your research be selected for audit, the Board will advise you and indicate any other requests at that time.

Important Instructions and Reminders

Submit all correspondence to Ethics Manager Bev White or Ethics Coordinator, Joanne Street at the address listed at the top of this letter (do not send your response to the IWK-REB Chair or Co-Chair)

Be sure to reference the Board's assigned file number, 1023183 on all communications.

Highlight all changes on revised documents and remember to update version numbers and version dates, include a clean copy of all revised documents.

Research Ethics Board Committee Members		
Tricia	Beattie	Pediatric Psychology
Kimberly	Brewer	BIOTIC
Kelly	Cameron	Lay Representative
Jill	Chorney	Pediatric Psychology (Clinical Researcher)
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Adam	Huber	Pediatric Rheumatology (Clinical Researcher)
Greg	Muzika	Lay Representative
Francois	Tremblay	Pediatric Ophthalmology

* REB members are not in attendance during review of their own proposed research involving human subjects or where there is conflict of interest with the proposed research

This statement is in lieu of Health Canada's Research Ethics Board Attestation: *The Research Ethics Board for the IWK Health Centre operates in accordance with:*

- Food and Drug Regulations, Division 5 "Drugs for Clinical Trials involving Human Subjects"

- The Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans - TCPS(2)

- International Conference on Harmonization - Good Clinical Practice Guidelines - ICH-GCP

- FWA #: FWA00005630 / IORG #: IORG0003102 / IRB00003719

Appendix D

Informed Consent

STUDY TITLE:	The Role of Stereopsis in Microsurgical Performance on the EYESi Ophthalmic Surgical Simulator
PRINCIPAL INVESTIGATOR: (Graduate Student)	Hanouf Alkharashi, OC(C), MSc. candidate Clinical Vision Science Program Dalhousie University IWK Health Center 5980 University Ave. Halifax, NS, B3K6R8 Canada Email: Hanouf@dal.ca
Co-INVESTIGATOR: (Supervisor)	G. Robert La Roche, MD Professor of Ophthalmology Department of Ophthalmology and Visual Sciences, Dalhousie University Chief of Service, Pediatric Ophthalmology and Adult Strabismus IWK Health Centre

Introduction

You are being invited to take part in the research study named above. This form provides information about the study. Before you decide if you want to take part, it is important that you understand the purpose of the study, the risks and benefits and what you will be asked to do. You do not have to take part in this study. Taking part is entirely voluntary (your choice). Informed consent starts with the initial contact about the study and continues until the end of the study. A staff member of the research team will be available to answer any questions you have.

You may decide not to take part or you may withdraw from the study at any time. This will not affect the care you or your family members will receive from the IWK Health Centre in any way.

Why are the researchers doing the study?

Stereopsis (depth perception or 3-D vision) is thought to be very important in helping us decide where an object is in space and how big it is- skills we use every day to pick up and set down objects without spilling or dropping them. Many people have little or no 3-D vision but are able to judge depth by using adaptive skills and can do fine in most daily activities.

Certain jobs require 3-D vision in order to perform them safely such as truck driver, airplane pilot, etc. Performing Surgery, especially eye surgery, requires good judgement of depth. Surprisingly, we do not know what level of depth perception is exactly needed for these jobs.

The purpose of this study is to determine if people with long-term reduced or no 3-D vision can perform surgical tasks as good as those with perfect 3-D vision. The findings of this study will help us determine if having perfect depth perception should be required to become an eye surgeon or not.

How will the researchers do the study?

Three groups of participants are needed for this study: one group has no 3-D vision, a second group with reduced 3-D vision and a third group that has perfect 3-D vision. You may fall in one group or the other depending on how your 3-D vision measures. The study is non-randomized since participants cannot be randomly assigned to normal, reduced or absent 3-D vision groups.

We plan to enroll 10 participants in each group, for a total of 30 subjects. Participants will be matched for age in all the groups. Age matching means that the age of the

participant in each group will be within 1 year of the matched subjects in the other two groups.

The study has two components; the first part will be conducted in the eye clinic at the IWK Health Center while the second part of the study will take place in the neighboring Victoria General Hospital (The Skills Centre for Health Sciences at Bethune building).

What will I be asked to do?

If you are interested in enrolling in the study, we will first go over this consent form. You will also be given a copy of this form to keep. You will be asked to read a short questionnaire to make sure you are eligible to participate. If you decide to participate and are considered eligible, an appointment time to perform the testing will be scheduled. If you are a patient of the eye clinic at the IWK Health Center, it can be arranged to be at the same day of your regularly scheduled appointment. When you arrive for testing, one of the researchers will review this information and consent form with you again and answer any questions you may have. You will then be asked to sign the consent form. All testing will be for research purposes only.

The actual testing will have two components, a **short eye examination** and a **virtual reality surgical simulation task** (virtual reality means that the image you will see is not real but is computer-generated). The eye examination will consist of testing your vision and binocular status (your ability to use your eyes together). Whether or not you have depth perception will be confirmed as part of the binocular status assessment. None of the testing will require us to physically touch your eyes or use eye drops. If you come during your regular scheduled appointment to the eye clinic, you will complete the majority of these testing during your regular appointment as part of your standard-of-care assessments.

Before starting the second part of the study: the virtual reality surgical test, you will have a practice session in which you will be asked to perform a similar but simpler and real (not virtual reality) task on a basic eye model. This helps to give you an idea about the surgical task you are going to perform in the simulator and for the researchers to assess your ability to complete the surgical test.

The virtual reality surgical test will be conducted at the Skills Centre for Health Sciences in the neighboring Victoria General Hospital (Bethune building). You will be seated at a table that has a model head and a microscope. The researcher will help you adjust the microscope and provide more explanation if needed before starting the task. You will then be given a probe to insert inside the model eye. Looking through the microscope, you will see several red spheres floating inside the eye. You will have to touch each sphere with the probe until the sphere turns green. The task is completed when all the red spheres are turned into green. You will be given up to 5 minutes to complete this task. The machine will be taking fine measurements while you are performing the task

and will generate scores based on your performance. You will be asked to repeat the task 3 times and will be given 1-minute rest in between.

Once the two testing components are done, your participation in the study will end. No medicines or eye drops will be required and no follow-up visits are needed for the research. The results of the test will not be forwarded to your family doctor or optometrist.

How long will the study take?

This study will take about 2 hours: 1 hour for explanation of the research, answering questions, and performing the eye examination, *if you have a scheduled eye clinic visit at the same day this part will take around 30 minutes because the majority of the needed testing will be part of your standard-of-care assessment*. The surgical simulation task in the Skills Centre at VG hospital will take another 1 hour.

Both components of the study can be done in the same day, or scheduled on different days for your convenience and depending of the availability of the surgical simulator machine.

Are there risks to the study?

Testing may reveal that you have reduced vision or reduced depth perception that you were previously unaware of and if that is the case, you may be advised to see an eye care professional for an examination.

All of the tests for this research project have been proven to be safe. There is no expected harm from your participation. We do not anticipate any risks due to the nature of the tests used. There is no contact with your eyes. Mild fatigue might occur during the test but some rest periods are planned. However, as with any research, we have to state that there is always the possibility of unexpected risks caused by totally unforeseen circumstances during your participation in the study.

What are the possible benefits?

Participating in this study will give you an idea what it feels like to do eye surgery. You will be using the same surgical simulator the eye surgeons in training here at Dalhousie University use to practice their surgical skills. Otherwise, taking part in this study may be of no help to you personally.

Knowledge gained from this study will help us better understand how people with reduced and no 3-D vision see the world. This will also help determine the need for specific visual requirements regarding depth perception for surgeons in training. This

information can also be relayed to individuals with little or no depth perception who want to know how their condition will affect their career options.

What alternatives to participation do I have?

You do not have to participate in the study. This is completely optional. If you decide not to participate, your decision will not affect the care that you or your family receives at the IWK Health Centre.

Can I withdraw from the study?

If you decide you no longer want to participate in the study, you may withdraw from the study at any time. This will not affect the care you or your family receives at the IWK Health Centre. We would ask you to request in writing that you be removed from the study. If you choose to withdraw, all your collected data will be removed from the study and destroyed according to IWK policy.

Also, Dr. La Roche and the principal investigator have the right to stop patient recruitment or cancel the study at any time.

Will the study cost me anything and, if so, how will I be reimbursed?

The study will not cost you anything other than your time to participate in this study. As a compensation for your time and parking costs, you will be given a $5 Tim Horton's gift card and parking reimbursement.

Are there any conflicts of interest?

There are no conflicts of interest on the part of the researchers or the IWK Health Centre. None of the researchers involved in this study have financial interests to disclose or receive payment for the study. Whether you participate or not will not change the way your doctor takes care of you.

What about possible profit from commercialization of the study results?

This study is not anticipated to be involved in any commercialization resulting in sales or products.

How will I be informed of study results?

The study results will be available once the research is complete. You can indicate in the consent form whether you would like to receive a copy of your results and/or a summary of the study results.

How will my privacy be protected?

Protecting your privacy is an important part of this study. Every effort to protect your privacy will be made. All personal information collected from you will be kept private. The only people who will have access to your personal information will be those who are involved in conducting the research. Paper records will be kept in a locked area and electronic data will be password-protected. These records will be kept for five years after publication of the results, as required by the IWK Research Ethics Board and then destroy it according to IWK policy. Even though the risk of identifying you from the study data is very small, it can never be completely eliminated. If the results of the study are published in the medical literature, no information that could identify you will be included. However, complete privacy cannot be guaranteed. For example, the principal investigator may be required by law to allow access to research records.

If you decide to participate in this study, the researchers will look at your personal health information and collect only the information they need for this study. “Personal health information” is health information about you that could identify you because it includes information such as your name, address, telephone number, age, new and existing medical records.

The researchers in this study will be accessing your previous records only to ensure that you are eligible for this study. No data will be collected from past charts or hospital visits. Your personal health information will not be shared with others without your permission.

What if I have study questions or problems?

If you have any additional questions about the study, you may contact the principal investigator (Hanouf Alkharashi) by e-mail at: hanouf@dal.ca.

What are my research rights?

You have the right to ask questions about this study and to have them answered to your satisfaction before you make any decision about participating in this study. You also have the right to ask questions and to receive answers throughout this study. You are free to withdraw from the study at any time without jeopardizing the health care you are entitled to receive.

Your signature on the form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the investigators or involved institution(s) from their legal and professional responsibilities. If you become ill or injured as a direct result of participating in this study, necessary medical treatment will be available at no additional cost to you.

If you have any questions at any time during or after the study about research in general you may contact the Research Office of the IWK Health Centre at (902) 470-8520, Monday to Friday between 8 a.m. and 4 p.m.

Consent Form Signature Page

I have reviewed all of the information in this consent form related to the study called:

"The Role of Stereopsis in Microsurgical Performance on the EYESi Ophthalmic Surgical Simulator"

I have been given the opportunity to discuss this study. All of my questions have been answered to my satisfaction.

I authorize access to my personal health information, and research study data as explained in this form.

My signature on this consent form means that I freely agree to take part in this study.

I understand that I am free to withdraw at any time without affecting my future care.

Name of Participant:(print) _____

Participant Signature: _____

Date(dd/mm/yyyy): _____ Time: _____

- ❖ Would you like to receive a copy of your results? ☐ Yes ☐ No
- ❖ Would you like to receive a summary of the study results? ☐ Yes ☐ No

If you checked "yes", please provide your mailing address:

_____

STATEMENT BY PERSON PROVIDING INFORMATION ON STUDY

I have explained the nature and demands of the research study and judge that the participant named above understands the nature and demands of the study.

Name (Print)_____Position

Signature _____ Date _____ Time

STATEMENT BY PERSON OBTAINING CONSENT

I have explained the nature of the consent process to the participant and judge that they understand that participation is voluntary and that they may withdraw at any time from participating

Name (Print)_____Position

Signature _____Date _____ Time

You will be given a signed copy of this consent form