Adult Strabismus and Vision Therapy

Thesis

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Abstract

Introduction: Current research suggests that the visual cortex has plasticity that may allow for successful therapy treatment of strabismus and other binocular vision disorders in adults. The purpose of this study was to investigate the predictive factors of success with vision therapy in adults with strabismus. A secondary goal of this research project was to evaluate the changes that occur with orthoptic therapy in adults who underwent therapy for a childhood onset strabismus.

Methods: A retrospective chart review of 52 subjects with childhood onset strabismus who underwent vision therapy treatment as adults was performed. Subjects were sent a quality of life evaluation (AS-20 questionnaire). Subject data from before and after vision therapy was analyzed for predictive factors of success with vision therapy treatment.

Results: Subject ages ranged from 18-74 years old with a mean of 34 years. Vision therapy varied but generally focused on vergence training therapies (brock string, barrel card, and vectograms). Neither age, sex, history of surgery, nor suppression were statistically significantly related to success of treatment. Presence of global stereopsis pre-therapy was related to a successful outcome (p=0.008). Direction and laterality of
deviation were not significantly related to success, but frequency of deviation at near was related to success (p=0.02) with success being more likely with intermittent deviations. Stereopsis showed significant improvements with therapy (p≥0.04). Subjects’ AS-20 questionnaire scores were not significantly different from published normal scores.

Conclusion: This study demonstrated that adults with strabismus might benefit from vision therapy. Factors that were statistically significantly related to success included presence of global stereopsis before therapy and intermittent (versus constant) deviations at near.
Dedication

This document is dedicated to my family who have been supportive of my academic endeavors my entire life.
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Fields of Study

Major Field: Vision Science
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Chapter 1: Introduction

Strabismus

Strabismus is a misalignment of the eyes, where one or both eyes are turned away from the object of regard. Approximately 2-4% of children (Friedman, et al., 2009)(McKean-Cowdin, et al., 2013) and as many as 4% of the adult population are affected by strabismus (Coats, et al., 2005). Strabismus may be attributed to sensory causes, motor causes, or innervational causes. (Rutstein & Daum, 1998) Strabismus may develop if refractive error keeps the brain from receiving normal signals from each eye, or if chronic ocular disease diminishes the sensory feedback for motor control. Abnormalities of the orbital structure anatomy, including abnormalities in the function of extraocular muscles can cause strabismus. Innervational causes include dysfunction in the oculomotor control center in the brain or abnormal innervation and control of the extraocular muscles.

Strabismus can manifest throughout life, but most commonly will develop in early childhood (Rutstein & Daum, 1998). Congenital or infantile strabismus develops during the first six months of life (American Optometric Association). Strabismus onset after six months is referred to as childhood onset strabismus. Onset in adulthood is usually considered an acquired strabismus. Risk factors for developing strabismus include retinopathy of prematurity, mother smoking during pregnancy, low birth weight, and
family history. (Maconachie, Gottlob, & McLean, 2013) The hereditary component to developing strabismus is reflected in the higher percentage of strabismus in children whose family members have strabismus, 17-30% of children with a family history of strabismus will also develop strabismus. (Aurell & Norrsell, 1990) (Engle, 2007) The exact gene or mode of inheritance is unclear at this time. Twin studies have demonstrated the heritability of esotropia and exotropia as well. One study used a large sample of monozygotic and dizygotic twins to show that there is a 64% heritability of esotropia, whereas exotropia is caused mostly by environmental factors. (Sanfilippo, et al., 2012) They also showed that the heritability of esotropia is independent of refractive error.

People with strabismus may experience double vision, eyestrain, vision loss, and poor depth perception, as well as cosmetic issues (Hatt, Leske, Kirgis, Bradley, & Holmes, 2007).

**Suppression and Amblyopia**

Strabismus can be associated with decreased vision due to the development of suppression, amblyopia and/or eccentric fixation. (Freeman, Nguyen, & Jolly, 1996) Suppression develops because the turned eye sees a different image than the other eye, causing diplopia or double vision. The brain begins to ignore the image from the turned eye to prevent the double vision, a phenomenon known as suppression. Suppression happens under binocular viewing conditions and is caused by cortical inhibition of the visual input of one eye. (Freeman, Nguyen, & Jolly, 1996) This happens because the
brain is trying to ignore either a blurry image or a visually confusing image so the person can try to see clearly. A person may develop amblyopia if they suppress during early childhood, when the visual system is still developing. Amblyopia is defined as decreased visual acuity in one or both eyes that cannot be improved by correcting refractive error and cannot be explained by an eye health problem. (Birch, 2013) With amblyopia, normal vision does not develop and that results in decreased best-corrected visual acuity. Amblyopia is most common when the strabismus is constant and unilateral (affects only one eye). (Rutstein & Daum, 1998)

*Anomalous Correspondence*

In order to have single binocular vision, the object of interest must be imaged on corresponding points of the two eyes. In normal correspondence, the foveas of the two eyes are corresponding points such that if an object is bifoveally fixated, a single fused percept of the object is obtained. In strabismus, an object of interest cannot be bifoveally fixated. Thus strabismus in the presence of normal correspondence causes the object of interest to be imaged on non-corresponding retinal points and results in diplopia.

To eliminate the diplopia that results due to strabismus, some patients develop anomalous correspondence that affords them some form of anomalous binocularity. A non-foveal area of their strabismic eye takes on the role of the corresponding point to the fovea of the “good” eye. Anomalous correspondence is most common in patients with early childhood onset strabismus, usually before age four years. (Rutstein & Daum, 1998)
A clinical finding that occurs with anomalous correspondence is that the subjective angle of deviation does not equal the objective angle. The objective angle is the angle the eyes actually deviate from the object of interest and can be measured using the cover test. The subjective angle is the angle at which the patient perceives binocular fusion. This can be measured using Bagolini striated lens testing. The angle of anomaly is the difference between the objective and subjective angles. The angle of anomaly can be measured directly with the Hering-Bielschowsky After Image Test or Haidinger Brush Afterimage Transfer Test. (Rutstein & Daum, 1998)

There are several types of anomalous correspondence, harmonious anomalous correspondence (HAC), unharmonious anomalous correspondence (UHAC), and paradoxical anomalous correspondence (PAC). HAC is when the subjective angle is zero, so the objective angle equals the angle of anomaly. HAC allows the patient to perceive some binocular vision because, even though they have strabismus, a single percept of the world is obtained. UHAC happens when the subjective angle is smaller but in the same direction as the objective angle. PAC occurs in post-strabismus surgery patients, who were over- or under- corrected. PAC type I happens when the angle of anomaly is larger than the objective angle and PAC type II happens when the subjective angle is larger than the objective angle. (Rutstein & Daum, 1998)

_Eccentric Fixation_

Eccentric fixation is a monocular phenomenon where the eye is fixating with a non-foveal point instead of the fovea. (Rutstein & Daum, 1998) This develops in
children with strabismus and amblyopia. The person perceives that they are looking directly at the target even though they are using a non-foveal point to fixate. This adaptation causes a decrease in visual acuity that refractive error correction or patching cannot fix. (Freeman, Nguyen, & Jolly, 1996) The fovea provides the sharpest, clearest vision with the best visual acuity a person can attain because there is a high density of photoreceptors that are placed closely together. If a person is viewing objects from a non-foveal point then they are not able to attain their best visual acuity because the photoreceptors are less dense the further away you are from the fovea, the larger spacing between photoreceptors does not allow for as detailed vision as there is in the fovea.

Classification of Strabismus

Strabismus can be categorized in many different ways, including direction, magnitude, and comitancy. Esotropia and exotropia are terms used to designate horizontal deviations. Esotropia indicates a deviation where the eye(s) is turned in towards the nose, whereas exotropia indicates that the eye(s) is turned outwards towards the ears relative to the vergence demand. Hypertropia and hypotropia are used to describe a vertical eye deviation. Hypertropia is an eye that turns upward compared to the other eye and hypotropia is where an eye turns downward compared to the other eye. A cyclodeviation or cyclotropia is the torsional rotation (rotation around the visual axis) of the eye either toward or away from the nose. (Rutstein & Daum, 1998)

The magnitude of strabismic deviations is measured in units of prism diopters. The magnitude is essentially the amount of prism diopters needed to neutralize the
deviation. The magnitude can be less specifically designated by micro, small, medium, or large. Small deviations are 10 prism diopters or less. Moderate deviations are 11 to 30 prism diopters and large deviations are greater than 30 prism diopters. (Rutstein & Daum, 1998)

A strabismic deviation is comitant if the deviation is the same magnitude in all directions of gaze. If the deviation magnitude varies in different directions of gaze, the strabismus is called incomitant. Incomitancy can also come in A or V patterns depending on if the eyes are more converged in down or up gaze. For example, an esotropia (eyes turned in toward nose) would have a V pattern if the magnitude of esotropia is greatest in down gaze because that would mean the eyes are turned in the most in down gaze.

Strabismus can affect either the right or left eye, or both eyes. A unilateral strabismus is an eye misalignment that only involves one eye. If both eyes are involved, then the deviation is called alternating. When documenting strabismus, it is very important to indicate which eye is involved or if both eyes are involved. The frequency of the strabismus can be intermittent or constant. Intermittent strabismus can then be qualified by the percentage of time the eyes are turned. Esotropias are usually constant, while exotropias are usually intermittent. (Rutstein & Daum, 1998)

The time of onset of strabismus is also very important to note. Congenital or childhood onset strabismus in adults is less concerning to a practitioner than a newly presenting or acquired strabismus. Trauma, neurological diseases, stroke, or space occupying lesions in the brain can cause acquired strabismus. These conditions require immediate medical attention and can be medical emergencies. (Rutstein & Daum, 1998)
Esotropic strabismus can also be classified depending on the involvement of the patient’s focusing or accommodation. Under normal conditions, as a person accommodates to focus at near, their eyes also turn in (converge). Children and young adults with hyperopia may be able to accommodate or focus through their refractive error so that they see clearly at distance and near. Accommodative refractive esotropia occurs when the patient has to accommodate a large amount to compensate for a high amount of hyperopia. The eyes converge in proportion to the amount that the eyes are accommodating so this can lead to excess convergence, or esotropia. Patients with an accommodative aspect of their esotropia benefit significantly from full refractive error correction. Nonrefractive accommodative esotropia can also occur in individuals who have a high accommodative convergence to accommodation ratio such that a large amount of convergence is associated with each diopter of accommodation. This results in an esotropia that is larger in magnitude when focusing on objects up close. Finally, esotropia may also be partly accommodative or nonaccommodative. (Rutstein & Daum, 1998)

Clinical Evaluation of Eye Alignment

A cover test is the most common clinical test used to diagnose a strabismus. Unilateral cover test identifies the presence of strabismus and the direction. The magnitude of strabismus is determined using alternating or simultaneous prism and cover test and either a prism bar or loose prisms to neutralize the deviation. Performing a cover test in multiple gazes, i.e. up, down, right, and left gazes, a clinician is able to determine
comitancy. A clinician is also able to roughly determine the direction and magnitude using the corneal light reflex with Hirschberg and Krimsky tests. Hirschberg testing will reveal the direction of the strabismus if present because strabismus will show different locations of the corneal light reflexes between the two eyes. Krimsky test uses prisms to neutralize the difference between the corneal light reflexes, which determines the magnitude of the deviation. (Rutstein & Daum, 1998) (Carlson & Kurtz, 2004)

Treatment of strabismus

Strabismus can be treated with prescription glasses, prism lenses, vision therapy, or surgical interventions. The first step in treatment of strabismus is generally prescribing optical correction (glasses or contact lenses) for any refractive error, then additional treatment options can be utilized. (Coffey, Wick, Cotter, Scharre, & Horner, 1991) (Rutstein & Daum, 1998)

Prescription Glasses

As mentioned above, the first step in the management of strabismus is to account for the refractive error in both eyes. Correcting refractive error allows the patient to achieve their best corrected visual acuity, which in turn aids the visual system in fusion of images. In some patients refractive error correction alone may improve their fusion to reduce or eliminate their deviation (Coffey, Wick, Cotter, Scharre, & Horner, 1991). Some patients may benefit from additional power in their glasses or over-correction to aid them in attaining fusion. This concept takes advantage of the connection between
accommodative and vergence systems. Esotropic deviations may benefit from additional plus power to help relax their accommodative vergence system and thus decrease the amount the eyes convergence (Reddy, Freeman, Paysse, & Coats, 2009). Prescribing an add power for near is especially helpful for treatment of esotropia that is greater when focusing on objects up close. One study of 64 children with accommodative esotropia showed that with glasses alone 66% were aligned, 22% were aligned with bifocal lenses in addition to their refractive error correction, and 12% needed surgery to gain alignment (Reddy, Freeman, Paysse, & Coats, 2009). Exotropic deviations can benefit from extra minus power to help induce accommodative vergence, which causes the eyes to converge more. Intermittent exotropia can be treated with over minus lenses but constant exotropic deviations are more difficult to treat with over minus lenses (Coffey, Wick, Cotter, Scharre, & Horner, 1991). Although effective, over-minusing can only be used on individuals with accommodative ability and the method is not effective with presbyopes (Coffey, Wick, Cotter, Scharre, & Horner, 1991).

Prism lenses are also used to manage strabismus deviations. The image of an object viewed through a prism is deviated from where the object is located. Prisms reduce the demand on the fusional vergence system by compensating for part or all of the strabismus deviation. Prisms that help decrease the demand are called demand-reducing prisms while neutralizing prisms correct the complete deviation. Intermittent exotropia is most commonly treated with demand-reducing prisms, but may also be treated with neutralizing prisms (Coffey, Wick, Cotter, Scharre, & Horner, 1991).
**Vision Therapy**

Vision therapy consists of eye exercises that help the patient gain improved control of their eye movements. The goal of vision therapy is to achieve improved visual performance and relieve asthenopia. Vision therapy has been shown to be successful in treating amblyopia, strabismus, accommodative disorders, vergence disorders, ocular motility dysfunction, and visual information processing disorders. (The 1986/87 Future of Visual Development/Performance Task Force, 1988)

Vision therapy can be performed in office (usually with the optometrist or a vision therapist), at home, or using a combination of in-office and home-based therapy. Studies on convergence insufficiency treatments have shown that the most effective modality of vision therapy treatment for symptomatic convergence insufficiency is in-office sessions with supportive home-based therapy. (Convergence Insufficiency Treatment Trial Study Group, 2008) (Birnbaum, Soden, & Cohen, 1999)

Vision therapy exercises for strabismus focus on increasing fusional vergence ranges (e.g. increasing convergence in exotropes and increasing divergence in esotropes). Esotropia therapy for children has been shown to be more successful in individuals with a later onset of deviation, having an accommodative component to the deviation, and successful concurrent amblyopia treatment. (Krumholtz & FitzGerald, 1999). Exotropic children treated with vision therapy were most successful when they did not have amblyopia, had gross stereopsis, and had intermittent deviations. (Krumholtz & FitzGerald, 1999) Also, vision therapy treatment for intermittent exotropia has been
shown to have a higher success rate than surgical treatment (Coffey, Wick, Cotter, Scharre, & Horner, 1991).

Vision therapy on adults has not been as thoroughly studied. Convergence insufficiency has been successfully treated in adults using vision therapy techniques (Birnbaum, Soden, & Cohen, 1999) (Scheiman, et al., 2005). However, vision therapy for strabismus or other disorders in adults has not been extensively investigated. Although, two case studies of successful vision therapy treatment of childhood onset intermittent basic exotropia in adults have been documented. (Peddle, Han, & Steiner, 2011)

Common Vision Therapy Exercises

There are numerous vision therapy techniques that may be used. Procedures for improving strabismus treatment include brock string, vectograms, life saver cards, eccentric circles, aperture rule, jump vergences, and computer orthoptics (computer programs that train eyes).

Brock String

Brock string trains gross vergence ability (Figure 1). One end of the string is held at the patient’s nose and the other is either tied or held so the string can be pulled taut. The patient fixates the beads at different distances from their eyes to improve their convergence and divergence skills. An advantage of the Brock string is that it gives the patient visual feedback. As the patient performs the exercise, he/she should be able to appreciate physiological diplopia on either side of the fixation point. The patient should
see the one string form an “X”, with the point he/she is fixating in the center of the “X”. This feedback tells the patient he/she is using both eyes.

Figure 1. Brock String (Bernell, 2015)

Barrel Card
The barrel card trains convergence (Figure 2). The patient holds the card up to the bridge of the nose with the smallest barrel closest to the patient. The patient will work on looking at the different barrels, and they should see a combination of the red and green colors of each barrel.
Aperture Rule
Aperture rule trains both divergence and convergence (Figure 3). The device has a ruler-like stick with an aperture slide on one end and the viewing cards on the other. The single aperture is used for convergence and the double aperture is used for divergence. The aperture is moved along the stick corresponding with the numbered cards. This technique provides varying vergence demand beginning with 2.5 prism diopters up to 30 prism diopters, and also includes antisuppression tools.
Vectograms

Vectograms train divergence and convergence (Figure 4). Variable vectograms come as a pair of translucent slides with polarized images on them, one slide to be viewed by each eye when the patient is wearing polarized glasses. The patient’s goal is to keep the image single and clear during the exercise. The slides begin on top of one another requiring no vergence demand to fuse. As the slides are separated the vergence demand increases.

Figure 4. Vectograms: A clown, B quoits ring (Bernell, 2015)

Life Saver Card

These cards can be used for either convergence or divergence training, depending on the location of the patient’s focus (Figure 5). There are four magnitudes of set vergence demand on the card. These cards come in opaque or translucent options.
Computer Orthoptics

There are many options for computer orthoptic programs. These programs utilize different techniques to train vergence ability (e.g. ramp, jump), including increasing the velocity of vergence fusional responses. The basic set-up includes a patient, wearing either red-blue glasses or liquid crystal glasses, who views a monitor that displays varying activities to train the vergence system.

Surgical Procedures

Most surgeons will consider surgery for an esotropia more than 15 prism diopters, exotropia greater than 20 prism diopters, or a vertical deviation greater than 8-10 prism diopters. (American Optometric Association, 2010) Strabismus surgery can involve resecting or recessing one or more of the extraocular muscles. Resection results in strengthening of a muscle whereas recession results in a weakened muscle. The surgeon chooses the muscles to be altered based on the direction and magnitude of deviation.
Successful surgery results in 10 prism diopters or less of horizontal deviation or 4 prism diopters or less vertically (American Optometric Association, 2010) (Mills, Coats, Donahue, & Wheeler, 2004) (Hatt, Leske, Liebermann, & Holmes, Comparing Outcome Criteria Performance in Adult Strabismus Surgery, 2012) (Krumholtz & FitzGerald, 1999) Possible surgical complications include globe perforation (0.08%), lost muscle (0.02%), severe infection (0.06%), and scleritis (0.02%). (Bradbury & Taylor, 2013) Post-surgical diplopia and over- or under-correction of eye alignment are functional risks of strabismus surgery. (Mills, Coats, Donahue, & Wheenler, 2004)

Strabismus surgery is best performed before age 2 years for infantile or congenital strabismus. Surgical alignment as early as possible gives the largest chance for developing binocularity. (Simonsz, Kolling, & Unnebrink, 2005) Accommodative esotropes are not usually good surgical candidates, unless they have a large non-accommodative component due to the high risk of consecutive exotropia. (Jampolsky, von Noorden, & Spiritus, 1992)

Although it is conventional practice to operate on children, adults have had success with strabismus surgery as well. (Kushner, 2014) There is a recent shift in opinion by ophthalmologists that adult strabismus is more than just a cosmetic issue. (Stager Jr, 2014) (Rosenbaum, 1999) The American Association for Pediatric Ophthalmology and Strabismus and the American Academy of Ophthalmology released a joint policy statement in 2013 listing seven reasons why strabismus surgery on adults should be considered, including diplopia, visual confusion, restoration of binocular vision, intolerance of prism glasses or patch, restoration of visual field, elimination or
improvement of abnormal head posture, and psychosocial function/vocational status. (American Academy of Ophthalmology and American Association for Pediatric Ophthalmology and Strabismus, 2013) Coats et al., reported that adults have an average delay of 20 years for surgical treatment even though strabismus surgery in adults is successful up to 85% of the time. (Mills, Coats, Donahue, & Wheeler, 2004) Recent research has shown that there is the possibility of improved quality of life and improved binocularity after eye alignment surgery in adults. (Dickmann, et al., 2013) One study showed that 13 out of 20 subjects improved in quality of life scores after surgery. (Dickmann, et al., 2013)

_Botulinum toxin_

Botulinum toxin injection into one or more extraocular muscles to essentially weaken them is an alternative to the traditional strabismus correcting surgery. Botulinum toxin blocks acetylcholine release in neuromuscular junctions and causes temporary paralysis of injected muscle. (Donahue, 2013) This paralysis lasts approximately 3 months. Commonly, botulinum toxin is known to lessen the appearance of facial wrinkles and other plastic surgery applications. Botulinum toxin also has clinical ocular uses including treatment of benign essential blepharospasm and strabismus (Donahue, 2013). There is conflicting evidence concerning the effectivity of botulinum toxin versus surgery for strabismus treatment. Botulinum toxin is most often used for infantile esotropia treatment, but it has also been used for acute onset strabismic deviations in adults. (Donahue, 2013) One study of 422 children showed that surgery is a better
treatment for large angle infantile esotropias but that botulinum toxin was equally effective to surgery in small to moderate (less than 35 prism diopters) size esotropic deviations. With large angle deviations (>35 prism diopters) success from surgery was achieved 66% of the time whereas only 45% of Botox subjects were successful (p<0.001), but there was no difference in success between surgery and Botox for smaller deviations (60% success for surgery and 59% success for Botox). (de Alba Campomanes, Binenbaum, & Campomanes Eguiarte, 2010) Another study of 51 subjects found that there is no significant difference in long-term outcome of botulinum toxin injection compared to surgical muscle recession in large angle infantile esotropia. Botulinum toxin had success rate of 68% and surgery success rate was 77% (p=0.87). (Gursoy, Basmak, Sahin, Yildirim, Aydin, & Colak, 2012) Use of botulinum toxin as an adjunctive therapy to medial rectus recession with large angle infantile strabismus has been shown to have long term success as well. A retrospective study looked at patients who had botulinum toxin injections in their medial rectus muscles along with medial rectus recession to decrease their esotropic deviation. The patients had follow-up data for at least two years after the surgery and showed a 75% success rate. (Lueder, Galli, Tychsen, Yildirim, & Pegado, 2012) Botulinum toxin is still a controversial treatment option and use differs between surgeons. (Donahue, 2013)

Strabismus may be treated in various ways including prescription glasses, vision therapy, or surgical procedures. These treatments do not always completely fix the deviation or the deviation may return or some patients do not have treatment for their
strabismus at all. The lack of normal binocular vision processes and cosmetic concerns in patients with strabismus can lead to a decreased quality of life (QOL) (Tandon, Velez, Isenberg, Demer, & Pineless, 2014) (Durnian, Noonan, & Marsh, 2011).

**Quality of life with strabismus**

Studies have shown that patients with strabismus have lower QOL compared to those without strabismus. Patients with strabismus scored the same or worse than patients with ocular diseases including diabetic retinopathy, macular degeneration, glaucoma, and cataracts on the National Eye Institute Visual Functioning Questionnaire (VFQ-25). (Chang, Velez, Demer, Isenberg, Coleman, & Pineles, 2015) Psychosocial and functional aspects both play a role in QOL with strabismus. Psychosocial aspects are most likely due to the cosmetic issues of strabismus, a noticeable eye turn. (Durnian, Noonan, & Marsh, 2011) Defective binocular vision and stereopsis are functional aspects influencing QOL in strabismus. (Tandon, Velez, Isenberg, Demer, & Pineless, 2014)

In Hatt et al., health related quality of life (HRQOL) of strabismus patients was evaluated using eleven open-ended questions. The answers were analyzed by identifying common phrases and compiling them into topics. The topics were then evaluated for frequency of use by the subjects and the 20 item questionnaire was created. The questionnaire was administered to 32 subjects with strabismus, 13 normal subjects, and 18 with other eye diseases. The subjects with strabismus (56) had lower median overall scores (p<0.001) than the visually normal subjects (98) and subjects with other eye diseases (88). The authors concluded that the questionnaire had good discriminative
validity between normal and strabismus subjects. (Hatt, Leske, Kirgis, Bradley, & Holmes, 2007) This study was the basis for development of the Adult Strabismus-20 questionnaire (AS-20) utilized in this research project.

Among subjects with strabismus, those that suffer from diplopia have more functional concerns with QOL, whereas non-diplopic strabismus subjects were more concerned about psychosocial problems associated with their eyes. (McBain, et al., 2014) (Hatt S. R., Leske, Kirgis, Bradley, & Holmes, 2007) Although not significantly lower, diplopic subjects (53) scored worse than those without diplopia (59) on the AS-20. (Hatt R. S., Leske, Bradley, Cole, & Holmes, 2009)

Adults with strabismus who underwent surgery have reported improved QOL using the AS-20 questionnaire. Glasman et al. used the AS-20 to compare before and after surgery QOL scores in 86 subjects. They found that QOL scores improved for every subject after surgery (45 before versus 73 after surgery, p<0.0001). Improvement was most significant for the subjects who experienced the largest angle change after surgery. (Glasman, Cheeseman, Wong, Young, & Durnian, 2013) Koc et. al, looked at how restoration of binocularity after strabismus surgery changes QOL measures. The 61 subjects were grouped by their postoperative stereopsis testing, either binocular vision positive or negative. They found that there was no statistically significant difference in AS-20 scores between the binocular vision positive and negative groups. After controlling for amblyopia, there was a slight significant difference between the two groups, and subjects with binocular vision had better QOL than those without binocular vision (p<0.05). (Koc, Erten, & Yurdakul, 2013) Although achieving binocularity and
stereopsis is a functional goal for after surgery, they are not essential to improvement in overall QOL with strabismus surgery. Numerous studies have shown that although binocularity was most often not restored, the QOL scores still increase after surgery. (Dickmann, et al., 2013) (Liebermann, Hatt, Leske, & Holmes, 2014)

The psychosocial effects of strabismus are a large concern for patients. Strabismus can affect job prospects, finding a life partner, social life, and mental health. One study demonstrated that strabismus has a significant negative impact on socialization and employment. Photos were taken of orthophoric subjects in primary, right, and left gazes then the photos were digitally altered to simulate esotropia or exotropia. The photos were shown to 212 college students then the students filled out a questionnaire about personality characteristics related to socialization and employment capability. The simulated strabismic photos had signigicantly lower scores on the questionnaire compared to the orthophoric orientated photos. (Olitsky, Sudesh, Graziano, Hamblen, Brooks, & Shaha, 1999) Adults with strabismus who also had depressive symptoms scored worse on HRQOL measures than those without depressive symptoms. In Hatt et al., no correlation was found between more significant clinical factors and depression. It is unclear whether depression is caused by the strabismus or if it is an independent problem. (Hatt, Leske, Liebermann, Philbrick, & Holmes, 2014) Mohney et al. investigated mental illness in young adults with strabismus. The study retrospectively reviewed medical records for mental illness diagnoses in 407 subjects, 266 esotropes and 144 exotropes, Young adults with exotropia had 3.1 times the risk of developing mental
illness (95% CI). Subjects with esotropia did not have an increased predilection for mental illness. (Mohney, McKenzie, Capo, Nusz, Mrazek, & Diehl, 2008)

Functional and psychosocial effects of strabismus can be detrimental to patients so it is important that eye care practitioners are able to guide patients to the best solution for their binocular vision and cosmetic problems from strabismus. As discussed, strabismus is not just a pediatric condition. Strabismus is also present in adult populations and they have a decreased QOL due to their experiences with strabismus. A better understanding of vision development and brain plasticity may lead to increased success with treatment of adult strabismus.

**Visual Development and the Critical Period**

Critical periods are times in human development when the brain is most susceptible to environmental influences. During these times the brain has an increased responsiveness to those environmental influences. The critical period for visual development is from infancy to approximately 7 years old. (Birch, 2013)(Levi, 2012) Within that time frame there are specific times where certain aspects of vision are more susceptible. (Harwerth, Smith, Duncan, Crawford, & Van Noorden, 1986)

Hubel and Wiesel first introduced the visual critical period with their studies on the cat visual system. Hubel and Wiesel conducted a series of experiments exploring the plasticity of the brain during development. The cat visual experience was altered by sewing one eye shut or using an opaque occlude lens applied soon after birth. Upon examination, the visual cortex in these cats was responsive to the normal eye stimuli but
hardly at all responsive to the deprived eye stimuli. Interestingly, when Hubel and Wiesel repeated the monocular deprivation experiment with adult cats they found no decreased cortical responsiveness to stimulation of the deprived eye. (Wiesel & Hubel, 1963) They simulated infantile onset strabismus in cats and found that there was a decrease in binocular cells in the cortex. They discovered that strabismus in an adult cat does not cause the same functional change in the visual cortex. (Hubel & Wiesel, 1965) Hubel and Wiesel showed that there is a critical period in development after birth where the visual system matures based on visual experiences. (Hubel & Wiesel, 1970)

During the critical period it is necessary to have equal visual experiences in both eyes in order for the ocular dominance columns of the visual cortex to develop properly. The ocular dominance columns form the area of brain that first integrates signals from both eyes. The development of ocular dominance columns and subsequently functional binocular vision has three phases (Hooks & Chen, 2007). Hooks and Chen describe three phases of brain plasticity centered around the critical period. The first phase, the pre-critical period phase, neuronal connections are made independent of environmental influences or visual experiences. Next was the critical period, where maturation of the cortex was directly influenced by visual experiences. Lastly, the closure of the critical period where the same visual experiences that elicited changes during the critical period no longer have the same effect on the brain.

Strabismus can prohibit the visual cortex from developing normal functional binocular vision. Hubel and Wiesel successfully documented the altered function of the binocular vision cortical areas of cats with induced strabismus. Human functional
binocular vision is most commonly measured by stereopsis or the ability to see depth. Fawcett, Wang and Birch investigated the association between stereopsis and duration and age of onset of strabismus in 152 patients, ages 3-13 years with infantile esotropia and accommodative esotropia (Fawcett, Wang, & Birch, 2005). The study found that the period of plasticity for stereopsis begins in early infancy and lasts until 4.6 years of age, this is similar to previous findings of 1 to 3 years old. (Banks & Aslin, 1975) Children with longer times of normal binocular vision during the critical period had better stereoacuity outcomes. Therefore, development of strabismus later during the critical period would yield a smaller impact on stereopsis.

**Brain Plasticity**

Huang discusses the foundation of neuroplasticity as it relates to the efficacy of vision therapy techniques in her review paper. (Huang, 2009) Huang concludes that vision therapy efficacy is based on improving synaptic connections and alteration of cortical organization to gain maximum visual efficiency. Neuroplasticity of the visual cortex allows vision therapy to be a successful tool in treatment of binocular vision conditions in children and adults.

Improvement of amblyopia in older children and adults is an example of how brain plasticity persists past the critical period. Levi discusses the role of plasticity in amblyopia development and treatment. Amblyopia is essentially an imbalance in cortical function between the two eyes due to the lack of a clear visual experience in one eye during the critical period. Amblyopia does not develop after 7-8 years of age, the end of
the critical period when visual experiences shape binocular vision and ocular dominance. Previously it was thought that amblyopia must be treated during this same critical time period for improvement to be possible, but recent studies have shown that young adults and adults can experience improvement from treatment. One clinical trial demonstrated that amblyopia treatment after age 7 years still results in some improvement of amblyopia. (Scheiman; Mitchell; Cotter; Kulp; Cooper; Rouse, 2005) Hess used a novel approach to treat adult amblyopes. The subjects were treated by viewing images under altered contrast conditions for each eye. The altered contrast helped the subject have binocular viewing experiences by inducing balanced output between the eyes, the amblyopic eye had higher contrast and the other eye had lower contrast. Eventually, 8 out of 9 of the subjects were able to attain binocular vision under normal viewing conditions. (Hess, Mansouri, & Thompson, 2010)

Although Hubel and Wiesel set the foundation for research of brain plasticity, they were unable to duplicate in their experiments what we know now about the amazing ability of the mature brain to continue to change throughout life. The critical period is a crucial part of normal vision development but the visual system can be trained and improved after the critical period has passed. The plasticity of the mature visual system has been documented with amblyopia in adults but strabismus treatment of adults has not been sufficiently explored.

In an age where technology rules, many of us take for granted the ability to appreciate the new 3-D movie. The technology is able to create three-dimensional
perception by using the way own eyes perceive depth every day. Except there are people who do not perceive depth using two eyes, and those people are unable to view media in three dimensions. Susan Barry explains her journey to see in three dimensions in her book, Fixing My Gaze (Barry, 2009). It was a life altering event after living almost fifty years in a two dimensional world. Barry has constant alternating esotropia, a type of strabismus. Her eyes never pointed towards the same point in space at the same time so she never developed binocular vision or stereopsis. Barry pursued vision therapy training in adulthood and successfully trained her eyes and brain to work together so she could finally experience binocular vision. Susan Barry’s story inspired the focus of this research project. This study investigated the predictive factors of vision therapy treatment success for adults with strabismus.
Chapter 2: Methods

The goal of this research project was to evaluate the changes that occur with orthoptic therapy in adults who underwent therapy as an adult for a childhood onset strabismus. This study included a retrospective record review and the AS-20 QOL survey. This research study was approved by The Ohio State University Institutional Review Board. Data collected from each subject was de-identified by participating providers to protect the personal health information of the patients.

The AS-20 questionnaire was selected for use in this study because it is a patient derived health related QOL questionnaire developed to specifically evaluate the quality of life of adults with strabismus. There are twenty questions, with a five-point scale for responses. Maximum score is 100, which indicates the best QOL, and minimum score is zero. Patients with strabismus were shown to score lower than those without strabismus on the twenty-question survey, and patients with other eye diseases scored closer to normal than those with strabismus. (Hatt R. S., Leske, Bradley, Cole, & Holmes, 2009)

The AS-20 questionnaire has been utilized to evaluate QOL in adults with strabismus in many research studies since its development.

Seven optometrists who were known to provide care to adults with strabismus were invited to participate in the study. Providers were asked to identify the patients in their practices who would meet the inclusion and exclusion criteria. Eligibility criteria
included age 18 years or older, childhood onset (before age 18 years) strabismus, no history of systemic diseases known to affect accommodation, vergence, or ocular motility (e.g. Graves Disease), no history of neurological dysfunction (e.g. traumatic brain injury or stroke), and no ocular cause for reduced visual acuity.

The providers were mailed packets for each subject. The packets included a Patient Data Form and AS-20 Survey with a unique ID number for each subject by site. The ID number allowed tracking of responses from providers and the ability to link AS-20 Questionnaires to the matching Patient Data Forms. Providers were asked to complete the Patient Data Form for each subject and forward the AS-20 questionnaire to each subject. The AS-20 questionnaires were sent along with a stamped envelope addressed to The OSU College of Optometry so the subject could easily return the completed questionnaire.

The Patient Data Form included three pages, the first page collected entering or baseline exam data before vision therapy, the second page detailed the vision therapy program, and the last page gathered post-therapy exam data. The provider also had the opportunity to send de-identified copies of the subject records instead of filling out the specific form. The same data from the Patient Data Form was extracted from the copies of subject records during data entry.
Statistical Analysis

Success was defined as non-strabismic deviation after treatment or 10 prism diopters or less of a strabismic deviation after treatment. Chi-square tests were used to investigate the impact that sex, history or surgery, suppression, and stereopsis had on success. Logistic regression was used to investigate the impact of age on success. Subjects with vertical strabismus were excluded from the analysis of success due to the small number of subjects with vertical deviations and prior literature showing vertical deviations to be more difficult to treat with therapy than horizontal deviations.

Chi-square tests were used with cover test data and suppression to investigate a significant connection to success. Direction, laterality, and frequency of strabismus deviation were evaluated. The nature of suppression (laterality and frequency) was also studied.

Stereopsis measurements of subjects were analyzed by comparing pre- and post-data. We artificially assigned values to those subjects with a reported stereopsis measurement of “none” or “nil”, (2501 was chosen for global stereopsis and 401 for local). These values were chosen because they are one more than the maximum value reported for global and local stereopsis. Related-samples Wilcoxon Signed Rank Test was used to compare pre- and post-therapy results of stereopsis measurements. McNemar’s test was used to investigate the difference between pre- and post-therapy stereopsis using dichotomous variables. Stereopsis data was converted into pass or fail, if a patient had any level of stereopsis they were labeled as “pass”. The pass and fail rankings of the pre- and post-therapy data measurements were compared. This analysis
allowed us to determine how many of those without stereopsis before therapy (fail) had stereopsis after therapy (pass).

The AS-20 questionnaire raw results were averaged and one-sample t-tests were used to compare AS-20 scores to expected values. The AS-20 scores were also compared to successful outcomes.
Chapter 3: Results

A total of 52 subjects were identified. Tables 1-3 show the pre- and post-therapy clinical data collected. Ages ranged from 18 to 74 years old, with a mean of 34 years and 57.7% of the subjects were female. More than 80% of subjects saw 20/20 or better at distance and more than 70% at near. The visual acuities were converted to Log MAR and the mean interocular difference of distance visual acuity was 0.12. There were 5 patients with only vertical strabismic deviations, 11 with both horizontal and vertical deviations and 36 with horizontal deviations alone. The 5 subjects with vertical deviations only were evaluated separately for success and changes in clinical data measurements. One or more strabismus surgeries were reported for 18 subjects. Of those who had surgery, 10 had only one surgery, 5 had two surgeries, and 3 had three surgeries.

The subjects were divided into those with esotropias, exotropias, or vertical deviations. The characteristics of the strabismus deviations of the subjects can be seen in Table 4. On distance cover test there were 24 (51.1%) esotropes, 18 (38.3%) exotropes, and 5 (10.6%) who only had a phoria at distance. Seventeen (36.2%) were constant deviations, 15 (31.0%) were intermittent, and 10 had missing data regarding frequency. Twenty-three (48.9%) were unilateral and 18 (38.3%) were alternating, and 1 subject had missing data about the laterality of the strabismus. On near cover test, 19 (41.3%) were esotropes, 19 (41.3%) were exotropes, and 8 (17.4%) only had a phoria. Constant
deviations were present in 13 (28.3%) subjects, 15 (32.6%) were intermittent and 10 had insufficient data regarding frequency. Seventeen (37.0%) had unilateral deviations, 19 (41.3%) had alternating deviations, and 2 subjects had insufficient data regarding laterality.

Amblyopia was reported in 9 subjects and eccentric fixation was reported in 5 subjects. Diplopia was reported in 11 subjects, although this data was not specifically included in data form so more subjects may have been diplopic than reported. Anomalous correspondence was reported for 5 subjects. A total of 27 (52%) subjects were reported to have suppression. Constant suppression was reported in 16 (59.3%) and intermittent in 7 (25.9%).
<table>
<thead>
<tr>
<th>ID</th>
<th>Age</th>
<th>Sex</th>
<th>Surgery</th>
<th>Amblyopia</th>
<th>Stereo (global/local)</th>
<th>Distance Cover Test</th>
<th>Near Cover Test</th>
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<td>18 CAET</td>
<td>3 EP</td>
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<td>5 EP</td>
<td>20 IAET (c +1.50 7 EP)</td>
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<td>4 RET</td>
<td>25 CRET, 3 RHT</td>
<td>6 RET</td>
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<td>2 EP</td>
<td>N N</td>
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<td>500/40</td>
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<td>10 EP, 4 RHP</td>
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<td>Y HAC</td>
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<td>OD, C</td>
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Blank space; data not reported. Success: I Non-strabismic post-therapy 2 Non-strabismic post-therapy or ≤ 10° deviation post-therapy, yes (Y), no (N), excluded (x). Surgery; yes (Y), no (N). Amblyopia; determined by visual acuity reported, no amblyopia (N). Stereo; none (N), missing value (x). Suppression; none (N), alternating (A), unilateral (OD or OS), constant (C), intermittent (I). Eccentric Fixation; only PRE values reported. Diplopia; near and distance (Y), near only (N), distance only (D), missing value (x). Anomalous correspondence; only PRE values reported. Methods: amblyoscope (a), bagolini (b), HBAIT (h). *Subject 27 was previously esotropic, hs surgery OU as child, suppression OS

Table 1: Esotropia Subject Data
<table>
<thead>
<tr>
<th>ID</th>
<th>Age</th>
<th>Sex</th>
<th>Surgery</th>
<th>Amblyopia</th>
<th>Stereo (global/local)</th>
<th>Distance Cover Test</th>
<th>Near Cover Test</th>
<th>Suppression</th>
<th>Diplopia</th>
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<td>Post</td>
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<td>10 XP</td>
<td>Pre</td>
<td>Post</td>
<td>Pre/Post</td>
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<td>N</td>
<td>OD</td>
<td>100/20</td>
<td>20 RXT, RHT</td>
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<td>12 RXT</td>
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<td>Y</td>
<td>OS</td>
<td>Gross c amblyoscope</td>
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<td>12 AET</td>
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<td>8</td>
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<td>M</td>
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<td>N</td>
<td>40/100</td>
<td>10 ILXT, 2 LHoT</td>
<td>Pre</td>
<td>Post</td>
<td>Pre/Post</td>
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</tr>
<tr>
<td>9</td>
<td>22</td>
<td>M</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>x/20</td>
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<td>Post</td>
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<td>Y</td>
<td>N</td>
<td>N</td>
<td>x/25</td>
<td>15 LXT</td>
<td>Pre</td>
<td>Post</td>
<td>Pre/Post</td>
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<td>F</td>
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<td>N</td>
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<td>Post</td>
<td>Pre/Post</td>
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<td>N</td>
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<td>N</td>
<td>125/16</td>
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<td>10 XP</td>
<td>23 IAXT</td>
<td>20 XP</td>
<td></td>
</tr>
<tr>
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<td>44</td>
<td>M</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>125/20</td>
<td>15-20 ILXT (30%)</td>
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<td>Post</td>
<td>Pre/Post</td>
<td></td>
</tr>
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<td>N</td>
<td>Y</td>
<td>N</td>
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<td>6 CAXT, 6 CHoT</td>
<td>Pre</td>
<td>Post</td>
<td>Pre/Post</td>
<td></td>
</tr>
<tr>
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<td>46</td>
<td>M</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>50/160</td>
<td>16 CHoT, 4 CHoT</td>
<td>Pre</td>
<td>Post</td>
<td>Pre/Post</td>
<td></td>
</tr>
<tr>
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<td>M</td>
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<td>N</td>
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<td>50/160</td>
<td>16 CLXT</td>
<td>Pre</td>
<td>Post</td>
<td>Pre/Post</td>
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</tr>
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<td>N</td>
<td>N</td>
<td>100/20</td>
<td>20 RXT, RHT</td>
<td>Pre</td>
<td>Post</td>
<td>Pre/Post</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>29</td>
<td>F</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>250/20</td>
<td>35 CAXT</td>
<td>Pre</td>
<td>Post</td>
<td>Pre/Post</td>
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</tr>
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<td>N</td>
<td>N</td>
<td>250/20</td>
<td>35 CAXT</td>
<td>Pre</td>
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<td>300/100</td>
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<td>Pre</td>
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<td>Y</td>
<td>N</td>
<td>N</td>
<td>100/100</td>
<td>10 ILXT</td>
<td>Pre</td>
<td>Post</td>
<td>Pre/Post</td>
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</tr>
<tr>
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<td>41</td>
<td>F</td>
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<td>N</td>
<td>N</td>
<td>125/16</td>
<td>10 ILXT</td>
<td>Pre</td>
<td>Post</td>
<td>Pre/Post</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>44</td>
<td>F</td>
<td>N</td>
<td>Y</td>
<td>OD</td>
<td>N/20</td>
<td>12 CRX</td>
<td>Pre</td>
<td>Post</td>
<td>Pre/Post</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>51</td>
<td>F</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>OD/OD</td>
<td>12 CRX, 15 CRX</td>
<td>Pre</td>
<td>Post</td>
<td>Pre/Post</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>52</td>
<td>F</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>250/20</td>
<td>250/20</td>
<td>55 IAXT (5%)</td>
<td>Pre</td>
<td>Post</td>
<td>Pre/Post</td>
</tr>
</tbody>
</table>

Blank space; data not reported. Success: 1. Non-strabismic post-therapy 2. Non-strabismic post-therapy or ≤ 10 Δ deviation post-therapy, yes (Y), no (N), excluded (x). Surgery: yes (Y), no (N). Amblyopia: determined by visual acuity reported, no amblyopia (N). Stereo: none (N), missing value (x). Suppression: none (N), alternating (A), unilateral (OD or OS), constant (C), intermittent (I). Eccentric Fixation: only PRE values reported. Diplopia: near and distance (Y), near only (N), distance only (D), missing value (x). Anomalous correspondence: only PRE values reported, methods: amblyoscope (a), bagolini (b), HBAIT (h). \(^{1}\)Post therapy subject alternated between anomalous and normal correspondence.

Table 2: Exotropia Subject Data
Exotropia (n=47)
Esotropia (n=46)

<table>
<thead>
<tr>
<th></th>
<th>Exotropia (n=47)</th>
<th>Esotropia (n=46)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D</td>
<td>N</td>
</tr>
<tr>
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<td>3</td>
</tr>
<tr>
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<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Unilateral</td>
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<td>8</td>
</tr>
<tr>
<td>Alternating</td>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 4: Characteristics of Subjects' Strabismic Deviations

Vision Therapy

Vision therapy techniques varied slightly between doctors and specific patient needs but 49 out of 52 (94%) subjects were treated with vergence training therapies. There were 3 subjects for whom vergence therapy was not reported as treatment. Only “ocular motility” therapy was reported for one subject with no specific procedures given. Another subject completed only amblyopia, eccentric fixation, and accommodative
therapy before discontinuing vision therapy by choice. The last subject completed approximately 12 sessions of amblyopia and eccentric fixation therapy.

Brock string or barrel card and vectograms were the most frequently used vergence therapies (45). Computer orthoptics was used with 37 subjects. Eccentric circles (32), aperture rule (31), jump vergences (26), and life saver cards (26) were also reported as vergence therapy techniques used. Amblyopia therapy was reported for 9 subjects, eccentric fixation therapy was reported for 6 subjects, anomalous correspondence therapy in 4 subjects, and anti-suppression therapy in 15 subjects. Other therapies written in by doctors included cheiroscope, stereoscope fusion cards, amblyoscope, Hart chart, visicare series, and bernelloscope.

Determining exact duration of therapy for each subject was difficult because some reported in number of sessions and other months or years of therapy. The participating doctors who reported duration in terms of time (e.g. months) were asked to estimate the number of vision therapy sessions per month they usually have and this number was used to estimate the number of sessions for each subject. The mean duration was 27 sessions, with a minimum of 6 and a maximum of 168 sessions. Maintenance therapy was reported in 28 (53.8%) of the subjects.

Success

Three different criteria for success were evaluated. Specifically, success was defined as 1) non-strabismic deviation after treatment (strabismus pre-treatment) or, 2) 10 prism diopters or less of a strabismic deviation after treatment or 3) success using either
of the first two criteria. If the subject was successful at either distance or near they were classified as a success. Of the 47 total subjects with horizontal deviations (or horizontal and vertical), 41 had sufficient clinical data for both before and after therapy to be included in the analysis for success. When success was defined as a pre-therapy strabismus and then a post-therapy non-strabismic deviation, the subjects with improvement but not complete resolution of their strabismus were classified as not successful. Microtropes were excluded from analysis using the criteria of ≤10 prism diopters as the definition of success because microtropes would have been classified as a success both before and after treatment and would, therefore, artificially inflate the success values. Using both definitions allowed inclusion of those subjects who had an improvement but not total resolution of their deviation and those subjects with microtropia (Table 5). Analysis showed a 53% success rate with the definition of ≤10 prism diopters after therapy, 47% success rate when success was defined as non-strabismic post-therapy, and 60% success when using a definition of nonstrabismic or ≤10 prism diopters after therapy. There was no association between the percentage successful (non-strabismic or ≤10 prism diopters) and the number of vision therapy sessions (Figure 6).
≤ 10 Δ POST-deviation¹ | Non-strabismic POST² | ≤ 10 Δ POST-deviation or Non-strabismic POST³
---|---|---
Successful | D | N | Total (%) | D | N | Total (%) | D | N | Total (%)
Not | 12 | 20 | 25 (53) | 17 | 18 | 22 (47) | 20 | 21 | 28 (60)
Successful | 14 | 8 | 11 (23) | 26 | 19 | 23 (49) | 22 | 14 | 17 (36)
Excluded | 21 | 19 | 11 (23) | 4 | 10 | 2 (4) | 5 | 12 | 2 (4)

For each definition of success there was 1 subject excluded due to insufficient data and 1 subject excluded because they had only a phoria at distance and near. ¹≤10Δ Post-deviation: Subjects were excluded if they had 10 Δ or less deviation. ²Non-strabismic Post: Subjects were excluded if they were not strabismic before therapy. Subjects with success at either distance or near were considered overall successful and included in the total for each category.

Table 5: Percentage of Subjects Successful After Therapy

Figure 6: Number of vision therapy sessions compared to percentage successful
Factors Associated with Success

We evaluated whether age, sex, history of surgery, suppression or stereopsis of the subject were related to whether or not the subject had a successful outcome using the following definitions of success: 1) non-strabismic post-deviation or 2) non-strabismic post-deviation or ≤10 prism diopters strabismic post-therapy. We also evaluated whether type of deviation (esotropia versus exotropia), laterality or frequency of deviation were related to success (non-strabismic or ≤10 prism diopters strabismic post-therapy). These factors were chosen based on importance for clinical relevance and quantity of subjects with adequate data.

Factors Associated with Success Defined as Non-strabismic Post-therapy

Thirty two subjects had sufficient clinical data provided in the five areas explored for predictors of success. Univariate logistic regression analysis to investigate the relationship between age and success (p=0.60) showed that age was not related to success. Chi-square tests revealed that sex (p=0.48), history of surgery (yes or no) (p=0.69), and presence of suppression (unilateral, alternating, and none) (p=0.17) were not statistically significantly related to success. Presence of pre-therapy global stereopsis was significantly related to success (p=0.005). Of the 16 subjects who had global stereopsis before therapy, 12 (75%) were successful (Table 6).
Factors Associated with Success Defined as ≤ 10 Δ or Non-strabismic Post-therapy

Thirty three subjects had sufficient clinical data provided in the five areas explored for predictors of success. Univariate logistic regression analysis to investigate the relationship between age and success (p=0.99) showed that age was not related to success. Chi-square tests revealed that sex (p=0.83), history of surgery (yes or no) (p=0.47), and presence of suppression (unilateral, alternating, and none) (p=0.61) were not statistically significantly related to success. Presence of pre-therapy global stereopsis was significantly related to success (p=0.008). Of the 17 subjects who had global stereopsis before therapy, 14 (82%) were successful (Table 7).

<table>
<thead>
<tr>
<th>Stereopsis</th>
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</thead>
<tbody>
<tr>
<td>Success</td>
<td>Pass</td>
<td>Fail</td>
<td>Total</td>
</tr>
<tr>
<td>Y</td>
<td>12</td>
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</tr>
<tr>
<td>N</td>
<td>4</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>Total</td>
<td>16</td>
<td>16</td>
<td>32</td>
</tr>
</tbody>
</table>

Table 6: Success (Non-strabismic post-therapy) vs. global stereopsis status pre-therapy
Association between Ocular Alignment and Success

Of the 47 total subjects, 47 had sufficient cover test data to compare before and after therapy for distance and 46 for near. There were no statistically significant differences between exotropes and esotropes when compared to successful outcomes at distance or near (p=0.33, p=0.63) (non-strabismic or ≤10 prism diopters). With distance cover test (N=42) 13 out of 24 subjects with esotropia were successful and 7 out of 18 exotropia subjects were successful. There were 9 out of 17 subjects with esotropia and 11 out of 18 subjects with exotropia with near cover test (N=35) who were successful. Similarly, there were no statistically significant differences in the percentage of subjects successful between alternating and unilateral deviations (p=0.89, p=0.25). At distance (N=41) 9 out of 18 subjects with alternating strabismus and 11 of the 23 subjects with unilateral deviations were successful. There were 12 out of 18 subjects with alternating deviations and 7 of 17 subjects with unilateral deviations at near (N=33) who were successful. The percentage of subjects successful was not statistically significantly related to frequency of the deviation (constant vs. intermittent) at distance (N=32, p=0.08) but was statistically significantly related to frequency of the deviation at near (N=26, p=0.02). There were 6 out of 17 subjects with constant deviations and 10 out of 15 subjects with intermittent deviations who had success post-therapy. Only 4 out of 12 subjects with constant deviations at near had success, whereas 11 (78.6%) out of 14 of the subjects with intermittent deviations at near were successful post-therapy.

The preceding analyses were also repeated for esotropes and exotropes separately. There was no statistically significant difference between constant and intermittent
esotropes (p=0.15, p=0.31) or exotropes (p=0.143, p=0.099) when compared to success for both distance and near cover test measurements. Laterality (unilateral versus alternating) was also not statistically significantly related to success for esotropes (p=0.93, p=0.13) or exotropes (p=0.059, p=0.86) at distance and near.

Association between Suppression and Success

Of the 41 subjects for whom success (non-strabismic or ≤10 prism diopters) could be determined, there were 25 subjects with suppression. Suppression was alternating in 11 subjects and unilateral in 14 subjects. Constant suppression was present in 16 subjects, 6 had intermittent suppression, and 3 were missing data about the nature of their suppression. Although not statistically significant (p=0.30), 8 out of 11 (72.7%) of the subjects with alternating suppression were successful and 7 out of 14 (50%) subjects with unilateral suppression were successful (Table 8). While the rate of success between those with constant versus intermittent suppression was not statistically significantly different (p=0.084, exact chi-square p=0.089), 8 out of 16 with constant suppression were successful whereas all of the subjects (6) with intermittent suppression were successful (Table 9). A pair-wise comparison of alternating, unilateral, or none found a marginally significant result when comparing constant and intermittent (p=0.051).
Table 8: Success vs. Alternating or Unilateral Suppression

<table>
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<th>Unilateral</th>
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<td>7</td>
<td>12</td>
<td>27</td>
</tr>
<tr>
<td>N</td>
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Table 9: Success vs. Constant or Intermittent Suppression

<table>
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<tr>
<td>Total</td>
<td>16</td>
<td>6</td>
<td>19</td>
<td>41</td>
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</table>

Stereopsis

Of the 47 subjects, 27 were included in an analysis of change for global stereopsis and 30 for change in local stereopsis. The remaining subjects were excluded due to insufficient clinical data. When “nil” values were artificially assigned a value, (2501”) the global stereopsis mean was 1381” (SD=1103) pre-therapy and 1045” (SD=1057) post-therapy, the median was 500” before and after therapy. Local stereopsis “nil” values were assigned 401”, the mean pre-therapy was 194 (SD=165) and post-therapy 142” (SD=162) and the median before therapy was 120” and after therapy 50”.

Stereopsis measurements before and after therapy were compared to determine if there was a difference after therapy. There was a statistically significant difference
between pre- and post-therapy for local stereopsis (p=0.003) and the change in global stereopsis approached significance (p=0.051). Stereopsis status before therapy was compared to stereopsis status after therapy by classifying subjects as pass or fail (Tables 10 and 11). Four subjects (30.7%) who failed stereopsis testing before treatment passed stereopsis testing after treatment for global and 4 (36.4%) subjects who failed before therapy passed local stereoacuity after treatment, but the change was not statistically significant (p=0.13).

We also looked at change in stereoacuity after therapy for subjects who had stereoacuity at baseline. Fourteen subjects had global stereopsis and 19 subjects had local stereopsis before therapy. Global stereopsis before and after therapy was not significantly different (p=0.79) but local stereopsis before treatment was significantly different from post-therapy stereoacuity measurements (p=0.014).

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</tr>
<tr>
<td>PRE</td>
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<tr>
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Table 10: Pre-therapy vs. Post-therapy Global Stereoacuity
Table 11: Pre-therapy vs. Post-therapy Local Stereoacuity

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</tr>
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<td>PRE Local</td>
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<tr>
<td>Total</td>
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<td>7</td>
<td>30</td>
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Quality of Life – AS 20 Questionnaire

The 20-item Adult Strabismus questionnaire (AS-20) was completed by 14 subjects. The retrospective nature of this study did not allow for evaluation of pre-treatment AS-20 questionnaire results. The threshold for the composite score is 84 in normal subjects. (Hatt R. S., Leske, Bradley, Cole, & Holmes, 2009) Normal subject threshold for psychosocial subscale is 93 and 70 for the functional subscale. (Hatt, Leske, Bradley, Cole, & Holmes, 2009)

The mean composite score of the subjects was 84.4. When compared to the threshold composite score of 84 for normals, there was no significant difference between the subjects post-therapy and the normal value (one-sample t-test, p=0.91). The mean psychosocial score (97.5) was significantly better than the normal value of 93 (p <0.001). The mean functional score of 71.3 was not significantly different from the normal value of 70 (p=0.85).

The composite scores were classified as either abnormal or normal based on the normal threshold value of 84 and compared to classification success (non-strabismic or ≤10 prism diopters). Twelve of the 14 subjects with horizontal deviations who completed
the AS-20 had sufficient data available to be classified with respect to success. One did not have sufficient data and two had vertical strabismus. Eight out of 11 were successful, and 5 of the successful subjects had normal AS-20 composite scores.

The 2 subjects with vertical deviations that had AS-20 responses both had abnormal AS-20 composite scores. The functional subscores were very low but the psychosocial subscores were above the normal threshold.

**Vertical Strabismus**

The 5 subjects with vertical strabismus deviations are represented in Table 3. One was a left hypotropia and then rest were right hypertropias. The pre- and post- clinical measurements generally did not improve with the vertical deviations. When success was defined as non-strabismic after therapy, one (ID 18) of the 5 subjects was successful at both distance and near, and one (ID 22) was successful at near only. In addition, one subject (ID 24) was able to decrease their diplopia and suppression.
Chapter 4: Discussion

This study demonstrated that adults with strabismus may benefit from vision therapy. Factors that were statistically significantly associated with success included global stereopsis before therapy and intermittent deviations at near. Subjects with global stereopsis pre-therapy had more successful outcomes than those without any global stereopsis and intermittent deviations at near were more likely to be successful with vision therapy compared to constant deviations. Success was not related to age, sex, history of surgery, or suppression.

Success was evaluated using two different definitions, non-strabismic after surgery, and non-strabismic after surgery or ≤ 10 Δ of strabismus after treatment. The definition of success as ≤ 10 Δ of strabismus after treatment was chosen in this study because previous research of adult strabismus surgery has used 8-12 Δ as a measure of success. (Mills, Coats, Donahue, & Wheeler, 2004) (Hatt, Leske, Liebermann, & Holmes, Comparing Outcome Criteria Performance in Adult Strabismus Surgery, 2012) (Krumholtz & FitzGerald, 1999) The definition of success as those who were strabismic before therapy and had no strabismus after therapy allowed inclusion of small angle deviations in the analysis.
There are other aspects of the visual system that may also be helpful in defining a successful outcome that were not investigated in the present study. For example, diplopia would seem to be an important measurement of functional success because non-diplopic subjects have been reported to have an improved quality of life compared to diplopic subjects. (Hatt S. R., Leske, Kirgis, Bradley, & Holmes, 2007) (McBain, et al., 2014) Another success measure could be vergence ranges because with vision therapy we don’t necessarily expect the deviation magnitude to improve but we do expect an improvement in the amplitude and control of vergence movements.

Although subjects were classified as successful or not for statistical analysis of the data, it is important to appreciate the differences between pre- and post-data values of the subjects. Tables 1-3 showed that most (39/52) subjects had at least some improvement in clinical measurement after therapy. Subjects may have not met criteria to be included in evaluations of success but they still demonstrated some improvement. Clinically, any meaningful improvement in stereopsis, deviation, suppression, or diplopia may lead to reduced symptoms and an improved quality of life for that subject.

Global stereopsis before therapy was related to a successful outcome. The association between local stereopsis and success was not evaluated due to insufficient pre-therapy data. Global or random dot stereoacuity requires the fusion of both eyes without any monocular clues but local or contour stereopsis allows for monocular cues to assist in perception of depth. (Fricke & Siderov, 1997) The lack of monocular cues increases the difficulty for strabismus and amblyopia patients to attain global stereopsis because they do not always use both eyes and rely on monocular cues to determine depth.
One would expect then that those subjects with global stereopsis have some moments when they attain fusion that would make vision therapy treatment easier to complete.

Our data showed a difference between stereopsis measurements before and after therapy. We compared pre- and post-therapy stereopsis to determine whether there was a difference after therapy. Post-therapy local stereopsis measurements were significantly better than pre-therapy measurements. We would expect that if therapy was causing improvement that there would be a difference between pre- and post-therapy subjects like this study showed. Comparison of global stereopsis before and after therapy showed no significant difference. This may suggest that local stereopsis may be able to be improved while global stereopsis may not be improved. On the other hand, it may be that the tests used for global stereopsis were not sufficiently sensitive to measure a change (e.g. if a test was used that only assessed large disparities). Comparison between pre- and post-therapy classification of passing or failing stereopsis showed a trend of improvement of stereopsis status with vision therapy. Although not statistically significant, 30.7% of subjects who did not have global stereopsis before therapy had stereopsis after therapy and 36.4% of the subjects gained local stereopsis after therapy. The lack of statistical significance is most likely due to the small sample size of this study, but it is important to note that some subjects without stereopsis before treatment are able to attain stereopsis after therapy. This study demonstrated that stereopsis can be improved in adults using vision therapy techniques as treatment. Some subjects without stereopsis before therapy were able to attain measurable stereopsis and some subjects with stereopsis showed improvements in local stereopsis measurements.
Distance cover test descriptors (direction, frequency, and laterality) were not significantly associated with success. Although direction and laterality on near cover testing were not related to success, frequency of the deviation at near was significantly related to success. Of the 14 subjects with intermittent deviations 78.6% had success, whereas only 33% of the subjects with constant deviations had success. Previous studies have also documented that intermittent deviations are easier than constant to treat with vision therapy. (Krumholtz & FitzGerald, 1999) Subjects are able to have binocular fusion occasionally with an intermittent strabismus so teaching fusion with vision therapy may be easier than with a constant deviation. There was no difference in success between subjects with esotropia and exotropia. Although it would be predicted that exotropia subjects may have a better chance of success because their deviations are most often intermittent this study did not find a significant difference. This may be because the sample size limits the statistical relevance of the matter.

Vertical and horizontal deviations parameters are difficult to compare so in this study the few (5) subjects with only vertical deviations were evaluated separately. Two of the subjects with vertical strabismus had a decrease in the magnitude of the vertical deviation after therapy. Vertical vergence ranges are more difficult to treat than horizontal vergences but symptoms can be eliminated with prism glasses and orthoptics. (Cooper, 1988) This study also had a group of subjects with both horizontal and vertical deviations, which were included in the overall analysis based on their horizontal deviation. All but one of these subjects had improvement in both their vertical and horizontal deviations after therapy.
Suppression was not found to be significantly related to success but general trends can be noted. Subjects with alternating or intermittent suppression were more successful than those with unilateral or constant suppression. These trends would be expected because alternating or intermittent suppression allows for some binocular fusion. Unilateral suppression decreases fusion between the eyes. Constant suppression prohibits binocularity, which creates an obstacle for successful vision therapy treatment because the suppression must first be addressed to allow for vergence training.

The vision therapy programs reported were similar between subjects and 49 subjects did vergence training. Brock string, barrel card, and vectorgrams were most frequently used exercises. Computerized binocular home vision therapy program (HTS) and/or Vision Therapy System (VTS3/4) were the computer orthoptic training programs reported. The design of this study did not allow for evaluation of specific vision therapy exercises in regards to successful treatment of strabismus in adults. Although similar exercises were reported for most subjects, every clinician performs therapy differently and that could influence success. The estimated number of vision therapy sessions in this study varied from 6 to 168 sessions. The wide range of therapy sessions may partly be due to patient drop out and variation in the rate and level of improvement with therapy. There was no relationship between success and number of vision therapy sessions. Future research should use a more exact way of tracking vision therapy sessions or restrict vision therapy to the same number for each subject.

Only 14 of the 52 subjects returned the AS-20 questionnaire. The participating doctors mailed the AS-20 to their subjects so it is difficult to determine an expected
response rate because we do not know how many subjects received the questionnaire. The questionnaire was mailed in an Ohio State University envelope so some subjects may not have opened the envelope. The responding subjects with strabismus who had undergone vision therapy had similar HRQOL questionnaire scores when compared to the expected normal value. The AS-20 composite scores of the subjects were not significantly different from the normal threshold score. When broken down into the questionnaire subsections, the mean post-therapy functional score was not significantly different from the normal threshold and the mean post-therapy psychosocial score (97.5) was higher than the normal threshold (93). Depending on the definition of success there were 47-60% of subjects who were successful, but 72.7% of the subjects who returned the AS-20 questionnaire were successful. This may indicate that those who had more successful outcomes were more likely to return the questionnaire.

HRQOL questionnaires have been used to document success of strabismus surgery. The questionnaire is administered before and after surgery to compare HRQOL scores. (Hatt, Leske, Liebermann, & Holmes, Comparing Outcome Criteria Performance in Adult Strabismus Surgery, 2012) A similar technique could be employed as another determinant of success for vision therapy treatment in future research. This study only had AS-20 questionnaire scores from after treatment due to the retrospective nature of the study so we were unable to compare before and after.

Sample size was a limiting factor in this pilot study investigating the success of adults who undergo vision therapy for strabismus. Only a small group of patients were identified as meeting the inclusion and exclusion criteria. Also, adults with strabismus
may be an underserved population who are not receiving eye care or have not been offered the option of treatment due to the lack of research supporting vision therapy as a successful treatment for strabismus in adult populations.

The retrospective nature and size of this study limited the statistically significant results that could be found. The clinical data provided varied between subjects leading to even smaller sample sizes for evaluation of before and after for clinical measurements. This study was also limited by the determination of success for subjects after therapy. Success was only measured by cover test in this study, although other areas of clinical testing may also be used to determine success. Moving forward, a prospective study using a specific vision therapy program, consistent data measurements for before and after therapy, and quality of life questionnaires administered before and after therapy, would allow for more thorough investigation of predictive factors for success of vision therapy treatment for adults with strabismus.

In conclusion, this study showed meaningful improvements after therapy in some adults with strabismus. Furthermore, those with global stereopsis and those with an intermittent deviation were more likely to be successful with therapy.
References


Appendix A: Patient Data Form
Adult Strabismus and Vision Therapy

Please complete the form with **ENTERING/BASELINE** patient data. If more space is needed, please use the back of page or another page if necessary.

Age: 

Gender: □ Male  □ Female

**Strabismus History**

Age of onset: 

Surgery: □ Yes  □ No 

Number of Surgeries: 

Age(s) of Surgery:

**Refractive Error & Correction**

OD: Prism: Add: Distance: Near:

OS: Prism: Add: Distance: Near:

**Stereopsis**

Random Dot: Linear/Local:

Type of stereo test used:

**Versions/Ductions**

Cover Test:

Distance: 

Near:

**Cyclo deviation**

**Suppression** □ None  □ O/O  □ Intermittent  □ Central 
□ OS  □ Constant  □ Peripheral 
□ Alternating

**Fixation**

**Fusion Ranges**

Type of test used:

**Accommodative Ability**

(non-presbyopes) Type of test used:

**Other Pertinent Data:**
Adult Strabismus and Vision Therapy

Diagnosis:

Vision Therapy Methods

☐ Amblyopia Therapy:
☐ Eccentric Fixation Therapy:
☐ Anomalous Correspondence Therapy:
☐ Anti-Suppression Therapy:
☐ Accommodative Therapy (push-up, rock, etc):
☐ Vergence Therapy:
☐ Brock String/Barrel Card
☐ Computer Orthoptics
☐ Vectograms
☐ Life Savers Cards
☐ Jump Vergences
☐ Eccentric Circles
☐ Aperture Rule
☐ Other

If other, please describe:

Duration of therapy:

Is patient doing maintenance therapy?:  ☐ Yes  ☐ No
**Adult Strabismus and Vision Therapy**

Please complete the form with EXITING/POST-THERAPY patient data. If more space is needed, please use the back of page or another page if necessary.

| Age: | Gender: □ Male □ Female |

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<td>□ Intermittent □ Constant □ Central □ Peripheral</td>
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<td>Fusion Ranges</td>
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<td>Accommodative Ability (non-presbyopic)</td>
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| Other Pertinent Data: |
Appendix B: Adult Strabismus Questionnaire (AS-20)
Adult Strabismus Quality of Life Questionnaire (AS-20)  
(May 2008 version)

Instructions for Patient

The AS-20 is a short questionnaire with statements about how strabismus (misaligned eyes) may affect you in your everyday life.

If you are unable to complete this on your own, please ask for someone to assist you.

Instructions:

• Please respond to EACH statement by circling the response that best reflects how you feel.

• Circle only ONE response for each statement.

• Please answer based on your experiences during the past month, or since your last appointment if sooner.

• If you wear glasses or contact lenses respond as if you were wearing them.

• If you are not sure how to respond, please circle the response you think is most appropriate and make a comment in the margin.

If you have any questions please ask.

Thank you for completing this questionnaire.
1) I worry about what people will think about my eyes
   | Never | Rarely | Sometimes | Often | Always |

2) I feel that people are thinking about my eyes even when they don't say anything
   | Never | Rarely | Sometimes | Often | Always |

3) I feel uncomfortable when people are looking at me because of my eyes
   | Never | Rarely | Sometimes | Often | Always |

4) I wonder what people are thinking when they are looking at me because of my eyes
   | Never | Rarely | Sometimes | Often | Always |

5) People don't give me opportunities because of my eyes
   | Never | Rarely | Sometimes | Often | Always |

6) I am self conscious about my eyes
   | Never | Rarely | Sometimes | Often | Always |

7) People avoid looking at me because of my eyes
   | Never | Rarely | Sometimes | Often | Always |

8) I feel inferior to others because of my eyes
   | Never | Rarely | Sometimes | Often | Always |

9) People react differently to me because of my eyes
   | Never | Rarely | Sometimes | Often | Always |

10) I find it hard to initiate contact with people I don't know because of my eyes
    | Never | Rarely | Sometimes | Often | Always |
11) I cover or close one eye to see things better

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<th>Rarely</th>
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12) I avoid reading because of my eyes

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13) I stop doing things because my eyes make it difficult to concentrate

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<th>Rarely</th>
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14) I have problems with depth perception

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<th>Rarely</th>
<th>Sometimes</th>
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15) My eyes feel strained

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<th>Rarely</th>
<th>Sometimes</th>
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16) I have problems reading because of my eye condition

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<th>Sometimes</th>
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17) I feel stressed because of my eyes

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18) I worry about my eyes

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19) I can’t enjoy my hobbies because of my eyes

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20) I need to take frequent breaks when reading because of my eyes

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May 2008 version