# Preoperative Binocular Vision Characteristics in the Age-related Cataract Population

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# Abstract

**Background:** This study is the first part of the "Binocular Vision Anomalies after Cataract Surgery" study that aimed to investigate the impact of cataract surgery on binocular vision status in adults with age-related cataract. This study aimed to investigate the preoperative binocular vision status of participants with age-related cataract.

**Methods:** Patients who elected to undergo bilateral cataract surgery ($\geq$50 years of age) were recruited. Clinical measures of binocular vision including stereopsis, ocular alignment, fusional vergence, vergence facility, convergence amplitude and a symptom survey related to binocular vision anomalies were administered. A detailed classification protocol was established to identify the presence of binocular vision anomalies. The frequency of specific binocular vision anomalies and normative data of binocular vision measures were reported.

**Results:** A total of 73 subjects were evaluated. No strabismus was detected in the cohort. Non-strabismic binocular vision anomalies were detected in 24 subjects (32.9%), of whom 18 (24.7%) had convergence insufficiency, 3 (4.1%) had basic exophoria, 2 (2.7%) had convergence excess, and 1 (1.4%) had fusional vergence dysfunction. Decreased vergence facility and convergence amplitude were more common compared to the pre-presbyopes ($p < 0.0001$).

**Conclusion:** Binocular vision problems, especially convergence insufficiency, are common in the adults with age-related cataract. The study results demonstrate that the lack of normative binocular vision data for the presbyopic population is a significant gap in the literature and suggest the need for a study of normative data for this population.

## Trial Registration

The study was registered at ClinicalTrials.gov (NCT03592615, USA).

# Background

Cataract surgery is the most commonly performed ophthalmic surgical procedure[1], and satisfactory monocular visual function is usually achieved in most patients[2]. However, studies indicate that post-surgical strabismic and non-strabismic binocular vision anomalies may occur leading to symptoms such as diplopia and asthenopia[3–8]. Diplopia and strabismus are the most commonly reported binocular vision-related complications after cataract surgery due to extraocular muscle paresis caused by infiltration anesthesia.[3, 6] In recent years, with almost universal application of topical anesthesia, the postoperative frequency of diplopia and strabismus is less common[9]. However, there were still indications in the literature that non-strabismic binocular vision anomalies may occur after topical anesthetic cataract surgery, including heterophoria[4, 5, 8], aniseikonia[4], and abnormalities in sensory and motor fusion[10]. Most studies have failed to provide data about pre-surgical binocular vision status, and/or have not performed a comprehensive binocular vision evaluation.

According to previous studies, the frequency of non-strabismic binocular vision anomalies varies from 13.2–56.2% in children or young adults[11–14]. This wide variability may be due to inconsistency in selection of diagnostic criteria[15], and the variability in binocularity among various age groups[16, 17]. As suggested by previous studies, age has an impact on binocular vision function, primarily because of the gradual loss of accommodation in presbyopia[16, 17]. However, major gaps in the current literature are a lack of data about the frequency of binocular vision anomalies in the presbyopic population, and limited information about expected findings in the older adult.

In the only relevant study of older adults, Leat et al.[18] retrospectively reviewed the medical records of an optometry clinic population aged 60 and older. They calculated the frequency of abnormal binocular vision test results including strabismus or phoria, incomitance, poor pursuits, and remote near point of convergence. They found that the frequency of any abnormal binocular vision test was 41–51% among different age subgroups. Leat et al.'s study[18] was the first reporting frequency data for abnormal binocular vision test results in older adults. While useful, the results unfortunately did not answer the question of what the frequency of binocular vision disorders is in older adults. Binocular vision disorders are considered syndromes, and therefore rather than a single test, the diagnosis is based on a series of test results[19]. As suggested by Scheiman and Wick, such tests include a minimum database consisting of the near point of convergence, the cover test at distance and near, and step vergence ranges at distance and near[19].

This study was designed to prospectively address one of the gaps in the literature by determining the frequency of binocular vision disorders in patients scheduled for bilateral cataract surgery, using well-defined clinical criteria, and a comprehensive test battery. In a follow-up paper we will compare the frequency of binocular vision anomalies and binocular vision measures before and after cataract surgery and determine risk factors that could predict those patients who might experience new binocular vision anomalies after cataract surgery. Herein, we present baseline data from a cohort of older presbyopes scheduled for bilateral cataract surgery.

# Methods

# Study design and subjects

This prospective study followed the tenets of the Declaration of Helsinki, and the study protocol was approved by the Institutional Review Board of Salus University (HQT1809). Patients with age-related cataract were consecutively recruited at The Eye Institute of Pennsylvania College of Optometry at Salus University and the medical practice of James S. Lewis, MD. (Elkins Park, PA). Written informed consents were obtained from all participants before any study testing was administered. The study was registered at ClinicalTrials.gov (NCT03592615, USA).

Major eligibility criteria included: ≥50-years-old, patient has elected to undergo bilateral cataract extraction and intraocular lens implantation, best corrected visual acuity ≥ 20/80 in each eye. Patients

with any ocular pathology other than cataract or strabismus, or a history of previous ocular surgery related to the extraocular muscles, intraocular lens implantation or laser refractive surgery were excluded.

A comprehensive battery of binocular vision tests (Table 1) was administered to all the subjects before cataract surgery. A detailed diagnostic classification protocol (Table 2) was used to identify and classify the presence of a binocular vision anomaly.

Table 1
Descriptions of outcome measures

| Binocular function assessed | Equipment/units of measure | Administration details |
| --- | --- | --- |
| Stereoacuity | Randot Stereo Test/ arc seconds (") | Begin with global stereotest, then contour test was performed to determine the exact stereoacuity that could be measured up to 20". |
| Ocular deviation | Occluder, prism bar/Δ, exodeviations recorded with a minus sign, esodeviations with plus sign. | Unilateral cover test followed by the alternate prism cover test. Near and distance ocular deviations were measured, respectively. |
| Fusional vergence | Horizontal prism bar/Δ. | A target (thin vertical line) was held 40 cm away and a hand-held prism bar was used. Near and distance, positive fusional vergence (BO) and negative fusional vergence (BI) were measured by slowing increasing the amount of prism. The result was 4 measures: distance BI, distance BO, near BI, near BO. Each measure was recorded as 3 values: blur/break/recovery. |
| Vergence facility | 12 BO/3 BI prism flipper/FPM. | A target (thin vertical line) was held 40 cm away and a hand-held prism bar was used, and the prism side with most difficulty was recorded. Near and distance vergence facility were measured, respectively. |
| Near point of convergence | Near Point Rule with narrow vertical line/cm. | Near Point Rule held against brow, target slowly moved towards eye to until first sustained report of double vision (break), then moved away until recovery of single vision (recovery). Results were recorded as 2 values: near point of convergence break and recovery. |
| Convergence Insufficiency Symptom Survey (CISS) | 15-item questionnaire/score from 0 up to 60. | Patient was asked to complete the survey. A higher score indicating more symptoms. |
| Δ = prism diopter, BO = base-out, BI = base-in, cm = centimeters, FPM = flips per minute. | | |

## Table 2
## Diagnostic criteria for non-strabismic binocular vision anomalies
### (adapted from the BAND study[12])

**Convergence insufficiency**

Symptoms:

Associated with reading or other near tasks and generally worse at end of day. The most common symptoms include asthenopia and headaches, intermittent diplopia.

Signs:

1) Exophoria at near ($\geq 4\ \Delta$), greater than distance.

2) Receded near point of convergence break with accommodative target $\geq 6$ cm.

3) Insufficient positive fusional vergence at near (i.e., failing Sheard's criterion or positive fusional vergence $\leq 15\Delta$ base-out break).

4) Vergence facility $\leq 9$ cycle per minute (CPM) (difficulty with 12 $\Delta$ Base out prism).

For diagnosis: 2-sign criterion: sign 1) plus sign 2) or 3); 3-sign criterion: all the first three criteria are mandatary.

**Divergence insufficiency**

Symptoms:

Associated with distance viewing. The most common symptoms include intermittent diplopia for distance, headache, and eyestrain.

Signs:

1) Esophoria greater at distance than near by $\geq 3\ \Delta$.

2) Reduced negative fusional vergence break $\leq 6\ \Delta$ for distance.

3) Vergence facility $\leq 9$ cycle per minute (CPM) (difficulty with 3 $\Delta$ Base in prism).

For diagnosis: Criterion 1 is mandatory with a minimum of one criterion from 2 and 3.

**Convergence excess**

Symptoms:

Associated with reading or other near tasks and generally worse at end of day. The most common include asthenopia, headaches and intermittent diplopia.

Signs:

1) Esophoria greater at near than distance by $\geq 3$PD.

2) Reduced negative fusional vergence break $\leq 8\ \Delta$ at near, or if Sheard's criterion is not met (that the negative fusional vergence measures less than twice the magnitude of the near phoria).

3) vergence facility $\leq 9$ CPM (difficulty with 3 $\Delta$ Base in prism).

| Convergence insufficiency |
| --- |
| For diagnosis: Criterion 1 is mandatory with a minimum of one criterion from 2 and 3. |
| **Divergence excess** |
| Symptoms: |
| Associated with distance viewing than near. The most common complaint is related to cosmesis. |
| Signs: |
| 1) High exophoria or intermittent exotropia at distance with the magnitude of the deviation for distance greater than near of $\geq 10\ \Delta$. |
| 2) The proportion of time the deviation is intermittent is greater at distance than at near on the office control score. |
| 3) Low negative fusional vergence break $\leq 8\ \Delta$ for distance. |
| For diagnosis: Criterion 1 is mandatory. |
| **Fusional vergence dysfunction** |
| Symptoms: |
| Associated with reading or other near tasks and generally worse at end of day. The most common symptoms include asthenopia and headaches, blurred vision and difficulty concentrating on near visual tasks. |
| Signs: |
| 1) Reduced negative fusional vergence $\leq 8\ \Delta$ and positive fusional vergence $\leq 15\ \Delta$ break at near or if Sheard's criterion is not met. |
| 2) vergence facility $\leq 9$ CPM (difficulty with $3\ \Delta$ base in and $12\ \Delta$ base out prism). |
| For diagnosis: All criteria are mandatory. |
| **Basic esophoria** |
| Symptoms: |
| Associated with reading or other near tasks and with distant activities. The most common near point complaints include eyestrain, headaches, and blurred vision. Common symptoms associated with distance include blurred vision and diplopia, when watching television and in classroom. |
| Signs: |
| 1) Equal magnitude of esophoria at distance and near (within $5\ \Delta$ are considered equal). |
| 2) Reduced negative fusional vergence break $\leq 3\ \Delta$ at distance and $\leq 8\ \Delta$ at near. |
| 3) vergence facility $\leq 9$ CPM (difficulty with $3\ \Delta$ Base in prism). |
| For diagnosis: Criteria 1 is mandatory with one out of the next two criteria. |

| Convergence insufficiency |
|---|
| Basic exophoria |
| Symptoms: |
| Associated with reading or other near tasks and with near and distant activities. The most common near point complaints include eyestrain, headaches, and blurred vision. |
| Signs: |
| 1) Equal amount of exophoria at distance and near (within 5 $\Delta$ are considered equal). |
| 2) Receded near point of convergence break ≥ 6 cm with accommodative target. |
| 3) Reduced positive fusional vergence break ≤ 10 $\Delta$ for distance and ≤ 15 $\Delta$ at near. or if Sheard's criterion is not met. |
| 4) vergence facility ≤ 9 CPM (difficulty with 12 $\Delta$ Base out prism). |
| For diagnosis: Criterion 1 is mandatory with two out of the next three criteria. |

# Outcome measurements

The eligibility assessment was performed using routine eye examination procedures to rule out ocular pathology other than cataract, refractive error, and strabismus. As described in Table 1, a comprehensive battery of binocular vision tests including stereopsis, ocular alignment, fusional vergence, vergence facility, near point of convergence, and a symptom survey for binocular vision anomalies was administered to all the subjects. All examinations were performed using the habitual prescriptions or trial frames that provided best corrected visual acuity. The testing protocol required about 25 minutes. To evaluate the near point of convergence, a thin vertical line target mounted on a Near Point Rule was used. In the only previous report on the near point of convergence measurement for older presbyopes the procedure and target used was not described[18]. The standard target used in children or pre-presbyopes is a vertical column of 20/30 letters, but in pilot testing the presbyopic participants in this study were unable to see the line clearly. Thus, a thin vertical line was used based on a previous study[20] that compared the use of a vertical line target mounted on a Royal Air Force rule with N5 letter target, in which there was no significant difference in the result with the two targets. All participants were presbyopic in this study, so accommodative testing was not performed.

# Diagnostic criteria for classification of binocular vision anomalies

Diagnostic criteria were adapted from the BAND study[12] (Table 2)). The only modification was to grade convergence insufficiency with a 3-sign criterion as recommended in previous studies, in which convergence insufficiency was sub-classified into 3-sign (definite), 2-sign (high suspect) and 1-sign (low suspect)[21]. The three clinical signs and their critical cut-offs used to grade convergence insufficiency include: exophoria at near ≥ 4 $\Delta$, greater than distance; receded near point of convergence break ≥ 6 cm; and, insufficient positive fusional vergence at near (i.e., failing Sheard's criterion or positive fusional

vergence ≤ 15Δ base-out break). Classification criteria were defined as follows: 3-sign convergence insufficiency requires all the three clinical signs; 2-sign convergence insufficiency requires sign 1 plus sign 2 or 3; 1-sign convergence insufficiency requires only sign 1[21]. In this study, the 2-sign and 3-sign criteria determined frequency data were reported. The unilateral cover test was used to determine if a constant or intermittent strabismus was present.

# Statistical analysis

All analyses were performed using SPSS Statistics 25.0 with an alpha level of 0.05 to determine the statistical significance. A calculation for the frequency of binocular vision anomalies was performed. Continuous data were expressed by means and standard deviations (SD), while categorical data were expressed by percent or numeric. A one-sample *t* test was used to compare the obtained binocular vision measures to that reported elsewhere for pre-presbyopes.

# Results

# Participant characteristics

From January to November 2019, 74 participants met the eligibility criteria, of whom 1 participant failed to complete the outcome evaluation, thus 73 participants were included. The mean age was 70.2 years. Demographics and participant characteristics are shown in Table 3.

Table 3
Demographics and characteristics of the participants

| Demographics and characteristics | Values |
|---|---|
|  | Number |
| Gender (female/male) | 57/16 |
| Race (African American/Caucasian/Hispanic or Latino) | 68/4/1 |
|  | Mean ± SD |
| Age (year) | 70.2 ± 6.7 |
| Corrected distance visual acuity OD (LogMAR) | 0.15 ± 0.15 |
| Corrected distance visual acuity OS (LogMAR) | 0.16 ± 0.15 |
| Spherical equivalent OD (diopter) | -0.06 ± 2.24 |
| Spherical equivalent OS (diopter) | -0.03 ± 1.86 |
| Stereoacuity (arc second) | 160.68 ± 160.17 |
| OD: right eyes; OS: left eyes; LogMAR: logarithm of the minimum angle of resolution; SD: standard deviation. | |

# Frequency of binocular vision anomalies

As shown in Table 4, of the 73 participants enrolled, no strabismus was detected, while 18 (24.7%) had 3-sign convergence insufficiency and 40 (54.8%) had 2-sign convergence insufficiency. There were a small percentage of participants with other binocular vision conditions such as convergence excess, basic exophoria, and fusional vergence dysfunction.

Table 4
Frequency of binocular vision anomalies in the study cohort

| Condition | Frequency |
|---|---|
| Normal binocular vision | 67.1% (49/73) |
| 3-sign convergence insufficiency | 24.7% (18/73) |
| 2-sign convergence insufficiency | 54.8% (40/73) |
| Basic exophoria | 4.1% (3/73) |
| Convergence excess | 2.7% (2/73) |
| Fusional vergence dysfunction | 1.4% (1/73) |

# Binocular vision data from participants with normal binocular vision

In Table 5, the binocular vision data of the 49 participants with normal binocular vision in this study are presented.

#### Table 5
#### Binocular vision norms of 49 normal binocular vision presbyopes

| Clinical measures | Values (Mean ± SD) |
|---|---|
| Ocular deviation at distance (Δ) | -0.9 ± 2.2 |
| Ocular deviation at near (Δ) | -3.9 ± 3.8 |
| BI break at distance (Δ) | 10.5 ± 7.2 |
| BI recovery at distance (Δ) | 7.2 ± 5.8 |
| BO break at distance (Δ) | 20.4 ± 11.2 |
| BO recovery at distance (Δ) | 15.4 ± 9.5 |
| BI break at near (Δ) | 14.0 ± 5.7 |
| BI recovery at near (Δ) | 10.3 ± 4.0 |
| BO break at near (Δ) | 30.6 ± 12.6 |
| BO recovery at near (Δ) | 23.5 ± 11.6 |
| Vergence facility at distance (FPM) | 13.6 ± 11.5 |
| Vergence facility at near (FPM) | 23.0 ± 10.5 |
| Near point of convergence break (cm) | 8.6 ± 3.7 |
| Near point of convergence recovery (cm) | 10.6 ± 4.4 |
| Convergence Insufficiency Symptom Survey score | 20.0 ± 11.1 (42.9% subjects ≥ 21) |

Δ = prism diopter, BO = base-out, BI = base-in, cm = centimeters, FPM = flips per minute; SD: standard deviation.

## Discussion

Although the participants in this study were all diagnosed with cataracts requiring surgical intervention, the baseline data still provide valuable information for eye care clinicians regarding the presbyopic population with cataract. Among the 73 participants, no strabismus was detected, while non-strabismic binocular vision anomalies were common (32.9%), and the majority had convergence insufficiency (24.7%) based on a 3-sign diagnostic criterion.

The frequency of non-strabismic binocular vision anomalies reported in previous studies on pediatric or pre-presbyopic population varies from 13.15–40%, with convergence insufficiency the most frequently occurring disorder with a frequency ranging from 2.25 to 33%[11–14]. The wide variance among studies can be attributed to the age ranges of the studied populations, and inconsistency in the diagnostic testing and criteria used by investigators.

Comparison of these results to the existing literature is challenging for two reasons. First, there are no prospective normative data available in the literature for binocular vision function in older presbyopic patients, and only one retrospective study by Leat et al.[18] In addition, the study by Leat et al. did not include assessment of fusional vergence and vergence facility, and they did not report the actual frequency of binocular vision disorders. Rather, they reported the frequency of abnormal, individual test results for the cover test and near point of convergence. Hence, we were unable to directly compare our results to Leat et al.'s.

The second problem is that the previous studies of binocular vision in presbyopia did not include a comprehensive binocular vision evaluation. None of the previous studies evaluated all three necessary components of a binocular vision evaluation: eye alignment, near point of convergence and fusional vergence. For the few measures (ocular alignment at far and near, fusional vergence at far, vergence facility at near, convergence amplitude) that are available from previous studies[17, 22–24], there appears to be reasonably good agreement with our data.

However, when comparing our data to the expected finding in pre-presbyopes[25, 26], it is noteworthy that vergence facility was significantly slower in the presbyopic population. The expected values for near and distance vergence facility recommended by Gall et al. for the young adults[25, 26] are 30 flips per minute for near and 24 flips per minute for distance respectively, while in the present study we found 23 flips per minute for near ($t$ = -4.63, $p < 0.0001$) and 13.6 flips per minute for distance ($t$ = -6.32, $p < 0.0001$). Previous studies revealed a lack of correlation between vergence facility and the disparity vergence range[27]. This is supported by the results in this study showing normal, mean fusional vergence ranges, yet a decreased mean vergence facility measure detected. These findings suggest that to adequately assess fusional vergence a clinician should measure both the amplitude (fusional vergence ranges) and vergence facility. The mean break for the near point of convergence in the present study was 8.6cm compared to 2.5cm suggested by Scheiman & Wick[19] for young adults ($t$ = 11.56, $p < 0.0001$). Previous studies suggest that while there is an age-related decline in accommodative amplitude the convergence response remains relatively constant during the development of presbyopia[16, 17].

The Convergence Insufficiency Symptom Survey (CISS) is a well-validated symptom survey designed to be used as an outcome measure before and after intervention for patients with convergence insufficiency[28–30]. In young adults, a score of $\geq 21$ is considered significant, suggesting that the patient is symptomatic[29]. In this study, a mean CISS score of 20 was present and 42.9% participants showed CISS score $> 21$. However, it is important to remember that the CISS has been only validated for use in children and young adults. It has not been validated for use in presbyopic patients. Thus, the use of CISS for assessment of symptoms in the older presbyopic population should be used with caution until it is validated for this population.

Our data suggest, that if the current normative data are applied to the presbyopic population with cataracts requiring surgery, there is a high frequency of non-strabismic binocular vision anomalies. However, these data also suggest that new research should be directed at developing normative data for

this population. There is also a significant need for prospective studies of the presbyopic population with no cataract or other eye disease.

There are limitations in this study: 1) Because our data were derived from the "Binocular Vision Anomalies after Cataract Surgery" study, in which the participants were all cataract patients, the results may not be extrapolated to the older adult without cataracts. However, given the high frequency of cataracts in older adults, these study data do provide a meaningful picture of binocular vision in older adults; 2) The majority of this cohort was African American, which makes generalization to other populations potentially problematic.

## Conclusions

The results from this study using both a comprehensive binocular vision assessment, and universally applied diagnostic criteria demonstrate that several clinical measures of binocular vision in the presbyopic population are significantly different from the young adult population, and the frequency of non-strabismic binocular vision anomalies particularly convergence insufficiency is common before cataract surgery. This finding suggests the need for future research to establish normative data for the presbyopic population and the frequency of non-strabismic binocular vision anomalies for this population.

## Abbreviations

BAND: Binocular Vision Anomalies and Normative Data; CISS: Convergence Insufficiency Symptom Survey; BO: base-out; BI: base-in; FPM: flips per minute; CPM: cycle per minute; LogMAR: logarithm of the minimum angle of resolution; SD: standard deviation.

## Declarations

### Ethics approval and consent to participate

This study followed the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board of Salus University (HQT1809). Written informed consents were obtained from all participants.

### Consent for publication

Not applicable.

### Availability of data and materials

Available upon request from the corresponding author.

### Funding

## Authors' contributions

Concept and design (QQT, JSL, MMS); data acquisition (QQT, JSL); data analysis/interpretation (QQT, JSL, CJL, XL, XLT, JW, MMS); drafting of the manuscript (QQT); critical revision of the manuscript (QQT, CJL, XL, XLT, JW, MMS); statistical analysis (QQT); securing funding: (QQT, JW, MMS); supervision (QQT, JSL, MMS); All authors read and approved the final manuscript.

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