Modeling Visual Symptoms and Visual Skills to Measure Functional Binocular Vision

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Abstract. Obtaining a clear image of the world depends on good eye coordination (“binocular vision”). Yet no standard exists by which to determine a threshold for good vs poor binocular vision, as exists for the eye chart and visual acuity. We asked whether data on the signs and symptoms related to binocular vision are sufficiently consistent with children’s self-reported visual symptoms to substantiate a construct model of Functional Binocular Vision (FBV), and then whether that model can be used to aggregate clinical and survey observations into a meaningful diagnostic measure. Data on visual symptoms from 1,100 children attending school in Los Angeles were obtained using the Convergence Insufficiency Symptom Survey (CISS); and for more than 300 students in that sample, 35 additional measures were taken, including acuity, cover test near and far, near point of convergence, near point of accommodation, accommodative facility, vergence ranges, tracking ability, and oral reading fluency. A preliminary analysis of data from the 15-item, 5-category CISS and 15 clinical variables from 103 grade school students who reported convergence problems (CISS scores of 16 or higher) suggests that the clinical and survey observations will be optimally combined in a multidimensional model.

Introduction

Using two eyes together to provide merged and unconfused images to the brain is a neurological challenge. Though we rarely think about it, the visual system must be trained to achieve ocular coordination, just as the body must be trained to swing a bat or ride a bicycle. It may seem surprising, therefore, that no gold standard akin to the eye chart for assessing monocular visual acuity exists for a first-level assessment of functional binocular vision.

The clinical diagnosis of “convergence insufficiency” has classically been used to connote binocular dysfunction that is not as extreme as strabismus yet indicates an inability to use the two eyes together in an optimally coordinated fashion. Convergence ability is assessed in a variety of ways, including near point tests or fusion ranges. Although each vergence measure has a continuum of possible values, the criteria for positioning a diagnosis on the continuum can be wide-ranging. While all agree that a tropia (an eye that does not converge under stimulation) indicates strabismus [1-2], and tables exist to assess

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near point with regard to age [3], and most might agree that accommodative or tracking problems contribute to non-strabismic binocular discomfort and function, there is no universal agreement on the basic criteria for overall functional binocular vision.

A body of previous research investigated these issues without the benefit of probabilistic construct models [4-5]. Results demonstrated:

- A significant relationship between symptoms of visual skill problems as measured by the Convergence Insufficiency Symptom Survey (CISS) [6] and three separate measures of reading fluency. One measure was administered by the school, and thus was completely free of experimenter bias.
- Reading speed slowed significantly when subjects with normal convergence skills read through prisms. Magnitude of reduction was directly related to the degree of vergence instability. Stress on the vergence system, as in conditions such as FBV, may result in slower reading rates for children in school.
- Significant correlations between symptom scores from the FBV symptom survey and actual signs measured during school visits on the same subjects, which suggests that the CISS is a valid indicator of visual skill problems in children of school age.

Those familiar with Rasch models may assume that they are used only to evaluate questionnaire or educational test data. But, by adopting innovative theoretical developments [7-8] and previous applied research methods [9-13], the aim here is to evaluate FBV as a measureable state variable that can be estimated from a combination of clinical and survey observations. The availability of a large dataset with multiple variables and the CISS responses will support the formulation and testing of an underlying model that could ultimately support development of a standard FBV test.

Original study design

Students were recruited from four elementary schools in Los Angeles, grades 3 through 6 (N=1062). The CISS was administered to all students. Subjects were selected for inclusion in the study if the CISS score was less than 15, indicating convergence problems, reducing the sample size to 418. Clinical variables, including aspects of acuity and binocular vision, were organized into primary (11 items) and secondary (four items) dimensions of signs and symptoms. Clinical variables were measured for 312 cases. Some subjects participated in a binocular visual skill training program via internet at their school (N=51; six did not complete the intervention). All variables were measured at each of four time points: pre-intervention, and after each of three training sessions. The analysis presented here involves 103 students from one school; of these, 42 had measures at all four time points.

Frequencies of the original optometric measures were examined and ratings were assigned to express the inferences usually made about the impact of the variable on FBV. Data were fit to a multidimensional random coefficients multinomial logit model [14-15] to assess the visual and survey dimensions measured by the clinical and survey variables, and the relationship between them.

Preliminary results

Preliminary reanalyses of subsamples of this study’s CISS data have provisionally established reasonable fit to Rasch rating scale models. Comparisons of item difficulty locations with similar items from other tests were used to investigate whether the underlying latent variables are similar: Pre-training CISS item location estimates based on 202 students with CI from three schools correlated 0.71 with CISS item logit values computed from Borsting, et al.’s [6] “Always” category response frequencies for 47 CI students. The correlation was 0.93 for item locations estimated from Borsting et al.’s 56 NBV student responses and our previous 635 NBV student responses. Borsting et al. [6] do
not report item location reliabilities, so it is not possible to disattenuate these correlations; however, given the low sample sizes in the Borsting et al. study, calibration error is likely high, so disattenuation would increase the correlations. In addition, Rasch item location estimates reported by Conlon, et al. [16] for the Visual Discomfort Scale correlated 0.71 with nine CISS items having matching content.

Of 103 students from one school in grades 3-5, 257 measures were made across four time points. Students ages ranged from 8-12, with a mode = 9; 91% were between ages 8-10. No students had had eye surgery, 7 of the 42 with measures at all four time points had worn glasses/contacts at some time, 5 of 42 owned glasses at that time, and 3 of 42 wore glasses/contacts regularly in class and had them that day.

Measures changed in the expected directions of improved FBV but were not statistically significant due to the small sample size. Measures of the primary FBV signs correlated 0.23 with the secondary signs, and -0.13 with the CISS measures (indicating worsening conditions as the CISS scores dropped and the FBV measures increased). The secondary signs correlated -0.38 with the CISS measures.

Conclusion
The small sample size in this analysis, from only one school, precludes assessing a multidimensional model that parameterizes time points. A larger sample from all 4 schools will enable comparison of changes in FBV with reading outcomes. Analyses presented elsewhere show a poor correlation ($r = 0.17$ to $0.23$; $r^2 = \text{approx.} 0.05$) between acuity and visual reading symptoms. Thus, monocular eye chart measurements are a poor predictor of reading problems in school, supporting the need for broader FBV assessments and standards.

Neither Powers nor the developers of the CISS hypothesized a unified FBV construct or proposed to develop a theoretical model of FBV. Powers’ existing data will enable us to understand whether the high correlation between the CISS and FBV orthoptics implies that the integration of an FBV symptom survey (a revised CISS) with an orthoptics assessment would be likely to produce a common or separate self-report and clinical measure(s) of FBV, and also how the resulting measure or measures relate to reading outcomes.

The significance of the project lies in its attempt to provide a measurement tool to assess FBV in the classroom. The results will be important both to the field of Special Education, where there is great need to assess physical readiness for reading in order to avoid over-categorization as well as promote appropriate remediation, and also for classrooms at large, where many students’ reading fluency may be poor due to slow or inaccurate visual skills during reading. Teachers are more likely than anyone to notice that a child seems uncomfortable while reading. This work could provide them with an assessment tool for their use. In most states (California included) students are screened for visual acuity and referred to an eye care professional outside of school if they fail. But the test only assesses distance acuity and does not allow screening for visual skills close to the face that require both eyes.

Hence it is important for those in education to have the ability to assess or screen for FBV so that they can take the appropriate action. Part of the present work will use existing data to answer such questions as: How much of reading behavior is determined by acuity? By binocular skills? By oculomotor function? Answers to questions like these can help shape health and education policy in the future as well as give teachers and parents the insights they need to enable them to provide the best guidance for their child’s education. And the development of a tool that can be used to easily assess binocular vision ability would be a welcome addition to educators, who struggle daily with determining which children might need help with basic sensory processing issues before they are ready to learn.
References

[1] Duke-Elder S 1973 System of Ophthalmology, Vol 6: Ocular Motility and Strabismus Mosby, London
[2] Hoyt C S, and Taylor D 2013 Pediatric Ophthalmology and Strabismus 4th Edition Elsevier
[3] Griffin J R, and Grisham J D 2002 Binocular Anomalies New York: Butterworth-Heinemann, Fourth Edition
[4] Morita Y, Hoffman R and Powers M 2010 Visual skills and reading: Symptoms and fluency in elementary school students In Low Vision, Task Performance, Plasticity and Rehabilitation Session 3632/A241, Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, Tuesday, May 4
[5] Powers M K, Miner G L, Morita Y and Tyler C W 2010 Vergence stress significantly affects reading rates In Reading in Aging and Disease 3068/A263 conducted at the Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, Tuesday, May 4
[6] Borsting E J, Rouse M W, Mitchell G L, Scheiman M, Cotter S A, Cooper J, et al 2003 Optom. and Vision Sci. 80 832-838
[7] Christensen K B 2007 In Advances in Statistical Methods for the Health Sciences: Applications to Cancer and AIDS Studies, Genome Sequence Analysis, and Survival Analysis pp 95-108 New York: Springer-Verlag
[8] Zwinderman A 1991 Psychometrika 56 589-600
[9] Best W R 2008 In J N Cadwallader Ed, Crohn’s Disease: Etiology, pathogenesis and interventions Chapter 5 New York: Nova Science Publishers, Inc
[10] Cipriani D, Fox C, Khuder S and Boudreau N 2005 J. Appl. Meas. 6 180-201
[11] Fisher W P Jr, and Burton E 2010 J. Appl. Meas. 11 271-287
[12] Hughes L, Perkins K, Wright B D, and Westrick H 2003 J. Alzheimer’s Dis. 5 367-373
[13] Massof RW, and McDonnell PJ 2012 Investigative Ophthal. & Visual Sci. 53 1905-1916
[14] Adams R J, Wilson M R, and Wang W-C 1997 Appl. Psychol. Meas. 21 1-24
[15] Briggs D, and Wilson M 2003 J. Appl. Meas. 4 87-100
[16] Conlon E G, Lovegrove W J, Chekaluk E, & Pattison P E 1999 Visual Cognition 66 637-663

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