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Toward a Standard for Measuring Functional Binocular Vision: Modelling Visual Symptoms and Visual Skills

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Abstract. Clear visual images require an ability to coordinate eye functions. Despite the central importance of binocular vision in everyday functioning, no standard exists for distinguishing good vs poor binocular vision, in contrast with monocular vision's eye chart and visual acuity measures. This study begins to relate the signs and symptoms of binocular vision with children's self-reported visual symptoms to substantiate a model of Functional Binocular Vision (FBV). Following Rasch's probabilistic application of Maxwell's method of analogy, we tested whether observations of visual symptoms and skills were sufficiently consistent to define interval units of measurement. Visual symptom data were obtained from over 1,000 students in grades 3-6 in four California schools using the Convergence Insufficiency Symptom Survey (CISS). An additional 21 optometric acuity and FBV measures were made for more than 459 of those students, as their CISS scores indicated problems in binocular vision. Of these 459, 78 completed an intervention training the eyes in binocular function and provided at least two sets of CISS and optometric measures. The CISS, acuity, and FBV measures all define interval measures spanning at least three statistically distinct groups (Cronbach's alpha >0.75). The final CISS measure was predicted in a regression model by the initial and final FBV measures ($F=3.5$, 2 df1, 74 df2, $p=.03$). Further research will be needed to refine the measures and establish practical guidelines.

1. Introduction

Probabilistic approaches to modelling complex constructs offer new opportunities for scientific advancement that extend beyond the traditional areas of educational assessment and survey research in which these models are usually applied [1-4]. Measurement science in general has lately begun focusing on explicitly formulating and stating mathematical models of its objects of investigation [1], as opposed to conceiving of modelling primarily in terms of data analytic algorithms. Probabilistic approaches to measurement modelling emerging in the work of Rasch and others [5-6] open up promising lines of investigation. These approaches are intellectual descendants of James Clerk Maxwell's modelling method of analogy [7-8], which has lately become a matter of intense interest among historians and philosophers due to the central role it played in the advances made by Maxwell and others.

Maxwell is a noted figure in the history of science not just for his method of analogy in modelling but also for his metrological approach to measurement. In psychology, Maxwell has been influential in an indirect manner via his influence on Rasch [5], a Danish mathematician whose work has become increasingly recognized as offering alternatives to the usual assumptions about and approaches to

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quantification in a number of fields [1-7]. The present research into vision is part of a larger trend toward integrations of existing physical measures in unidimensional models of constructs at higher orders of complexity, and the further integration of models of these kinds of constructs with models of associated constructs observed using the assessment and survey tools of psychology and the social sciences [9-13].

2. Functional Binocular Vision

The human body's visual system learns to achieve ocular coordination. Just as with almost any task involving muscular control, using our eyes to merge their separate images is a neurological feat. In the same way many things are learned to the point of becoming automatic reflexes, so also do we learn to use the information from our eyes to see. Why is it, then, that we do not have any kind of standard for functional binocular vision (FBV) analogous to the eye chart for assessing monocular visual acuity?

"Convergence insufficiency" has been used clinically to denote binocular dysfunction less extreme than strabismus yet severe enough to indicate an inability to optimally coordinate the two eyes. Convergence is commonly assessed using near point tests or fusion ranges. Each vergence measure has a range of possible values, and criteria for making a diagnosis vary markedly. There is no universal agreement on criteria for assessing FBV, though there is general agreement that a tropia (an eye that does not converge under stimulation) indicates strabismus [14,15]. Age-related tables inform assessments of near point [16], and many agree that non-strabismic binocular discomfort and function follow at least in part from accommodative or tracking problems.

Previous investigations of these issues [17-18] were undertaken without access to probabilistic construct models. These studies' results included documentation that:

- Stress on the vergence system, as occurs in FBV, may result in slower reading rates [17]. Reading speed slowed significantly when students with good binocular convergence skills read through prisms. Magnitudes of speed reduction were directly related to the degree of vergence stress induced by the prisms.
- Symptoms of visual problems measured by the Convergence Insufficiency Symptom Survey (CISS) were shown to be related to three separate measures of reading fluency. One of these measures was administered by school personnel, removing all chance of experimenter bias.
- Symptom scores from the FBV symptom survey were significantly correlated with vision optometrics measured on the same subjects during school visits [18], indicating that the CISS validly illuminates children's visual skill problems.

The aim in revisiting these data in the context of probabilistic models of measurement is to test the hypothesis that FBV is a measureable state variable estimable from a mix of clinical and survey observations. The existing dataset supports formulation and testing of a more advanced model that may eventually lead to a standard FBV test.

3. Study design

The CISS was administered to 1,062 students ages 8 - 11 attending elementary schools in Los Angeles. Inclusion in the study required CISS score greater than 15, indicating convergence problems, reducing the sample size to 418. Clinical variables, including aspects of acuity and binocular vision, were organized into an FBV scale (13 items) and an acuity scale (8 items). Clinical variables were measured for 312 cases overall. Some subjects participated in binocular visual skill training via the Internet. The analyses presented here involve, first, 78 students from three schools who each had at least two of each of the three measures (CISS, acuity, and FBV) made at time points separated by several months, and second, 39 of those 78 students who experienced marked improvement in FBV and associated reductions in convergence insufficiency symptoms.

Frequencies of the optometric measures were used to assign arrays of ratings in accord with the clinical inferences typically made concerning FBV. Data were fit to a probabilistic model formulated separately for each of the two visual dimensions and one survey dimension measured.

4. Results

With treated students' multiple measures, there were 1,412 total cases estimated for the 15-item CISS. The original five-category rating scale was collapsed to three categories to simplify interpretation of the measures. Measurement separation reliability ranged from 0.82 to 0.84 depending on how uncertainty is estimated (inflated by fit, or not). There were 59 extreme scores (4 maximum and 55 minimum) that had no effect on reliability. Cronbach's alphas was 0.88. Model fit was satisfactory, with the standard deviations of the standardized information weighted and outlier sensitive fit statistics both at 1.3, well below the 2.0 significance level. One contrast in a principal components analysis of the standardized residuals was 1.6, greater than the usual cut-off of 1.4, with several items loading at values greater than [0.40], but the measures implied by the different item groups all correlated 0.96 or higher, so the scale was determined to be unidimensional.

For the 21 vision items, however, the principal components analysis plainly distinguished acuity from FBV, as the ratio of the variance explained by the unidimensional scale to the variance explained by the first residual contrasts was only a little less than three to one. The unexplained variance in the first contrast was associated with an eigenvalue of over 4.0, and the second one was over 2.0. So the acuity and FBV items were separated into two measures. Model fit was satisfactory in both cases, with Cronbach's alphas of 0.76 and 0.81, respectively. The majority of the measures implied by item groups identified in the principal components' contrasts correlated 1.00 for both acuity and FBV.

Visual acuity measures generally did not change by more than measurement uncertainty. Acuity itself was not treated, and the acuity measures were not statistically associated with changes in FBV optometry or survey measures. For the 78 students with at least two of each of the three measures, in a paired-comparison t-test, CISS and FBV measures improved as expected (CISS: mean change was 0.22, $t=1.6$, 77 df, $p=0.11$; FBV: mean change was 1.35, $t=8.75$, 77 df, $p<.001$). A regression model predicted the last CISS measure from (a) the first and last FBV measures for 77 of those 78 cases ($Rsq=0.03$, $F=3.5$, 2 df1, 74 df2, $p=.03$) and from (b) the last FBV measures alone for the same 77 cases ($Rsq=0.08$, $F=6.6$, 1 df1, 75 df2, $p=.01$). A histogram of the standardized residuals from this latter model is shown in figure 1, and a scatter plot of the predicted and observed measures is shown in figure 2.

For the 39 students showing marked improvement in FBV, a paired-comparison t-test showed that the CISS mean change was 0.47, $t=3.0$, 38 df, and $p<.01$, and that the FBV mean change was 1.27, $t=7.67$, 38 df, and $p<.001$. A regression model predicted the last CISS measure from (a) the first and last FBV measures for 38 of those 39 cases ($Rsq=0.13$, $F=2.5$, 2 df1, 35 df2, $p=.10$) and from (b) the last FBV measures alone for the same 38 cases ($Rsq=.12$, $F=4.9$, 1 df1, 36 df2, $p=.03$).

Future investigations will associate the estimated measures with construct maps and interpretive guidelines for applications in classrooms and optometry clinics.

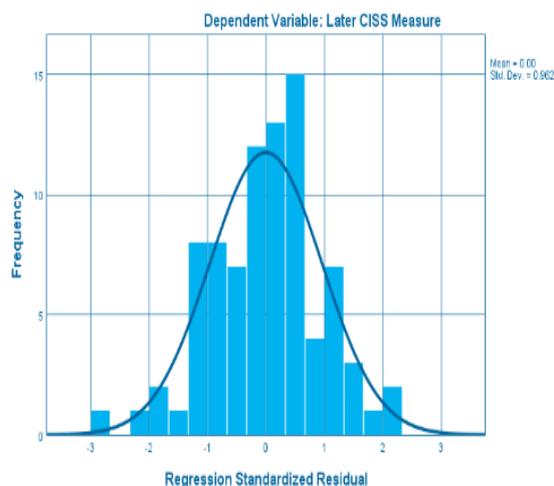


Figure 1. Standardized residuals

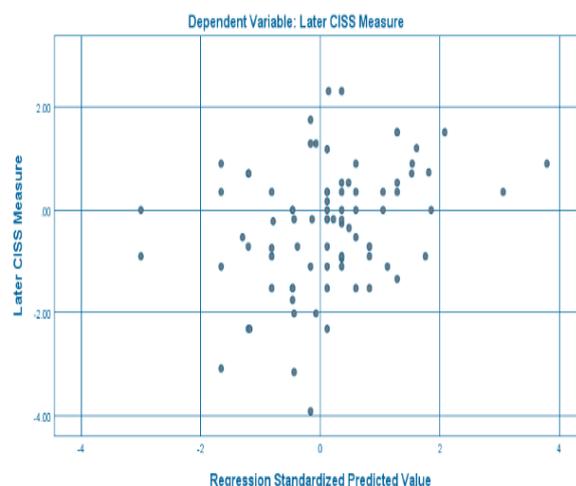


Figure 2. Predicted vs observed measures

5. Conclusion

Research in progress aims to assess a multidimensional model that parameterizes time points, and to compare changes in FBV with reading outcomes. Neither the originators of the CISS nor the research group producing the data reported here posited or tested hypotheses concerning a unified FBV construct or a theoretical model of FBV. The correlation between CISS measures and FBV orthoptics does, however, imply that integrating an FBV symptom survey (which is what revisions to the CISS would target) with an orthoptics assessment would be a productive endeavor.

This project is significant in envisioning and laying the foundations for a scientific model of FBV that could lead to new, positive impacts on student learning. Special Education, for instance, could benefit from new tools for assessing visual readiness for reading that point the way toward appropriate vision training and changes in reading instruction. General education would also benefit in that many students' inaccurate visual skills currently go undiagnosed, with negative impacts on reading fluency. An FBV assessment tool made available for use by teachers could enable them to screen for problematic vision, and to follow up with appropriate action. Most U.S. states (California included) refer students to eye care professionals outside of school if they fail monocular visual acuity tests. However screening for visual skills close to the face that require both eyes is not routinely done, thus allowing detectable and treatable problems to persist.

Questions for future research include: How much does visual acuity alone determine reading behavior? How much do binocular skills determine reading behavior? How much does oculomotor function contribute? Future health and education policy will be shaped by answers to these and similar questions. Further research developing tools for assessing binocular vision ability could help educators concerned with identifying and correcting children's problems with basic sensory processing issues.

Acknowledgments

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