SCIENTIFIC REPORT

Defining and measuring treatment outcome in unilateral amblyopia

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Br J Ophthalmol 2003;**87**:1229–1231

Aim: To offer a critique of current methods of defining amblyopia treatment outcome and to examine alternative approaches.
Method: Literature appraisal and descriptive case presentations.
Results: Currently, the outcome of amblyopia treatment is expressed as the number of acuity chart lines gained or, alternatively, achievement of an arbitrarily adopted level of visual acuity. As binocular vision is optimised with equal visual input from each eye the authors propose that the optimum outcome of amblyopia therapy is to achieve a visual acuity in the amblyopic eye equal to that of its fellow. In addition, improvement should be graded as the proportion of change in visual acuity with respect to the absolute potential for improvement (that is, that pertaining in the fellow eye at end of treatment).
Conclusions: There are two methods of appropriately describing the outcome of amblyopia treatment: firstly, by the difference in final visual acuity of amblyopic and fellow eye (residual amblyopia); secondly, the proportion of the deficit corrected.

One of the major challenges facing clinical practice and research in amblyopia is obtaining valid, accurate, and reliable measures by which the outcome of treatment can be quantified. Increasingly, Snellen based visual acuity measurements are being supplanted by charts scaled according to the logarithm of the minimum angle of resolution (logMAR),[1–3] which allow acuity to be recorded with improved accuracy and sensitivity to detect change.[4–6] However, advances in chart design have not impacted on the way in which treatment outcome, either at the level of the individual or group of patients, is quantitatively assessed. In this article we examine several approaches to defining treatment outcome in unilateral amblyopia.

DEFINING OUTCOME

There are two principal and complementary approaches to defining amblyopia treatment outcome: recording the final visual acuity achieved and quantifying the amblyopic deficit corrected.

Final acuity level achieved

Most treatment studies have defined success as the achievement of a specific acuity by the end of the treatment period, usually 6/9 or 6/12.[7–13] A few have adopted the arguably more strict criterion of 6/6 (''normal'' visual acuity) as their definition of success.[14–17] This latter approach assumes normal visual acuity to be a single value that is identical for all populations, whereas in reality, of course, it is represented by a range of values above and below 6/6.[5–6 18]

From a functional viewpoint, the condition best suited to promote normal visual development and the attainment of full binocular vision is that occurring when the visual input from each eye is equal.[19] On this basis we propose that the optimum outcome for children undergoing amblyopia therapy should be a visual acuity in the amblyopic eye equal to that of the fellow, non-amblyopic eye. The discrepancy from this—that is, the difference between the amblyopic eye and fellow eye at the end of the treatment indicates the extent of residual amblyopia. This approach takes into account any visual development that has occurred during the treatment period. Although it must be acknowledged that vision in the fellow eye of individuals with unilateral amblyopia may also be abnormal[20–22] it none the less provides a good indication of the best achievable acuity at this stage in development for a given individual. A negative discrepancy will indicate occlusion amblyopia of the fellow eye.

Quantifying the deficit corrected

Not every child with amblyopia undergoing treatment responds fully. This has resulted in another often employed outcome measure: the number of acuity chart lines gained (typically three[8 23]) during treatment. This approach has the drawback that it does not give any indication of how close the outcome acuity is to ''normal.'' Furthermore it does not indicate the proportion of the amblyopic defect that has been corrected. To overcome these limitations, we propose an alternative approach to defining outcome which quantifies the proportion of the amblyopic deficit corrected by treatment. That is:

$$\text{Proportion of change} = \frac{VAas - VAae}{VAas - VAfe}$$

where VAas is visual acuity of amblyopic eye at the start; VAae is visual acuity of the amblyopic eye at the end of treatment; and, VAfe is visual acuity of fellow eye at the end of treatment.

This formula (for ease and standardisation, visual acuity scores should be in logMAR values) also takes into account any visual development that might naturally occur in the fellow eye during the treatment period. A score of 1.0 represents the optimum outcome, where the amblyopic deficit has been fully corrected, and the visual acuity of the previously amblyopic eye equals that of its fellow.

To illustrate these different approaches, consider two children with amblyopia (cases 1 and 2). Both responded to treatment by an improvement of 0.3 log units (three chart lines), which in many studies would be considered an identical gain. However, case 1 improved from 6/60 to 6/30 (1.0 to 0.7 logMAR), while case 2 improved from 6/12 to 6/6 (0.3 to 0.0 logMAR). Both cases had fellow eyes with acuities of 6/6 (0.0 logMAR) at the end of treatment. For case 1 a three line improvement has corrected 30% (0.3) of the deficit, a clinically subnormal

Table 1 Methods of defining treatment outcome. (Proposed optimum expressions of outcome appear in lower shaded portion of the table)

Definition of treatment outcome	Disadvantage	Advantage
• Attainment of a certain standard (eg, 6/6 to 6/12)	• Does not account for initial severity of amblyopia—ie, how much improvement has occurred • Fellow eye acuity not considered	• A visual acuity of notional equivalence to a legal or occupational standard—eg, driving a motor vehicle
• An in improvement considered to be of clinical significance in visual acuity of the amblyopic eye (often 2 or 3 lines measured with Snellen charts or 0.2 log units as measured on a log based test	• Does not account for initial severity of amblyopia • Initial acuity dictates whether this achievement would benefit the child • Fellow eye acuity not considered • Assumes understanding of the acuity/function relation • Snellen chart has non-linear scale increments, therefore ''n'' lines improvement differs in actual acuity change dependent on the acuity level and chart used	• Simple indicator of clinical significant improvements
• Equal visual acuity of amblyopic and fellow eye	• Does not account for initial severity of amblyopia	• Accounts for individual variations in visual acuity of fellow eye and visual development during treatment • Acknowledges that normal binocular vision is optimised by identical inputs from each eye • Difference between amblyopic and fellow eye acknowledges extent of residual amblyopia
• Proportional improvement (ie, log unit change in visual acuity/difference between amblyopic eye at start and fellow eye at end of treatment)	• Need to define level of proportional improvement that constitutes good outcome • Accuracy compromised when occlusion amblyopia occurs	• Accounts for initial severity of amblyopia • Accounts for visual acuity of fellow eye • Accounts for development of both eyes during treatment

Table 2 Examples of theoretical cases with amblyopia during treatment

Case	Amblyopic eye (start)	Amblyopic eye (end)	Fellow eye (start)	Fellow eye (end)	⩾6/9	⩾3 lines	Residual amblyopia	Proportional improvement
1	1.00	0.7	0.05	0.0	No	Yes	0.70	(1.0−0.7)/(1.0−0.0) = 0.30
2	0.30	0.0	0.0	0.0	Yes	Yes	0.0	(0.3−0.0)/(0.3−0.0) = 1.00
3	0.72	0.62	0.20	−0.18	No	No	0.79	(0.72−0.62)/(0.72 to −0.18) = 0.11
4	0.20	0.0	0.06	−0.04	Yes	No	0.04	(0.2−0.00)/(0.2 to −0.04) = 0.83
5	0.90	0.15	0.30	−0.3	Yes	Yes	0.45	(0.90−0.15)/(0.90 to −0.3) = 0.63
6	1.0	0.35	0.25	0.25	No	Yes	0.1	(1.00−0.35)/(1.00−0.25) = 0.87
7	0.9	0.1	0.1	0.2	Yes	Yes	−0.1	(0.9−0.1)/(0.9−0.2) = 1.14

Outcomes for each case are presented according to each of the four methods of defining successful outcomes (achievement to 6/9 or better, improvement by three or more lines, residual amblyopia, and proportional improvement calculations).
Proportional improvement can be equivalently expressed in percentage.
A proportional outcome >1.0 signifies visual acuity of the once amblyopic eye improving to levels higher than that of the fellow eye while a negative proportional outcome signifies deterioration of the amblyopic eye during treatment.

outcome, whereas case 2, a three line improvement has corrected 100% (1.0) of the deficit and the acuity of the two eyes is now equal. The drawback of the proportional improvement approach is that subjects developing occlusion amblyopia will have a misleadingly elevated proportional improvement.

DISCUSSION

The aforementioned methods of defining treatment outcome are compared and contrasted in Table 1. To highlight the practical application of the outcome definitions, seven illustrative clinical examples are presented in Table 2.

CONCLUSION

We have reviewed several different approaches to quantifying treatment outcome in unilateral amblyopia, and describe their relative advantages and disadvantages based on case simulations. We conclude that the optimum approach requires an expression of (i) the difference in final visual acuity between the amblyopic and fellow eye (residual amblyopia) and (ii) the proportion of the amblyopic deficit corrected by treatment.

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Accepted for publication 16 February 2003

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