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Temporal perceptual training enhances visual acuity in adult amblyopia: a single-case study

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INTRODUCTION

Amblyopia is usually framed as a persistent spatial-acuity disorder, yet temporal processing is also abnormal, including impaired visual synchrony and prolonged temporal integration [1, 2]. This raises a mechanistic question: if residual acuity loss is partly constrained by temporal-resolution limits, temporal perceptual learning may improve acuity. Although perceptual learning can modify adult visual performance [3], most amblyopia protocols train spatial features. We therefore tested whether two-flash fusion training, a temporal discrimination task, transfers to monocular visual acuity.

METHODS

Four adults with amblyopia completed a replicated ABAB single-case experimental design [4] followed by delayed follow-up. Each phase

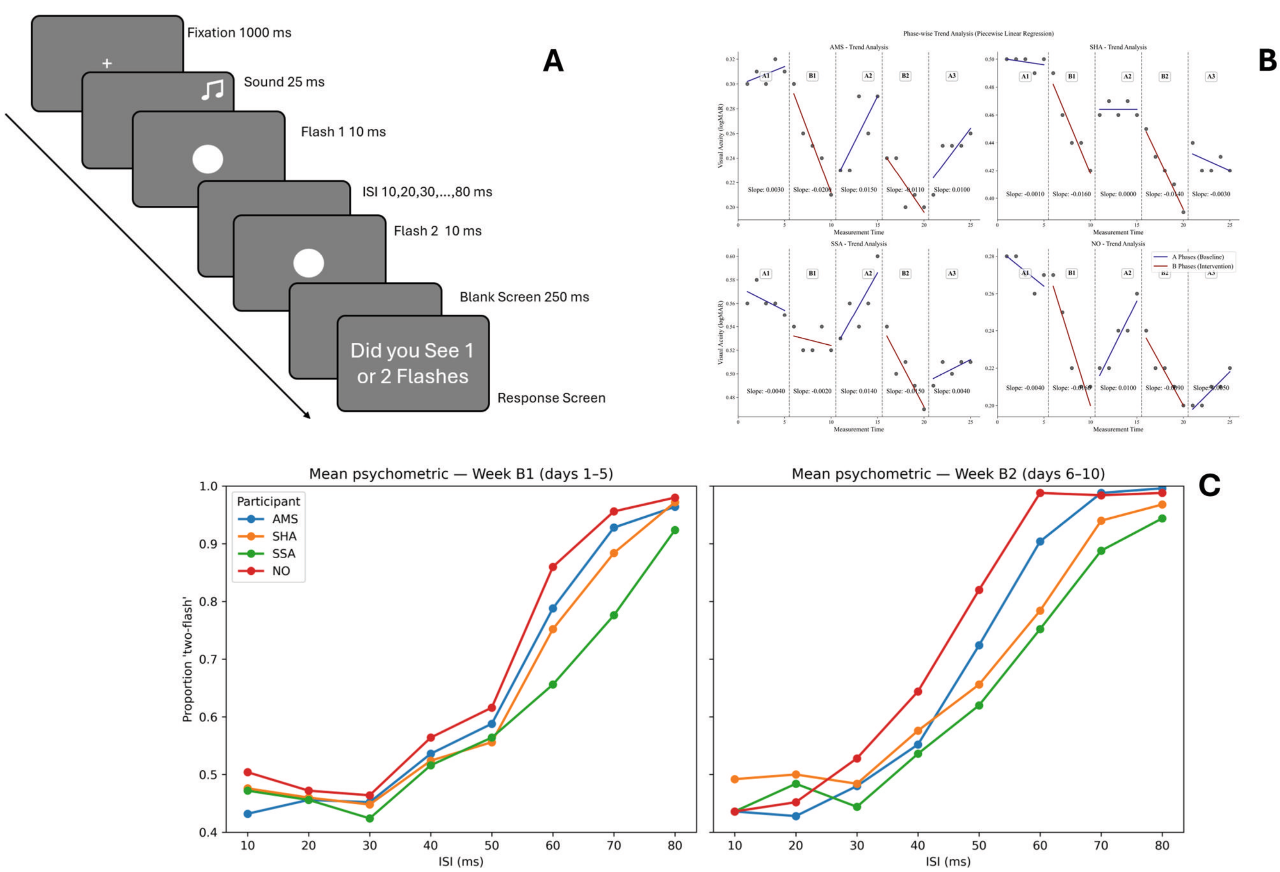

Fig. 1 Task Design and Results. A Two-flash fusion task used during intervention phases. Each trial began with fixation, followed by an auditory cue, two brief flashes separated by a variable inter-stimulus interval, and a single/two-flash response. **B** Phase-wise piecewise linear trends. Negative slopes during intervention phases indicate progressive acuity improvement during temporal training. **C** Mean two-flash psychometric functions during the first and second intervention blocks. Curves show the proportion of 'two-flash' responses across inter-stimulus intervals from 10 to 80 ms.

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Table 1. Participant-level clinical essentials, phase outcomes, single-case statistics and temporal-training indices.

Measure	AMS	SHA	SSA	NO
Clinical essentials				
Age/sex	25/M	32/F	26/F	26/F
Amblyopia subtype	Strabismic	Strabismic +anisometropic	Anisometropic	Strabismic
Amblyopic eye	R	L	R	R
Baseline Snellen acuity	20/40	20/63	20/80	20/32
Visual-acuity phase means, logMAR				
A1, initial baseline	0.308	0.498	0.562	0.272
B1, first intervention	0.252	0.450	0.528	0.232
A2, reversal baseline	0.260	0.460	0.552	0.237
B2, second intervention	0.241	0.420	0.510	0.220
FU, delayed follow-up	0.240	0.426	0.524	0.224
Δ A1–B2	−0.067	−0.078	−0.052	−0.052
Δ A1–FU	−0.068	−0.072	−0.038	−0.048
Tau-U non-overlap and trend-adjusted effects				
A vs B	−0.96*	−0.98*	−1.00*	−0.88*
Trend A	0.45	−0.32	−0.60	−0.67
Trend B	−1.00*	−0.95*	−0.26	−0.95*
A vs B − Trend A	−0.71*	−0.61*	−0.55	−0.40
A vs B + Trend B	−0.87*	−0.92**	−0.74*	−0.80**
Final adjusted Tau-U	−0.86**	−0.76**	−0.53*	−0.57*
Piecewise visual-acuity trend model				
Overall trend term	0.003	−0.001	−0.004	−0.004
Slope during B1	−0.023**	−0.015***	0.002	−0.012***
Slope during A2	0.012	0.001	0.018**	0.014***
Slope during B2	−0.014*	−0.013**	−0.011	−0.005
Slope during FU	0.007	−0.002	0.008	0.009**
Model R^2	0.915	0.972	0.902	0.962
Adjusted R^2	0.864	0.955	0.843	0.939
Two-flash fusion training				
Daily accuracy, first to last session	0.603–0.700	0.615–0.703	0.585–0.655	0.655–0.745
Δ daily accuracy	+0.097	+0.088	+0.070	+0.090
Mean accuracy, B1	0.643	0.634	0.599	0.677
Mean accuracy, B2	0.689	0.675	0.638	0.730
Δ mean accuracy, B2–B1	+0.045	+0.041	+0.039	+0.053
T_{50}, B1 threshold, ms	39.6	40.8	41.7	34.4
T_{50}, B2 threshold, ms	35.5	25.1	36.5	29.0
Δ T_{50}, B2–B1, ms	−4.1	−15.6	−5.3	−5.4
Overall two-flash mean	0.666	0.655	0.618	0.704

A1 = initial baseline; B1 = first intervention; A2 = reversal baseline; B2 = second intervention; FU = follow-up. Negative logMAR changes indicate improved acuity. Negative Tau-U values indicate lower logMAR values during intervention phases. Negative T_{50} changes indicate reduced fitted 50% two-flash fusion threshold from B1 to B2. *$p < 0.05$ for Tau-U analyses; **$p < 0.001$ for Tau-U analyses. For piecewise regression slopes, *$p < 0.05$, **$p < 0.01$ and ***$p < 0.001$. Significance markers are descriptive within this single-case framework and should not be interpreted as population-level efficacy evidence.
The table is transposed to emphasise within-participant patterns. Clinical detail is limited to information necessary for interpreting heterogeneity in amblyopia type and baseline severity.

contained five daily monocular logMAR acuity measurements with the fellow eye patched. Baseline phases contained no temporal training. Intervention phases contained one 400-trial two-flash fusion block per day. Each trial presented two 10-ms Gaussian flashes separated by inter-stimulus intervals of 10–80 ms with 10 ms steps. The design conceded 25 acuity observations and 4000 temporal-training trials per participant (See Fig. 1A). Outcomes were summarised by phase means, Tau-U, non-overlap indices, piecewise trend estimates and two-flash psychometric performance.

RESULTS

Visual acuity improved during intervention phases in all participants and was retained at follow-up (Fig. 1B; Table 1). Mean logMAR decreased from initial baseline to the second intervention by 0.067, 0.078, 0.052 and 0.052 for Participants. Final adjusted Tau-U values ranged from −0.53 to −0.86, indicating lower acuity thresholds during intervention phases after trend correction. Piecewise slopes were generally negative during intervention phases and positive or smaller during baseline phases. Temporal performance also improved: B1-to-B2 psychometric functions shifted upward, mean two-flash accuracy increased and fitted 50% fusion thresholds decreased by 4.1–15.6 ms (See Fig. 1C).

DISCUSSION AND CONCLUSION

This Brief Communication provides single-case evidence that temporal perceptual learning can coincide with improvement in adult amblyopic visual acuity. The findings do not establish population-level efficacy and require masked controlled replication. Their value is mechanistic: across heterogeneous amblyopic cases, a temporal task produced phase-linked acuity gains, supporting the hypothesis that temporal-resolution mechanisms contribute to residual spatial vision loss in adult amblyopia [5].

DATA AVAILABILITY

Participant-level visual-acuity and two-flash fusion data will be made available upon reasonable request to the corresponding author.

CODE AVAILABILITY

Analysis code will be made available upon reasonable request to the corresponding author.

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AUTHOR CONTRIBUTIONS

AK and LB conceived the study. AK collected and analysed the data and drafted the manuscript. LB supervised the project and revised the manuscript. Both authors approved the final version.

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COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

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