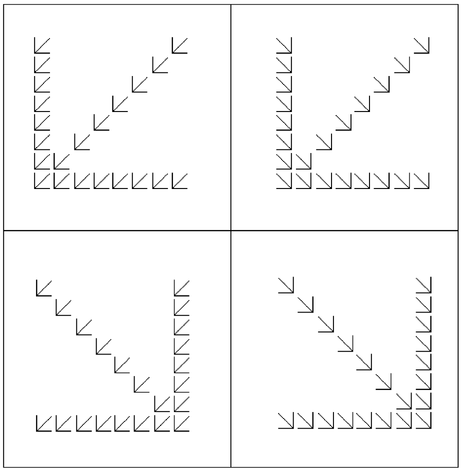

Fig. 1 Proximity-grouped compound stimuli. Global arrows made up of local arrows are presented on a blank background

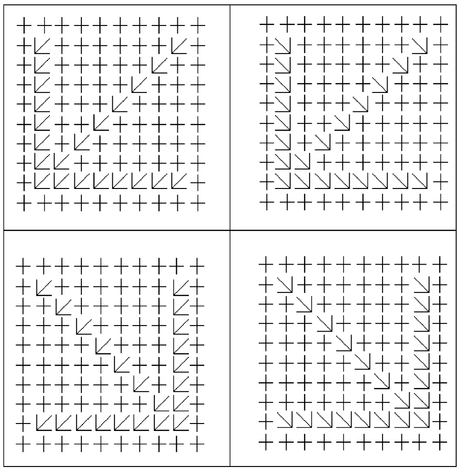

Fig. 2 Similarity-grouped compound stimuli. Global arrows made up of local arrows are presented on a background of crosses

arrows increase contour interaction and the difficulty of selection of a local arrow.

We recruited anisometropic amblyopes in the current study[1]. Compound shapes shown in Figs. 1 and 2 were presented to the subjects' amblyopic and fellow eyes, respectively. Performances of identifying global and local shapes were compared between the conditions when global structures are formed by proximity and perceptually salient or formed by similarity of shapes and perceptually less salient.

[1] Minor degrees of eccentric fixation are usually seen in strabismic amblyopia. Thus the difference in behavioral performances of the amblyopic eye with eccentric fixation and the fellow eye with central fixation may arise from the discrepancy between foveal and nonfoveal vision. To exclude this possibility, the current work recruited only anisometropic amblyopes whose both amblyopic and fellow eyes used central fixation. This may simplify the explanation of our results.

[illegible]

Subjects

Twelve anisometropic amblyopes with central fixation were recruited in the current study. The clinical details of each of the subjects are given in Table 1. All tests were performed monocularly with the amblyopic or the fellow eye occluded. Informed consent was obtained from all subjects.

Stimuli

Two sets of compound stimuli were black on a white background, as shown in Figs. 1 and 2. Each compound stimulus consisted of a global arrow made up of local arrows pointing down left or down right. The directions of local arrows were either consistent or inconsistent with that of the global arrow. Local arrows of the stimuli in Fig. 1 were presented on a blank background so that proximity dominated local element grouping. Local arrows of the stimuli in Fig. 2 were embedded in crosses so that similarity of shape dominated local element grouping. The local arrows were arranged in an 8 8 matrix. The global figure was 3.5 3.0 cm (height width), and the local figure was 0.3 0.25 cm. At a viewing distance of about 40 cm the global and local figures subtended a visual angle of 5.0 4.2 and 0.43 0.36 , respectively. The height and width of each background cross was the same as that of each local arrow. The stimulus used in the control condition was only one small arrow displayed at the center of the screen, which was as big as the local arrows composing the global shapes.

Table 1 Visual characteristics of amblyopes in the current work

Observer	Age (years)	Sex	Eye	Rx	Acuity
H.L.	5	F	OD	0.25	20/15
			OS	+3.25/+1.00 60	20/100
L.H.	10	F	OD	+0.75	20/20
			OS	+5.75/+1.50 115	20/200
X.K.	7	F	OD	+1.50/+0.50 100	20/15
			OS	+7.00/+0.50 110	20/200
X.Z.	12	M	OD	1.50	20/15
			OS	+1.00/+0.50 90	20/30
J.T.	12	M	OD	+2.00/+0.75 90	20/15
			OS	+1.00/+4.00 90	20/30
Z.Z.	6	F	OD	+1.00/+0.50 110	20/20
			OS	+5.00/0.75 85	20/40
C.F.	10	F	OD	+0.50/+0.75 185	20/20
			OS	+3.75/+2.00 180	20/50
S.M.	7	F	OD	+6.00/+0.50 60	20/60
			OS	+3.50	20/25
W.J.	8	M	OD	+0.50/+3.00 85	20/40
			OS	+1.75/+1.50 90	20/20
G.H.	13	F	OD	+3.00/+2.00 80	20/40
			OS	+2.00	20/20
M.X.	11	M	OD	Plano	20/15
			OS	+5.50	20/40
C.Q.	26	F	OD	Plano	20/15
			OS	+6.50/+1.00 90	20/200

Procedure

The experiment employed a four-factor within-subject design with the factors being: Grouping (local elements were grouped by proximity or similarity, i.e., stimuli in Figs. 1 and 2); Eye (the amblyopic or the fellow eye); Globality (discrimination of global or local level); and Consistency (the global and local levels are consistent or inconsistent). Each trial began with a 1000-ms warning beep and the presentation of a fixation cross located at the center of the screen, which was 0.4 0.3 cm subtending 0.58 0.43 of visual angle. After another 1000 ms, the fixation cross was replaced by the stimulus, which was presented at the center of the screen and stayed on until subjects responded. While maintaining fixation, subjects were required to identify the orientation of global or local arrows in separate blocks of trials by pressing one of two keys on a standard keyboard with the right and left middle fingers. The presentation sequence of stimuli in Figs. 1 and 2, the order of presentation for the two eyes, and the order of the global and local tasks were counterbalanced across subjects. For each stimulus condition, there were 16 practice trials followed by 48 trials in one block for the identification of the global or local shapes. Subjects were encouraged to respond as quickly and accurately as possible. In the control condition, subjects discriminated orientations of a small arrow presented at the center of the visual field. There were 60 trials, of which the first 12 were for practice. Stimuli were presented on the screen until subjects made a response.

RTs and error rates were subjected to a repeated-measure analysis of variance (ANOVA) with Grouping (proximity vs similarity), Eye (amblyopic vs fellow eye), Globality (global vs local), and Consistency (consistent vs inconsistent) as independent variables.

Error rates

The mean error rates under each condition are given in Table 2. The error rates were higher for the amblyopic than for the fellow eye [4.6% vs 2.2%, $F(1,11)=6.18$, $P<0.03$]. Subjects made more errors in responses to the local than global stimuli [4.5% vs 2.3%, $F(1,11)=6.07$, $P<0.03$]. The interaction of Grouping Globality was significant [$F(1,11)=10.02$, $P<0.009$] due to the fact that the error rates were higher in the local compared to the global conditions when local elements were grouped by proximity whereas no difference was observed between global and local conditions when local elements grouped by similarity. There were also reliable interactions of Grouping Eye Globality [$F(1,11)=6.55$, $P<0.03$], suggesting that the effect of amblyopia on differential global/local responses was stronger when local elements were grouped by proximity than by similarity shapes. Post-hoc analyses showed that, for the amblyopic eye, error rates to the proximity-grouped stimuli were higher in the local than global conditions, whereas error rates to the similarity-grouped stimuli did not differ between the global and local conditions [$F(1,11)=18.29$, $P<0.002$]. Moreover, subjects made more errors in responding to local targets when local elements were grouped by proximity than by similarity [$F(1,11)=6.98$, $P<0.022$], whereas error rates to the global targets did not differ between the two conditions [$F(1,11)=2.73$, $P>0.1$]. For the normal eye, however, the error rates did not differ between proximity- and similarity-grouped stimuli regardless of whether subjects identified global or local stimuli ($P>0.2$).

Reaction times

The average RTs for correct responses to proximity- and similarity-grouped stimuli are shown in Table 3. The analysis of RTs indicated significant main effects of

Consistency [F(1,11)=10.52, P<0.008]. Subjects responded faster to proximity- than similarity-grouped stimuli (850 vs 932 ms). RTs were longer to the stimuli presented to the amblyopic eye than to the fellow eye (965 vs 817 ms). For both sets of stimuli, responses to the global shape were faster than those to the local shape. RTs were shorter when global and local shapes were consistent than when inconsistent.

There were reliable interactions of Grouping Globality [F(1,11)=10.61, P<0.008], Eye Globality [F(1,11)= 8.74, P<0.013], and Grouping Consistency [F(1,11)= 8.29, P<0.014]. The interaction of Eye Consistency was marginally significant [F(1,11)=4.14, P<0.06]. The global RT advantage was more salient for proximity- than for similarity-grouped stimuli and stronger for the amblyopic than for the fellow eye. The interference effect was stronger for similarity- than proximity-grouped stimuli and more pronounced for the normal than the amblyopic eye. Post-hoc analyses showed that the responses to the global similarity-grouped stimuli were slower than those to the proximity-grouped stimuli [F(1,11)=39.7, P<0.001], whereas the responses to the local stimuli did not differ between the two conditions (F<1).

In the control condition, subjects responded slower and with more errors to the identification of orientations of a single small arrow presented to the amblyopic eye than to the fellow eye [817 vs 651 ms, t(11)=2.71, P<0.02; 6.8% vs 1.7%, t(11)=2.82, P<0.02].

As visual acuity of amblyopic eyes was distributed over a wide range, we further analyzed the correlation between visual acuity of amblyopic eyes and error rates (and RTs) to examine the influence of visual acuity on the performance of the amblyopes. The analyses did not show any significant correlation between visual acuity and the performance of the amblyopes (P>0.25 for all analyses), suggesting that the effect of perceptual salience of global structures on behavioral performances could not be accounted for simply by the variation of visual acuity.

[illegible]

Subjects responded faster to global than local targets when viewing the stimuli with both the amblyopic and the fellow eye. These results are consistent with the results of previous studies on healthy subjects [5, 14], indicating a global RT advantage. The global RT advantage was reduced when the local elements were grouped by similarity of shapes (stimuli in Fig. 2) compared with when local elements were grouped by proximity (stimuli in Fig. 1). These findings are in agreement with the previous work [5] and support the proposal that grouping by proximity occurs earlier than grouping by similarity and dominates the perception of global structures. The global RT advantage was more pronounced for the amblyopic eye than for the fellow eye, mainly because of the prolonged RTs to the local stimuli presented to the amblyopic eye. Moreover, for both proximity- and similarity-grouped stimuli, the RT difference between the amblyopic and fellow eyes was larger in the local condition, in which multiple local elements were displayed simultaneously, than in the control condition, in which a single local shape was presented. Therefore the local perception of compound stimuli was impaired by amblyopia, reflecting a strong crowding effect for the amblyopic eye.

Interestingly, responses to the local stimuli showed opposite to the prediction of the spatial frequency concept.

The results of our current work are in line with a proposal that the salience of a global structure in which local elements are required to be identified contributes to the crowding effect in anisometropic amblyopia. Our

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