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Can improving prism fusion range with training also improve stereo-acuity?

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Abstract

Aim: **We tested whether prism fusion range (PFR) could be improved by training and whether any improvement in PFR also led to improvement in stereo-acuity.**
Methods: **The PFR and stereo-acuity thresholds of 15 participants with normal or corrected-to-normal vision were tested intially then at 1 week and 5 weeks. Eight of the participants, the experimental group, were instructed in training their base-in and base-out near prism fusion at home for 10 minutes twice each day for 1 week. Seven participants, the control group, were simply tested on three occasions without training.**
Results: **For the experimental group after 1 week both near and distant PFR had significantly improved, by over 10^{Δ} compared with the control group. Stereo-acuity had improved significantly but modestly by about 3 sec arc. However, 4 weeks later, during which no further training occurred, both PFR and stereo-acuity were no longer significantly different between the groups.**
Conclusions: **Although in visually normal particpants training of near PFR can lead to improvement in near and distant PFR and stereo-acuity, in the longer term no differences were found between the trained group and a control group who were untrained. These results emphasise the importance of including for comparison a non-treatment group in such studies.**

Key words: Prism fusion range, Stereo-acuity, Vergence training

Introduction

Kerkhoff and Stögerer in 1994 gave fusional training to 3 patients with severe reduction in fusional convergence.[1] Three training methods were used, all of which presented dichoptic images that became increasingly disparate targets that the patient was asked to fuse actively for as long as possible. These methods were repeated for 50 minutes by the patient twice a week for 6 weeks. All 3 patients showed improved fusional range, of between 4^{Δ} and 13^{Δ}, and 2 patients showed marked improvement in stereo-acuity, as measured with the Titmus test. That these effects were due to spontaneous recovery was unlikely as repeated baseline measurements were taken for up to 4 weeks prior to treatment; also, once treatment was ceased no futher improvements were seen. From this study, however, it is not clear which of the three training methods had caused improvements. Were all three required or would one be sufficient?

Although some work has been done on stereopsis training[2,3] and more on vergence training,[4–6] to our knowledge very little work has been done to test whether stereo-acuity can be improved by increasing fusion range with training (for a review see Kerkhoff[7]). A relevant study is that of Kertesz,[8] who tested the effect in strabismus of repeated exercise of vergence for 30 minutes twice a week for between 4 to 12 weeks. The training involved viewing in a purpose-built device that dichoptically presented stereo stimuli where disparity could be slowly increased at a rate equivalent to 1 dioptre per second of changes in convergence (or divergence) until fusion broke, and which then reduced disparity until fusion was regained. After treatment, with different durations for each patient, it was found that 12 of the 15 patients converted tropias into phorias or significantly reduced the frequency of the manifest deviation; importantly in 6 patients stereo-acuity also improved. The improvements persisted in measures taken up to 3.5 years following treatment. The author acknowledged that one problem with this study was the absence of a control/no-treatment condition; such a condition is included in our experiment below.

In this experiment we tested whether a group of normal observers who trained their prism fusion range (PFR) for a week showed improved PFR and whether this also led to improvements in stereo-acuity. We also tested how well any improvements persisted after cessation of training.

Methods

Participants

Fifteen visually normal participants were recruited from the orthoptic and geography student population at the University of Sheffield, mean age 21.6 years (range 18–26 years). All had near (0.33 m) and distant (6 m) visual acuity of 6/6 or better assessed with Snellen charts and no manifest deviation. Visual correction was worn if needed.

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Procedure

The procedure was approved by the departmental ethics committee. Participants read a participant information sheet that informed them they would need to be tested on that day and also to return for further tests both 1 week and 5 weeks later. They also signed a consent form. A full ocular history was taken. Interpupillary distance (IPD) was measured with a ruler; this was used for later calculation of stereo-acuity. Snellen visual acuity was measured at near (0.33 m) and far (6 m). Cover tests were performed at near and far, smooth pursuit ocular movement and convergence were tested, and heterophoria was measured using prism and cover test (all participants less than 10°).

Convergent and divergent prism fusion range was then assessed looking at a 6/60 target at near (0.33 m) and far (6 m) using two Clement Clark prisms if the participant went beyond 45^{Δ} and/or to obtain as accurate a measure as possible, with a minute's rest between each. Counterbalancing was used to determine both the range tested first and the eye over which the prism was placed; this same order was used on subsequent re-tests of a participant as order effects have been shown to be important.[9] Care was taken to balance the order across the two groups. The participants were shown diplopic images with a 20^{Δ}BI prism for near to ensure they appreciated this as a break in fusion which they could report. When break of fusion was reported the prism strength was reduced until fusion was regained and then increased again until a break in fusion was again reported. The participant was instructed to try to keep the target single at all times. This second break was recorded; we did not record any blur points.

The participant was then familiarised with the Frisby near stereotest. This involved presenting each of the three plates 7 times, starting with the 6 mm plate, all at 80 cm viewing distance. This ensured that all participants were familiar with the test when it was used to measure stereo-acuity to threshold for the first time.

Stereo-acuity to threshold was measured starting at 1 m with the thickest (6 m) plate and then, depending on responses, increasing the distance in 25-cm steps until the participant failed to report the correct location of the target on at least two of three presentations. All three thicknesses of plate were used to start but we always used the thinnest (1.5 mm) plate to determine threshold. The viewing distance recorded and interpupillary distance (IPD) were used to calculate threshold using the formula in the test instructions.

Participants were next pseudo-randomly assigned to the control ($n = 7$) or experimental ($n = 8$) groups, ensuring that there were an equal number of orthoptics students in each group. The control group were simply asked to return 1 week and also 5 weeks later for further tests. The experimental group were given detailed written instructions on how to do PFR training and two Clement Clark horizontal prism bars and a Snellen stick to take home. Training was done at 0.33 m only, as a pilot study with 4 participants had shown that training at near also improved far PFR. Half the group were told to train their BO followed by their BI, the other half to train in the reverse order. The instructions included details of how to hold the prism bar and an order to train always under the same lighting conditions and in the same environment. The instructions also set out the training regime: a session consisted of the participant training the one range, BO for example, by increasing prism strength until fusion of the 6/60 H target on the fixation stick was lost, then trying to regain fusion but, if this was not possible, slowly reducing prism strength until fusion was regained, and then increasing prism strength again until fusion was lost. This cycle was repeated for 5 minutes. The participant then repeated this procedure for the other range, BI for example. They were told to do this training session twice a day with at least 3 hours between sessions. After each session they were told to rest for at least 10 minutes before doing any close work, such as reading, and as a very cautious precaution to satisfy the ethics committee, not to drive or use stairs during this rest period. The first author ensured that the participants understood both the written instructions, which they took away with them, and loss of fusion, by demonstrating diplopia again with a 20^{Δ}BI prism for near.

The stereo-acuity and PFR of both groups were then re-tested after 1 week, as above. The experimental group returned their prism bars and Snellen sticks to the experimenter to ensure they could not continue training. Both groups were then asked to return in 4 weeks, at which time the experimental group would have had 4 weeks without further PFR training. Although the tester knew which group a participant was in when re-testing, they did not look at their results from the previous week or weeks prior to re-testing.

Results

We first report the PFR data. As can be seen from the full data set shown in Table 1, all but one participant in the experimental group showed after training an increase in BO values from week 0 to week 1 for both near and far. The one exception showed the same value for BO at far. A similar pattern is seen for BI but changes were more modest. In contrast the changes in the control group for the same conditions were more mixed. For simplicity for each participant we added the BO and BI data for each condition (see Table 1 and Fig. 1) to give a total PFR. Separate analysis of the BO and BI measurements showed that in reality most of the effects of training were seen in changes in BO measurements. Fig. 1 shows mean PFR on the vertical axis for the two groups during the 5 weeks of the experiment shown on the horizontal axis. The experimental group's means are shown with filled symbols and the control group's means are shown with open symbols and dotted lines.

It is of interest that from Table 1 and Fig. 1 for both distances the mean values at week 0 of the two groups are very similar, suggesting they were well matched at this point. Independent *t*-tests showed no significant differences for total fusion range (for near: $t = 0.07$, $p = 0.94$; for far: $t = 0.46$, $p = 0.65$); similar lack of differences were seen for the BO and BI measures (see Table 1).

Fig. 1 shows that for both viewing distances the experimental group had an increase in mean PFR after

Table 1. Near (0.33 m) and far (6 m) base-out (BO) and base-in (BI) prism fusion ranges (PFR) and total (BO + BI) ranges measured on three occasions for the experimental group, who trained near PFR between weeks 0 and 1, and the control group who did no training. Means, standard deviations and standard error of the means are shown at the base of columns

	Experimental group ($n = 8$)																	
	Near									Far								
	Week 0			Week 1			Week 5			Week 0			Week 1			Week 5		
	BO	BI	Range	BO	BI	Range	BO	BI	Range	BO	BI	Range	BO	BI	Range	BO	BI	Range
	61	8	69	80	18	98	65	16	81	30	4	34	40	6	46	40	4	44
	16	18	34	35	18	53	35	18	53	18	6	24	35	6	41	25	6	31
	35	4	39	46	8	54	45	8	53	25	1	26	35	2	37	30	2	32
	45	10	55	65	12	77	65	12	77	12	8	20	14	6	20	16	6	22
	40	18	58	61	35	96	59	35	94	25	4	29	35	4	39	35	4	39
	20	8	28	25	6	31	18	8	26	14	0	14	14	2	16	18	2	20
	85	12	97	90	12	102	90	12	102	65	8	73	90	8	98	85	8	93
	65	16	81	75	20	95	90	20	110	20	12	32	30	12	42	40	12	52
Mean	**45.9**	**11.8**	**57.6**	**59.6**	**16.1**	**75.8**	**58.4**	**16.1**	**74.5**	**26.1**	**5.4**	**31.5**	**36.6**	**5.8**	**42.4**	**36.1**	**5.5**	**41.6**
SD	**23.4**	**5.2**	**24.0**	**22.7**	**9.1**	**26.6**	**25.2**	**8.8**	**28.6**	**16.8**	**4.0**	**18.0**	**23.7**	**3.3**	**24.9**	**21.8**	**3.3**	**23.4**
SE	**8.3**	**1.8**	**8.5**	**8.0**	**3.2**	**9.4**	**8.9**	**3.1**	**10.1**	**5.9**	**1.4**	**6.4**	**8.4**	**1.2**	**8.8**	**7.7**	**1.2**	**8.3**
	Control group ($n = 7$)																	
	Near									Far								
	Week 0			Week 1			Week 5			Week 0			Week 1			Week 5		
	BO	BI	Range	BO	BI	Range	BO	BI	Range	BO	BI	Range	BO	BI	Range	BO	BI	Range
	45	12	57	40	12	52	45	14	59	25	10	35	25	8	33	25	2	27
	65	14	79	61	16	77	65	16	81	25	2	27	18	4	22	25	4	29
	51	14	65	59	12	71	51	12	63	20	4	24	30	4	34	30	6	36
	75	10	85	75	12	87	80	14	94	25	4	29	30	4	34	59	4	63
	35	10	45	16	12	28	40	10	50	16	10	26	20	8	28	20	8	28
	30	14	44	40	16	56	70	20	90	25	6	31	25	6	31	49	6	55
	20	14	34	20	14	34	30	14	44	20	6	26	20	6	26	20	8	28
Mean	**45.9**	**12.6**	**58.4**	**44.4**	**13.4**	**57.9**	**54.4**	**14.3**	**68.7**	**22.3**	**6.0**	**28.3**	**24.0**	**5.7**	**29.7**	**32.6**	**5.4**	**38.0**
SD	**19.5**	**1.9**	**19.0**	**21.9**	**1.9**	**21.9**	**17.9**	**3.1**	**19.7**	**3.6**	**3.1**	**3.7**	**4.9**	**1.8**	**4.6**	**15.3**	**2.2**	**14.8**
SE	**7.4**	**0.7**	**7.2**	**8.3**	**0.7**	**8.3**	**6.8**	**1.2**	**7.5**	**1.4**	**1.2**	**1.4**	**1.8**	**0.7**	**1.7**	**5.8**	**0.8**	**5.6**

1 week of training when compared with the control group, but after 5 weeks the values were very similar for the two groups. This was supported by the results of a three-factor mixed measures analysis of variance (ANOVA) conducted on these data, the three factors being Group (experimental or control), Distance (near or far) and Time (weeks: 0, 1 and 5). This showed no overall difference between the groups ($F_{1,13} = 0.579$, not significant (n.s.)) but an effect of distance, as expected and seen from Fig. 1 ($F_{1,13} = 45.417$, $p < 0.0001$). We also found a significant effect of time ($F_{2,26} = 14.03$, $p < 0.001$). Most importantly there was a significant interaction of Time and Group ($F_{2,26} = 5.324$, $p < 0.05$), which supports the finding in Fig. 1 that the effect of time depends on which group the participant is in and that the training increased the experimental group PFR at week 1.

Paired scores *t*-tests illustrated this further. For both distances the experimental group show significant increases in PFR from week 0 to week 1 (for near: from 57.63^{Δ} to 75.75^{Δ}, $t = 4.385$, $p < 0.01$; for far: from 31.5^{Δ} to 42.38^{Δ}, $t = 3.894$, $p < 0.01$), whereas the control group showed no significant changes (for near: from 58.43^{Δ} to 57.86^{Δ}, $t = 0.166$, $p = 0.874$; for far: from 28.29^{Δ} to 29.71^{Δ}, $t = 0.772$, $p = 0.469$). Neither group showed significant changes from week 1 to week 5; the best improvement was for the control group at near (from 57.86^{Δ} to 68.71^{Δ}, $t = 2.128$, $p = 0.077$), but this was probably because they had shown little improvement from week 0 to 1. The increase in the control group means from week 0 to week 5 were also not significant for either near ($t = 1.667$, $p = 0.146$) or far ($t = 1.752$, $p = 0.13$).

Importantly, given that training was performed only at near, the ANOVA found no significant interactions with the distance factor (best $F_{2,26} = 0.964$, $p = 0.395$), suggesting that training at near had produced similar results for far in the experimental group.

We now report the stereo-acuity data. The full data set are shown in Table 2, where again the contrast between

Table 2. Frisby stereo-acuities in seconds of arc measured on three occasions for the experimental group, who trained near prism fusion range (PFR), and the control group who did no training. Means, standard deviations and standard error of the means are shown at the base of columns

	Experimental group ($n = 8$)			Control group ($n = 7$)		
	Week 0	Week 1	Week 5	Week 0	Week 1	Week 5
	11.90	5.97	5.97	7.80	10.60	7.60
	7.60	5.97	5.30	7.60	10.60	7.60
	10.60	5.30	5.97	5.97	5.97	5.97
	7.60	5.97	5.97	5.97	5.97	2.99
	7.60	7.80	7.60	5.30	7.60	5.30
	5.30	3.90	5.30	7.80	5.30	7.60
	5.97	3.90	5.30	11.90	15.30	7.60
	7.60	5.30	5.30			
Mean	**8.02**	**5.51**	**5.84**	**7.48**	**8.76**	**6.38**
SD	**2.20**	**1.26**	**0.79**	**2.20**	**3.62**	**1.77**
SE	**0.78**	**0.45**	**0.28**	**0.83**	**1.37**	**0.67**

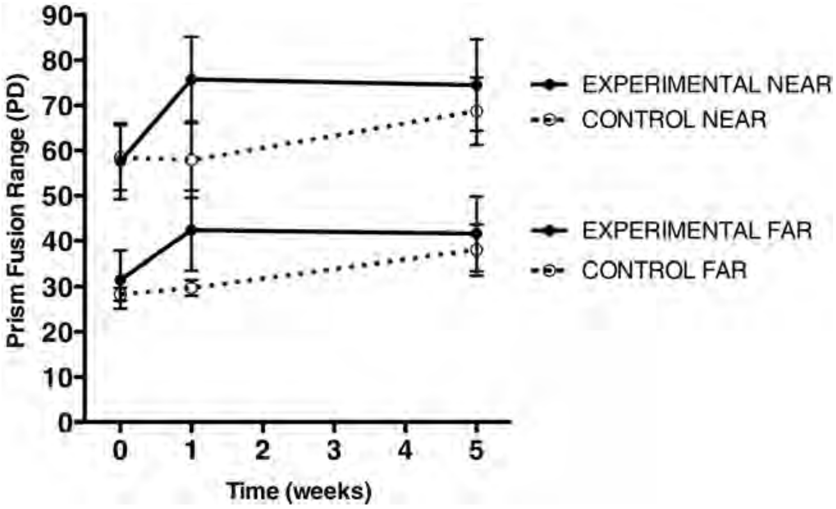

Fig. 1. Mean prism fusion range data for the two groups for the near (0.33 m) and far (6 m) measurements taken at the initial visit (week 0) and then 1 week later, after the experimental group had trained their range and then after a further 4 weeks during which neither group had performed any training. For each participant the base-out (BO) and base-in (BI) data were combined for each condition. Error bars are ± 1 standard error of the mean. In this way all data can be shown in one figure and analysed in one-way analysis of variance. Separate analysis of the BO and BI measurements showed that in reality most of the effects of training were seen in changes in the BO measurements.

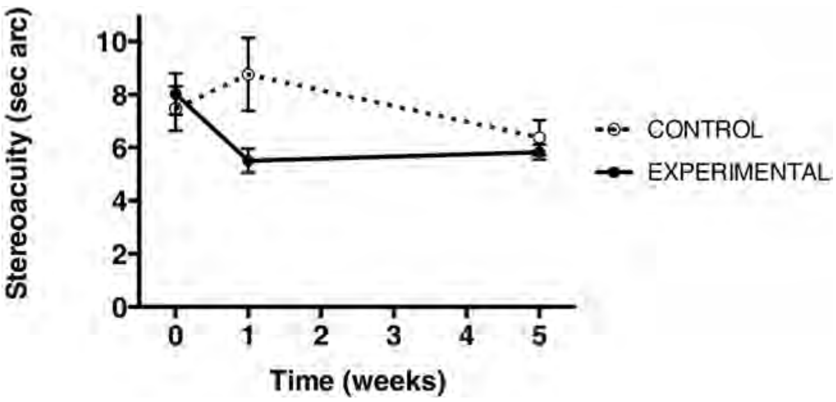

Fig. 2. Mean stereo-acuity values for the experimental and control groups measured on three occasions. At week 1 the experimental group had trained their PFR range for 1 week. Error bars are ± 1 standard error of the mean.

the experimental and control groups can be seen. From weeks 0 to 1 all but one of the experimental group showed improved stereo-acuity values whereas for the control group only one showed any improvement. At week 5 the two groups have similar stereo-acuities. The mean stereo-acuity values of the two groups measured on the three occasions are shown in Fig. 2, which shows a complementary pattern to that in Fig. 1.

The results of a two-factor mixed measures ANOVA conducted on these data support this. The two factors were Group (experimental or control) and Time (weeks: 0, 1 and 5). This showed no overall significant difference between the groups ($F_{1,13} = 1.433$, $p = 0.253$) but a significant effect of time ($F_{1,13} = 4.694$, $p < 0.05$). As expected, if the stereo-acuity had changed differently over the weeks for the two groups, a significant interaction between Group and Time was found ($F_{2,26} = 6.521$, $p < 0.01$). Independent *t*-tests showed no overall group differences at week 0 (experimental group mean, 8.0 sec arc; control group mean, 7.5 sec arc; $t = 0.477$, $p = 0.641$). So both groups were well matched for stereo-acuity at the start. A significant difference between groups was seen at week 1 (experimental group mean, 5.5 sec arc; control group mean, 8.8 sec arc; $t = 2.392$, $p < 0.05$). By week 5 this difference was no longer significant (experimental group mean, 5.8 sec arc; control group mean, 6.4 sec arc; $t = 0.785$, $p = 0.447$).

Looking within each group, for the experimental group from weeks 0 to 1 stereo-acuity significantly improved ($t = 2.705$, $p < 0.05$), but did not further improve from week 1 to 5 ($t = 0.633$, $p = 0.547$); the difference between weeks 0 and 5 was significant ($t = 2.492$, $p < 0.05$), showing that any improvement was still present at week 5. In contrast no differences over time were significant for the control group (weeks 0 to 1: $t = 0.832$, $p = 0.437$; weeks 1 to 5: $t = 1.684$, $p = 0.1684$; weeks 0 to 5: $t = 1.074$, $p = 0.324$).

From Figs. 1 and 2 it would appear that by week 1 the experimental group improved their PFR with training and this seems to have consequently improved their stereo-acuity, which was not trained. We also found that by week 5 any ‘benefit’ of PFR training on stereo-acuity in the experimental group had disappeared when compared with the control group, but the experimental group maintained any improvement is stereo-acuity from week 0 to 5.

We did test the experimental group data for any correlation between size of changes in PFR and stereo-acuity, but no significant correlations were found, possibly because of the small group size.

Discussion

As can be seen from Tables 1 and 2, and Figs. 1 and 2, the experimental group, who performed PFR training for a week, showed improvements in both near and far PFR and stereo-acuity. What is clear from Fig. 1 is that training near PFR also leads to similar changes in far PFR. Fig. 2 shows that the experimental group also showed better stereo-acuity when tested at week 1, but the two groups performed similarly at week 5. This suggests that for both PFR and stereo-acuity any improvements over the control group seen after 1 week of training PFR were lost once this training ceased, and are in any case by week 5 indistinguishable from changes, or improvements, that occur after repeated testing. To put this another way, over 5 weeks without training the control group can achieve the same levels of PFR and stereo-acuity as a group who have had 1 week of PFR training. This highlights the importance of including comparisons with a control group in such studies.

The differences between groups in stereo-acuity at week 1 seen in Fig. 2 are modest and clinically trivial, at just over 3 seconds of arc. It is likely that as all of our participants had normal or corrected-to-normal vision some, but not all, in each group would be near ceiling levels of performance at week 0, and so had little further room for improvement (Table 2). In order to influence clinical practice we need to see how such training could improve stereo-acuity in those with less good stereopsis and/or PFR. It would be of particular interest to see whether any improvements are sustained and whether such improvements are absent in a control group. Any changes in control group performance in orthoptic tests would also show whether repeated testing can lead to improvements without extensive training. This is a neglected area of research. Also just 1 week of training as used here is short compared with the training times used with patient groups,[1–8,10] so an exploration of the length and frequency of training needed would be useful; but importantly this must be compared with performance of a non-treatment group over the same time course.[6,10] It is also important that the studies are run with a double-blind design, and in particular that the examiner is not aware of which participants have received training. This was not the case in our study.

Conclusion

After 1 week significant improvements were found in both near and distant PFR in a group who had spent a week training near PFR. Over the same period stereo-acuity was significantly but modestly improved. However, 4 weeks after the completion of training by the experimental group the performance of the control and experimental groups were no longer significantly different on our PFR and stereo-acuity measures.

Competing interests: The authors declare no competing interests.

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