Negative Vergence Training and its Effect on the Divergence Range and Heterophoria Size

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Abstract

This study aimed to investigate the extent to which negative vergence training can influence the divergence range and the associated heterophoria size. Forty ocularly healthy participants (11 males & 29 females) with an age range between 17-64 years (mean age=26.6 yrs; SD=12.1 yrs) were included in the study. The participants were randomly allocated into four groups (n=10/Gp). The first group was trained using the diploscope treatment only, the second group was trained using the cat-stereograms card with additional modifications applied to it, the third group was trained using a standard cat-stereograms card without any modifications. Participants in these groups underwent training for 5 minutes, 3 times a day for 2 weeks. Lastly the control group did not undergo any training.

Results indicated that there was a significant change in the mean near heterophoria size post training in all groups. This significant change was attributed to chance occurrence and may not yield any clinical relevance. A close to significant interaction between the groups training the cat-stereograms card with modifications and the group training with the standard cat-stereograms card was also found, signifying a better treatment success with modifications applied to the standard cat-stereograms card. Single case analysis of three esophoric participants, pointed to a possible future study to examine the impact of treatment on this group.

Key words: Negative vergence, divergence, heterophoria size, diploscope, cat-stereograms card, additional modifications

Introduction

The ocular motor system is organized to integrate two independent major subsystems: versions and vergences1, 2. The former subsystem mediates conjugate eye movements, while the latter mediates disjugate (disjunctive) eye movements. Both subsystems operate to ensure bifoveal fixation when the eyes of the individual are directed at different directions (versions) and at different viewing distances (vergences).

It has been generally accepted amongst most eye care practitioners that the plasticity and the adaptability of the ocular motor system has enabled it to be freely trained with therapy3. The vergence subsystem has been one area where this plasticity has been shown to exist4. This has proven valuable in the therapeutic training of both the healthy asymptomatic individual and the symptomatic individual whom can present with measurable reduced vergence ranges5.

The vergence subsystem can be generally described according to three types: horizontal, vertical and torsional eye movements. The training of the horizontal vergences has been by far the most popular type of vergence to be trained clinically.

In 1893 Maddox6 classified four types of visual stimuli that can elicit horizontal vergences (i.e. both convergence and divergence). These visual stimuli are tonic, retinal disparity, accommodative and proximal stimuli6. Convergence has also been described as a voluntary response7. Maddox6 considered these visual stimuli are more or less independent additive components of the total horizontal vergence required to maintain any object on both fovea3.

Maddox6 also observed that the eyes under deep sleep, anaesthesia and death, tend to resume the normal anatomical resting position of divergence as a result of the lack of any neural activity keeping the eyes aligned straight ahead5. This resting position differs from the physiological resting position where the eyes resume an intermediate convergent position in the dark. That is, resume the normal anatomical resting position in the absence of any visual stimuli8.

It is pragmatic to assert that the amount of studies conducted on the positive vergence system or convergence outweighs by far the amount conducted on the negative vergence system or divergence in the literature. Studies such as those conducted by Daum1, 3,4,9, Vaegan10, 11 and Green12 demonstrated that the positive vergence system is easier to train, and a greater increase in its amplitude has been noted, when compared to the negative vergence system. Daum13 suggested that this difference observed between these two eye vergence movements, is possibly due to the existence of two different control systems or neural centres13.

Different types of training methods have been investigated in these studies, such as 'push up' training, variable vectograms, synoptophore and an 'aperture-ruler' trainer. These methods were generally categorised into two types of training involving smooth, slow tonic activities and quick, stepwise, more phasic tasks13 .

In 1986, Daum14 conducted a study primarily involving the training of the negative vergence system. The study involved a training period of 7 consecutive weeks. Daum14 acknowledged that negative vergence training could indeed increase the divergence amplitude by substantial amounts (an increase of 5.0^ at distance and 9.0^ at near), however this magnitude of increase remains smaller than the magnitude of change shown to be possible following positive vergence training, observed in other studies 1, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. Daum14 concluded that there must be a fundamental difference between both the positive and the negative horizontal vergence systems14.

Green12 similarly investigated the training of horizontal vergences as well as vertical vergences using a hand-held prism bar. Green's12 study demonstrated a mean divergence amplitude increase of 7.6^ (45%) at 1/3m and 1.2^ (18%) at 6m12. "The surprising element was revealed at the two-year follow up. There was no decline in the increases after two years, and there was a further increase of 117% after a further period of training"12. Green12 affirmed that this magnitude increase will be greater if the convergence amplitude is maximally trained prior to divergence amplitude training12. Green12 concluded that there is a possibility that divergence amplitudes could increase more readily with prism bar vergence training.

Despite the overall success and the numerous studies available on the therapeutic training of horizontal eye vergences, this area merits further study, particularly the negative vergence system. Therefore the current study aimed to establish the extent to which negative vergence training could influence the divergence range and the associated heterophoria size in a group of normal asymptomatic participants. Two different treatments not explored in previous studies were implemented: the traditional diploscope and the commonly used cat-stereograms. The level of effect of these two training treatments was evaluated using two outcome measures: the near (30cm) and the distance (6m) base-in range and the heterophoria size. The current study also aimed to ascertain if the cat-stereograms card was more effective in extending the two outcome measures with the application of additional modifications to the card. It was proposed that the treatments adopted in this current study would extend the range of divergence and influences the size of heterophoria present. It was also anticipated that the application of additional modifications to the cat-stereograms card would improve the treatment effect following training.

Method

Participants

Forty ocularly healthy participants were invited to participate in the current study on a voluntary basis. The participant's age ranged between 17-64 years with a mean age of 26.6 years, SD of 12.1 years. The inclusion requirements were based on participants passing a visual and an ocular motor assessment examination performed prior to random allocation into groups. The participants were required to have: corrected visual acuity of 6/6 or better for each eye; good general health and no history of any current or past ocular pathology, strabismus (intermittent or manifest) and retinal or ocular media disease. Any participants with a history of ocular surgery or regular medications were also excluded.

Design

The current study involved the use of a mixed experimental design consisting of a between groups and repeated measures. The participants were randomly assigned to one of four groups: the diploscope group, the cat-stereograms card with additional modifications group, the standard cat-stereograms card without any modifications group and lastly the control group, which did not undergo any training. Measurements of the base-in range and the heterophoria size for both near and distance were undertaken on (day 1) and (day 15) to ensure consistency of results. The treatments were given to participants to take home and perform for duration of 2-weeks (14 days) for 5 minutes 3 times a day (total of 15 minutes per day).

Apparatus

The measuring instruments included in the current study were: Snellen's 6m Visual Acuity chart (Clement Clarke International Ltd). A horizontal hand-held prism bar with increasing increments of 2^ (total of 40^) and a circular fixation target measuring 1.7cm. The treatments undertaken consisted of the 'diploscope' device and the 'cat-stereograms' card. A consent form, an information sheet about the study, a compliance daily calendar and a treatment instruction sheet, were all provided to each participant prior to commencing with training.

Testing Procedure

On day 1 a brief history was taken to select the suitable participants. A visual acuity test and a cover test were performed at both 6m and 1/3m distances. Once these preliminary measures were completed, the first initial measurements of both the divergence (base-in) range and the heterophoria size were commenced.

The divergence range measurement

A hand-held base-in prism bar was used to measure the divergence amplitude of participants. The examiner placed the prism bar before the participant's eye and asked them to fixate at the 6/60 letter 'A' on the 6m-vision chart when taking the distance measurement and at the fixation target held at 1/3m for the near measurement. The participants were asked to report when the letter 'A' or the near target became horizontally displaced into two completely separated images as the examiner increased the strength of the base-in prism (i.e. this prism which caused the image separation was recorded). The distance and near measurements were taken three times and averaged for analysis.

The heterophoria measurement

The von Greaf subjective heterophoria technique was used to attain an accurate quantitative measurement of the participant's heterophoria size. Tracy16 observed this heterophoria measuring method to yield high test-retest reliability with a coefficient greater than 0.90, since it uses prism dissociation as a dissociating technique16.

This method consisted of a vertical dissociative base-up prism, which interrupted the participant's fusion. The strength of prisms needed to achieve full dissociation varied between 3^-6^, depending on the participant's vertical range.

A vertical prism bar was placed before the participant's right eye as they fixated at the 6/60 'A' letter on the 6m-vision chart. The prism vertically displaced the image before the subject's line of sight, which allowed them to appreciate two vertically, separated 'A' letters. Perfectly vertically aligned 'A' letters indicated that the participant was orthophoric and a measurement of '0' was recorded. Diagonally placed images, indicated the presence of a horizontal deviation. A second hand-held prism was used to align the diagonal images, until they were vertically aligned one above the other. The prism strength required to achieve this was recorded. Similarly, measurements were repeated at near (1/3m) using the fixation target.

The order in which the distance and near measurements for both the base-in and heterophoria size, were randomised between participants to control for any sequence effects. All measurements were performed and repeated in the same manner on day 15 following completion of the treatment period.

Home treatments

The Diploscope treatment

The diploscope principally teaches "the awareness to the patient of his visual axis, and in acquiring dexterity in directing the axes to a given point at will"17. There are four points of fixation to which the participant can direct their visual axis. However, as this current study was chiefly training divergence, the participants only exercised the "fourth position" of fixation, as it was the only position primarily concerned with divergence.

The training of the diploscope required the participants to place the instrument (Figure 1) on their nose and direct their eyes slightly above and beyond its card (with the letters DOG printed on it) into a 6m distance or into a far away distance such as outside a window. This distance fixation was a mandatory requirement, as divergence was ensured to take place. Participants were subsequently instructed to diverge their eyes until they were able to achieve the letters DOOG. The participants were able to train their divergence range by consciously increasing the distance between the middle 'OO' letters. In theory, as the distance continued to further increase between those two middle letters, the divergence amplitude would have simultaneously increased17.

Once the participants exercised their divergence range looking into the distance, they were asked to redirect fixation to the near metal septum before their eyes. Consequently, the middle 'OO' letters joined and became one letter 'O'. However when asked to exert control by diverging their eyes further, the participants were able to maintain the distance between the two letters and keep them apart. This part of training aimed at strengthening and sustaining the divergence capability, the participants had achieved when looking into the distance17.

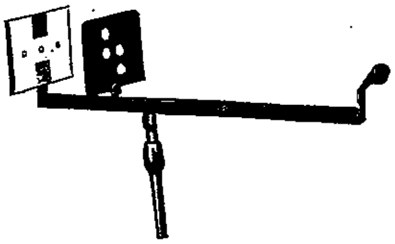


Figure 1. The diploscope treatment

The cat-stereograms treatment

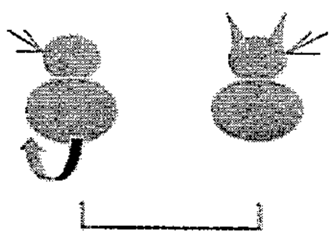
In the clinical setting, a standard cat-stereograms card, which has two cat pictures distanced 6cm apart, is used to train relative fusion. The distance between the two cat pictures is specifically set at 6cm to be equivalent to the average individual's interpupillary distance (IPD).

This card teaches "dissociation of accommodation from that part of convergence, which is variable, that is the metre angle minus the AC/A ratio"17. This principal was accomplished by the participant, via the movement of their visual axes into a position, which is either relatively convergent (positive relative fusion) or relatively divergent (negative relative fusion) with respect to the position of the card. Consequently, this visual axis movement resulted in one image of the cat pictures on the card, to fall on the fovea of the participant's right eye and the image of the other cat picture to fall on the fovea of their left eye17. Following, a bifoveal-fused image would have been perceived and projected straight ahead as a third complete cat picture in the centre of the card 8,17,18. Given that, divergence training was the primary aim of the current study, participants were encouraged to exercise the negative relative fusional aspect of the card, by holding the card at an arms length and looking slightly above and beyond it into the distance to achieve the picture of the third complete cat.

Clinically, this standard cat-stereograms card is not generally given with any additional modifications to assist the patient to adapt their eyes when they experience difficulties in achieving the third cat. The modifications applied to the cat-stereograms card in the current study, included the adjustment of the separation between the cats by further increasing the distance by 0.5 cm to reach 8cm and by reducing the image separation, by 0.5 cm reaching 4 cm (Figure 2). The adjustment of the distance between the images, aimed at assisting the participant to achieve the third cat with ease (i.e. by training using a distance that they were comfortable with). The increase in the distance between the two cat pictures, aimed at providing the participant a range of distances on which they can exercise and extend their divergence range (Figure 2). The other type of modification applied in the current study, entailed the removal of the middle part of the two-cat pictures17, 18(open stereograms; Figure 3) to have the participant look through them into the distance. This modification also aimed at allowing the easier achievement of the third cat, by encouraging the participant to relax the proximal convergence that takes place as a consequence of the nearness of the card. The modification also relaxes accommodation, ultimately assisting in divergence to be instigated with more ease.

The participants in the cat-stereograms with modifications group, besides having their IPD measured on day 0, were given a set of cat- stereogram cards with the additional modifications applied to them. The set consisted of pairs of 9 cat-stereogram cards (total of 18 cards). Each pair of the cat-stereograms cards had the cat pictures set at a certain distance and included one open cat-stereograms card and one closed cat-stereograms card. For example, a pair that had it's cat pictures set at 4cm, would have one open cat-stereograms card and one closed cat-stereograms card, with both cards set at 4 cm etc. The participants were instructed to choose the pair of cards with which they could achieve the third cat, then to start each pair with the use of the open cat-stereograms card to assist them to achieve the third cat easily. Subsequently, they were to train using the closed cat-stereograms card. Once they achieved the closed cat-stereograms card, they were able to progress to a further set distanced pair of cards until they could accomplish the 8cm cat-stereograms pair of cards or until the two weeks period concluded.

The participants using the standard cat-stereograms card were only given the standard closed cat-stereograms card without any modifications applied to it. The IPD of participants was also assessed in that group on day 0.

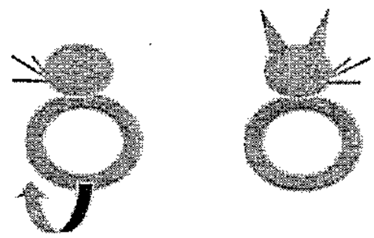


6cm
Standard card distance

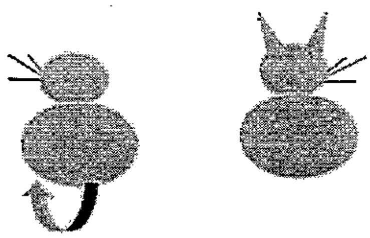
Distance was increased by
0.5cm (up to 8cm)

Distance was decreased by
0.5cm (up to 4cm)

Figure 2. Modifications of the cat-stereograms card involving distance adjustment by an increase of 0.5 cm (up to 8cm) and a reduction by 0.5 cm (up to 4 cm)



Open Cat-stereograms



Closed Cat-stereograms

Figure 3. Modifications of the cat-stereograms card entailing the elimination of the middle part of cat pictures (open cat-stereograms)

Control group

The control group was not given any treatment during the two weeks training period. The participants in that group were only measured in the pre and post visits (i.e. day 1 & day 15).

Statistical Analysis

A planned contrast analysis of variance (ANOVA) was used to analyse the data. Several planned contrasts were made with an alpha level of 0.05: On day1, the 'distance' measurements (base-in range & the heterophoria size) in all the four groups were compared with all the 'distance' measurements on day15. In all four groups the 'near' measurements on day1 were compared with the 'near' measurement on day15. Furthermore, all the 'distance and near' measurements in all the four groups on day1 were compared to all the 'distance and near' measurements on day15, and all the distance measurements (both the day1 & day15 in combination) were compared with all the near measurements (both the day1 & day15 in combination).

A between group analysis was also performed, where the diploscope group, the cat-stereograms with modifications group and the standard cat-stereograms card group were individually compared with the control group. Moreover, the cat-stereograms with modifications group was compared to the standard cat-stereograms card group, and the diploscope group was compared to both the cat-stereograms with modifications and standard cat-stereograms card groups. Finally all treatment groups in combination were compared to the control group.

Results

The data was screened for normality and two statistical outliers were removed. Consequently, the planned contrast ANOVA was performed using only 38 subjects.

Divergence range (base-in)

A close to significant interaction between the cat-stereograms with modifications group and the standard cat-stereograms group, on the distance base-in range variable was found (F (1,37)=3.857, p=0.058). The cat-stereograms with modifications group showed a training mean distance base-in range measure of 5.4^ (SD=1.28^) on day1 and a training mean distance base-in range measure of 5.6^ (SD=1.497^) on day15, giving a total mean increase of -0.2^ (SD=-0.216^; Figure 4). The standard cat-stereograms group showed a training mean distance base-in range measure of 5.9^ (SD=1.921^) on day1 and a training distance mean base-in range measure of 5.2^ (SD=1.327^) on day15, giving a total mean decrease of 0.7^ (SD=0.594^) post-training (Figure 4).

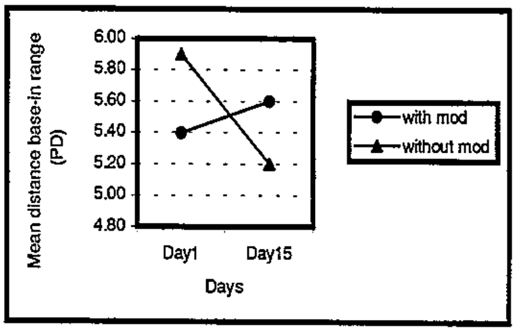


Figure 4. Significant interaction was found between the cat-stereograms with modifications group (with mod) and the standard cat-stereograms without modifications group (without mod).

Heterophoria size

A significant difference was found in the mean near heterophoria size pre and post training (F (1,37)=6.628, p=0.015). This significant change was found regardless of whether treatment was or was not given. That is, when compared to the mean distance heterophoria size post-training period, all three-treatment groups and the control group demonstrated an average increase in the mean near heterophoria (Figure 5). The groups showed a training mean near heterophoria measure of -1.42^ (SD=3.126^) on day1 and a training mean near heterophoria measure of -2.42^ (SD=3.023^) on day15, giving a total mean increase of 1^ (SD=0.103^) post-training (Figure 5).

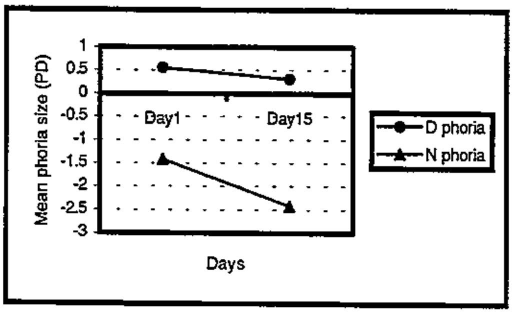


Figure 5. Change in the mean near heterophoria post-training period (D phoria=distance heterophoria; N phoria=near heterophoria)

A summary of the near heterophoria distribution across all experimental groups was attained to aid in finding a rationale to having had no overall treatment effect at the conclusion of the 2 weeks training period. The success of treatment is highly dependent on the types of the near heterophoria trained. Given that the treatments train divergence, esophorias would be the most successful treated heterophoria type. Orthophoric and exophoric types of heterophoria would be comparatively limited due to the smaller range available to diverge further. Figure 6 illustrates that the majority of participants clustered around the 0 line (i.e. orthophoric) or the -5^ line (i.e. exophoric) whereas only 4 participants showed an esophoric heterophoria type (Figure 6).

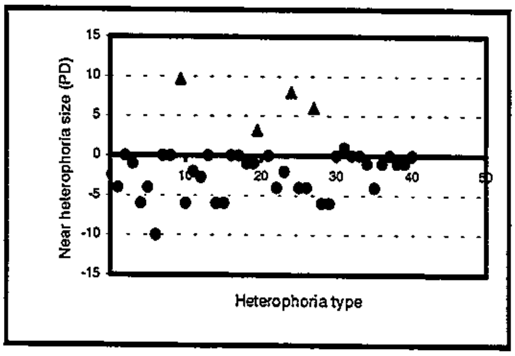


Figure 6. Summary of the near heterophoria distribution in all experimental groups

Single Case study

Three esophoric participants shown in figure 6 to measure more than 5^ of esophoria were considered closely as single case studies. The purpose of this was to observe any impact of the treatments those three participants trained during the 2-weeks period, on their near base-in range and heterophoria size.

Case study 1

Case study 1 participated in the diploscope group and was one of the outliers removed from the analysis. On day1, this participant presented with a near esophoria measurement of 10^ and on day15 following treatment presented with a near exophoria measurement of -2^ (Figure 7). Hence, there was a total 12^ reduction in the participant's near esophoria size post training. Comparatively, the diploscope group, which presented with a near heterophoria mean of -2.63^ on day1 and a post near heterophoria mean of -2.88^ on day15, showed a mean increase of only 0.25^ (Figure 7).

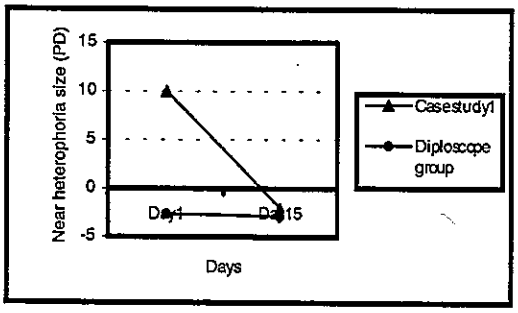


Figure 7. Change in the near heterophoria size in both case study1 and the diploscope group following training the diploscope treatment

Furthermore, case study 1 showed a change in the base-in range following the diploscope training. On day1 a base-in range measure of 12^ and on day15 base-in measure of 16^ were obtained. Hence, a total base-in range increase of 4^ was demonstrated following training (Figure 8). The total diploscope group, exhibited no mean change following training with the diploscope, given that it presented with the same mean base-in measurement of 13.5^ on both day1 and day15 (Figure 8).

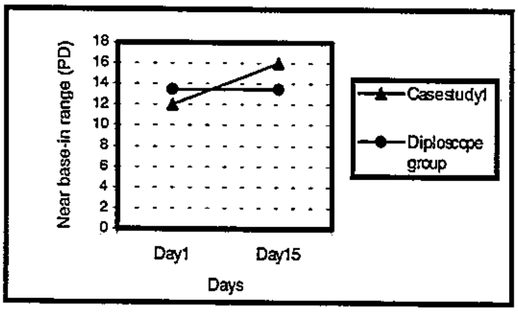


Figure 8. Change in the near base-in range of case study 1 and the diploscope group following training the diploscope treatment

Case study 2 & 3

Case study 2 and 3 represent the other two esophoric participants studied closely as single case studies. Both of these participants trained with the standard cat-stereograms without modifications card.

Case study 2 presented with near esophoria measurement of 8^ on day1 and a near esophoria measurement of 2^ on day15, demonstrating a total esophoria size reduction of 6^ following training (Figure 9). There was no change in the participant's base-in measurement, which was 6^, post training.

Case study 3 exhibited a near esophoria measurement of 6^ on day1 and a near esophoria measurement of 4^ on day15, signifying a total esophoria size reduction of 2^ (Figure 9). Equally, case study 3 did not show any change in the near base-in range, which measured as 10^, post training.

Comparatively, the standard cat-stereograms group, which presented initially with a mean near heterophoria measure of -1.2^ on day1 and a mean near heterophoria measure of -1.7^on day15, showed a total mean increase of 0.5^ post training period (Figure 9).

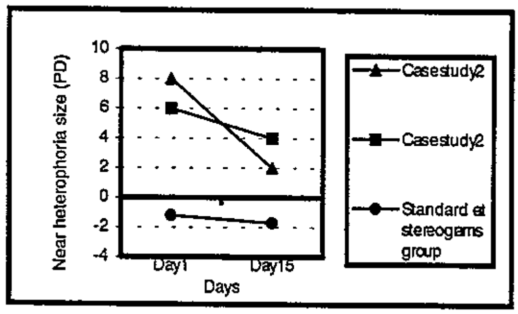


Figure 9. Change in the near heterophoria in case studies 2 and 3 and the standard cat-stereograms card following training the cat-stereograms without modifications card

Discussion

Overall, the current study did not find any significant difference in the base-in range or the associated heterophoria size following training with the diploscope or the standard cat-stereograms without modifications and the cat-stereograms with modifications card. The significant difference found in the near heterophoria in all experimental groups following treatments or no treatment given, could not be attributed to a specific reason in the literature. However, several authors6, 16, 19, 20, 21 have suggested that variability in the heterophoria measurement can occur due to different factors.

Schor6 suggested that, providing that the accommodative level is held fairly constant, heterophoria measurements can vary between 2^-3^ depending on the heterophoria measuring method used by the examiner6. Tracy16 observed that heterophoria measuring methods using similar methods of dissociation, for example flashing or prism dissociation, are more likely to report higher correlations than if different dissociation methods are used16. The method used in the current study (the von Graefe technique) would yield an overall good test-retest reliability with a coefficient greater than 0.9016 since it used prism dissociation which accordance to Tracy16 and accordingly, this method did not cause the variability in the near heterophoria observed in all groups.

Tracy16 also suggested that sources of error in measurement due to examiner and patient bias may cause variability in the near heterophoria. For example, errors in measurements caused by improper prism placement. Also variability could occur if the examiner overlooks small amounts of movements when assessing the near heterophoria when using a hand held prism.

In the present study the near heterophoria measurements procedure were kept as consistent as possible all through out the assessment of the four groups. This consistency was ensured as each measurement was taken three times in both day1 and day15 sessions. Nevertheless, it is possible that an uncontrolled for variation in the examiner technique could have occurred.

Variability in the near heterophoria size was also reported in the literature to occur following near vision stress. Few authors 19, 20 have shown that a near visual task (e.g. reading) that was either employed for 20 min18, or 90min20 lead to a near esophoric shift post task. According to Ehrlich20 this esophoric shift is in accordance with a current vergence theory that states "the vergence resting position moves closer following stress on the vergence system" (i.e. becomes more esophoric) 20.

The change in the near heterophoria in the current study was not in the esophoric direction. It instead showed an increase towards the exophoric direction, where orthophoric participants became exophoric, exophoric participants became more exophoric and esophoric participants became less esophoric post-training period. Therefore although the effect of near visual tasks on the near phoria was not controlled for in the study, it can be said that it had no direct effect on the participants near heterophoria due to having no esophoric shift evident post-training.

Therefore, it can be said that the significant change in the mean near heterophoria observed statistically in all four groups, is highly unlikely to be directly due to any of the factors discussed previously. The total mean difference of only 1^ (SD=0.103^) may not yield any clinical relevance. This total mean difference post training is most likely due to a chance occurrence.

A close to significant interaction between the cat-stereograms card with modifications group and the standard cat-stereograms card group was also found in the current study. The cat-stereograms card with modifications group, showed a total mean distance base-in range increase by -0.2^ (SD=-0.216^; Figure 4) post training. Conversely, the standard cat-stereograms card group demonstrated a 0.7^ (SD=0.594^; Figure 4) decrease in the mean distance base-in rang post training. These results signify that the cat-stereograms card with modifications group, showed better improvement due to the aid of the additional modifications applied to the card. The standard cat-stereograms card group, demonstrated a decrease in the distance mean base-in range following training, suggesting that the use of the cat-stereograms card without modifications might have created difficulties for the participants in achieving the third cat picture. This difficulty possibly may have lead the participants to achieve the third picture of the cat by way of convergence rather than divergence. That is, they exercised their eyes in the opposite direction to divergence and as a result their distance base-in range decreased.

The modifications applied in the cat-stereograms card group, has considered the participant's interpupillary distance (IPD). This factor, provided the participants in the cat-stereograms card with modifications group, an advantage over participants in the standard cat-stereograms card group, as the participants in the former group were able to begin training, using a cat-stereograms card with a distance between the two cats pictures, that is equivalent to their IPD. The latter group faced the dilemma of using the one card with the 6cm set distance between the two cat pictures, which in some cases exceeded the participant's IPD and created for them an obstacle in achieving the third cat.

Furthermore, the cat-stereograms card with modifications group had the middle part of the cat pictures removed (open cat-stereograms; Figure 3), which assisted the participants to achieve the third cat picture in an effortless fashion17. The standard cat-stereograms card group used the closed cat stereogram cards (Figure3), which contributed to making the task of achieving the third cat picture more difficult.

Principally the increasing in the distance between the two cats pictures in the cat-stereograms card with modifications group, facilitates the extension of the participant's divergence range through the extension of their negative relative fusion with the increasing of the card's IPD distances. The standard cat-stereograms card group trained using the set 6cm card IPD distance, which meant that achieving the third cat at that distance will not encourage any extension of the divergence range, it only improved the negative relative fusion of the participant at the that set distance.

Overall, the improvement shown in the cat-stereograms card with modifications group was only by -0.2^, and similarly the decrease in the standard cat-stereograms card group, was only by 0.7^. These results might not denote much clinical significance in either case, however, it does point towards a possible higher rate of success if additional modifications are applied to the card when training divergence.

The lack of change in the negative vergence and the associated heterophoria following training in the present study can be related to several factors. It is possible that the effect size of the two treatments was minor and possibly a larger sample size (n=>10/gp) might be needed to show greater treatment effect. A future study could allocate participants >10/gp and observe effect of divergence treatments on them.

The time spent in training the negative vergence (15 min/day) could have been insufficient. Similar studies have designated more time1, 3, 8, 13 and managed to achieve an improvement in the negative vergence range and the associated heterophoria size. Daum13 conducted a study using two participants for 45 min/day for 7 consecutive weeks, and suggested that at least 10-15 hours of divergence training is needed to achieve maximum effect. A future study may possibly increase both the duration (min/hrs) and training period (days/wks) for further treatment effect.

The time, at which the negative vergence and the associated heterophoria were assessed in relation to when the training was ceased, could have influenced the results obtained. Green11 and Daum3, 8 have observed an increase in the divergence range after a certain period have passed since the termination of training. A follow up study may possibly be conducted after a certain period of time on the forty participants of the current study, to observe any increase in the base-in range or/and the associated heterophoria.

Green11 had recommended maximal training of the convergence amplitude, prior to training divergence for enhanced divergence treatment effect11. A future study could allocate two groups to train divergence in isolation in one group, and maximal convergence followed by divergence training in the other group.

Lack of participant's compliance with carrying out the treatments for the entire 2-week training period, may possibly have affected the results acquired. A future study may conduct all training sessions in clinic rather than to give treatments to participants take home to ensure total participant's cooperation.

Daum12 investigated two types of horizontal vergence training: smooth, slow and tonic activities and quick, stepwise, more phasic task, for 10 min/day for 3 consecutive weeks. The slow activities encompassed two training methods: a 'push up' method and variable vectograms12. The quick, phasic tasks included base-in or base-out prisms placed in trial holders and an aperture-ruler trainer. It was concluded that the quick, stepwise type of training demonstrated a larger improvement in both the positive and negative vergence training than the slow, smooth training12. Despite this conclusion Daum12 pointed out that the difference between the two methods is less than 5^ and may not be clinically significant and thus should not exclude smooth, slow and tonic training methods. The two training treatments used in the present study would be considered to be a slow, smooth and tonic type of treatments. It is a possibility that the application of quick and more phasic type of training such as base-in prism training may have produced a larger effect than the slow tonic methods used in the current study. However, Daum12's study did point out that insignificant difference exists between the two methods and clinically should not make a difference.

It may be of importance to point out, that although both the diploscope and the cat-stereograms card are considered to be slow and tonic type of training, they are fundamentally training two different aspects of the negative vergence system. The 'diploscope' trains the negative vergence via increasing the subject's voluntary ability to diverge (section 5.1). Concurrently, the 'cat-stereograms' encourages the participant to achieve greater divergence range through exercising their negative relative fusion with increasing the cat-stereograms card IPD distances. Therefore the difference in the mechanisms behind the two treatments may have a reason to not achieving treatment effect, however a further study is needed to investigate these aspects more thoroughly.

Belasco21 have suggested a selection and a matching approach when considering successful 'training' "changes associated with training may be improved dramatically through advanced selection of those individuals most likely to benefit from the given kind of training" 21. The most likely candidates to benefit from negative vergence training would be esophoric individuals than orthophoric or exophoric individuals14, 15, 17. Esophoric individuals have larger room for improvement particularly at near, as their visual axis is anatomically converged and should respond more readily to divergence treatment. Orthophoric and exophoric individuals face the 'ceiling effect' problem where they may not be able to exert further divergence beyond a certain point, due to their visual axis being limited anatomically.

In the current study, the three single case studies illustrated the possible success of negative vergence training in asymptomatic esophoric individuals. Following training using the diploscope treatment case study 1 showed an improvement in both the near heterophoria size and the near base-in range with the near heterophoria showing the most positive result. Case study 1 demonstrated a 12^ of total near esophoria reduction following diploscope training. In comparison, the entire diploscope group demonstrated a mean near heterophoria change of only 0.25^ (Figure 7). The change in case study's 1 near base-in range which showed a total difference of 4^ post training, is also notable, particularly when compared with the entire diploscope's group total mean change of 0^ (Figure 8). Therefore, the demonstrated change in both the near heterophoria and near base-in range of case study 1 signifies the extent to which the diploscope training could influence the negative vergence system of an esophoric individual.

Case studies 2 and 3 also showed some improvements their near heterophoria size following divergence training using the standard cat-stereograms card (Figure 9). Although the change in their near heterophoria following treatment was not as notable as case study 1, the change can still be considered noteworthy when compared with the entire standard cat-stereograms group's mean change of 0.5^. The difference is particular in case study 2 as they demonstrated a total near esophoria size reduction of 6^ post training (Figure 9).

Therefore the improvements in the near heterophoria size shown to be possible through the three single case closely studies, point towards a further training once the negative vergence is trained primarily in a group of esophoric participants. Moreover, these results advocate treatment success in reducing the amount of esophoria present, following the diploscope training, than when training the standard cat-stereograms card. Therefore it is essential for a future study to train divergence solely in asymptomatic esophoric participants using both the diploscope and the standard cat-stereograms to observe any changes in their negative vergences and their associated heterophoria. The training of the cat-stereograms with additional modifications may also be applied in this future study, to compare its effect to the other two treatments on both the measuring outcomes.

The lack of change in both the base-in range and the heterophoria size following training could also be attributed to the fundamental difference between divergence and convergence. Past research 1, 3, 5, 8, 9, 10, 11, 12, 13, 14, 17 have pointed towards fundamental differences between the negative and positive vergences, in that two different control systems or neural centres may exists for both of these horizontal vergences. Following training the negative vergence for 7 consecutive weeks, Daum10 observed that change in the negative vergence is still smaller in magnitude when compared to what is achieved following positive vergence training10. Daum10 concluded that this fact suggests fundamental differences between both positive and negative vergences. Therefore, it is a possibility that no matter how much negative vergence training is applied; the divergence magnitude may not be able to reach the same magnitude achieved by positive vergence training. However, continued research in the area is needed to satisfactorily reach a conclusion to that effect.

Lastly, it is also possible that the diploscope and cat-stereograms treatments do not have any effect whatsoever and may not be a wise choice in the clinical setting to aid in training the divergence range or the associated heterophoria size. However, a conclusion cannot be reached to their clinical irrelevance until a future study investigating esophoric participants using the same treatments is conducted and no training effect is achieved such as in the current study.

Conclusion

Although the current study did not demonstrate any treatment effect following divergence training, previous work in the area 1, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 16 have shown an increase in the divergence range and the associated heterophoria following negative vergence training. However, the magnitude of change achieved has always been much less than what can be achieved training the positive vergence. Therefore, the training in the current study does not necessarily represent the maximum to which the negative vergence can be changed, particularly when several possibilities have been put forward which may suggest room for improvement.

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