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ORIGINAL ARTICLE

Fusional Amplitudes: Developing Testing Standards

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ABSTRACT
Purpose: The stability of binocular vision depends upon good fusional amplitudes, but the clinical assessment of fusional amplitudes varies around the world. The purpose of this study was to determine whether or not there is variation in the assessment of fusional amplitudes in normal subjects. The author looked at the testing distance, the order of testing, the role of examiner encouragement, and the subject's level of alertness.
Methods: In a prospective study using a modified crossover design, the author assessed fusional amplitudes in 99 subjects with normal eye exams. The measurements were done in two separate sessions on different days with each subject being randomized as to the order of fusional vergence testing. All subjects were assessed without and with encouragement in the first session. In the second session, all were assessed at different testing distances.
Results: The author previously presented data on 50 subjects. In this expanded cohort, statistical significance was reached confirming the previous findings that convergence is significantly affected by encouragement, divergence is significantly reduced if assessed after convergence, and near amplitudes are significantly higher than distance amplitudes. Finally, there is a negative correlation between age and convergence break point.
Conclusions: The results of this study demonstrate that divergence is significantly reduced if assessed after convergence in the subject with normal binocular function. Next, convergence is significantly affected by the use of encouragement. Measurements at near produced significantly higher results for all of the convergence and divergence tests. Finally, there is a significant negative correlation between age and convergence break point. We need to develop a standard of testing fusional amplitudes so there is consistency in the clinical assessment.

KEYWORDS
Convergence; divergence; encouragement; fusional amplitudes; vergence

Introduction

Fusional amplitudes play a critical role in our ability to maintain binocular single vision. As clinicians, our assessment of the range of vergence is an important diagnostic tool in our workup of a symptomatic patient. However, sources site different approaches to assessing horizontal fusional amplitudes. Some clinicians recommend a specific testing order,[1-3] whereas others test the critical range first.[4-6] Thus, if the patient had an esodeviation, divergence amplitudes would be assessed first, whereas convergence amplitudes would be assessed first in a patient with an exodeviation.

Many researchers describe the assessment of fusional amplitudes at distance and near.[2,3,5,7,8] Despite numerous publications noting a difference in fusional amplitude range for different testing distances, some clinicians are unaware of the impact that testing distance has on the amplitude of fusional vergence. Additionally, heterophorias have been described to affect the measured amplitude,[9] but this may not be taken into account by all clinicians.

Many references report a normal vergence value.[7,10-17] But these values vary by reference and the impact of age or size of target are not always addressed when citing normal vergence values. Another potential influence is the role of encouragement. The topic of encouragement has been well documented in the sports research literature[18] and psychology literature.[19-21] Often clinicians use motivation or encouragement during fusional amplitude testing or training,[22,23] but it is not done consistently by everyone. Finally, it is well known that optimal performance is affected by sleep deprivation.[24-27] Early researchers looking at fusional amplitudes noted that a patient's level of alertness might affect the final outcome.[3,28]

In 2013, Fray reported data from a prospective project involving 50 subjects with normal eye exams assessing fusional amplitudes but varying the testing distance and the order of testing.[29] In addition, the role of examiner

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encouragement and the subject's level of alertness at the time of testing was analyzed. Data were collected in 2 separate sessions, with each subject being randomized as to the order of fusional vergence testing in each session. The author found that convergence was significantly affected by encouragement and divergence was significantly reduced if assessed after convergence. Due to small numbers, the effect of fatigue on final outcome measures did not produce meaningful data. Based on these results, recommended guidelines were proposed for assessing fusional amplitudes.

The present study is a continuation of that project in which the same parameters were assessed using an expanded cohort. The purpose was to see if the results retained statistical significance and if previous conclusions remained valid.

Materials And Methods

Following protocol that was approved by the Institutional Review Board at the University of Arkansas for Medical Sciences and Arkansas Children's Hospital, written informed consent was obtained from 100 participants who met inclusion criteria. Adult subjects of at least 18 years of age with normal binocular functions and a best corrected visual acuity of 20/30 (6/9) or better in each eye were recruited. Exclusion criteria included best corrected visual acuity of worse than 20/30 (6/9) in either eye; a history of manifest or intermittent strabismus; a history of strabismus surgery; or symptoms of disrupted binocular vision or diplopia. A total of 99 participants met inclusion criteria.

The average age of study participants was 38 years, with a range of 20-70 years. The median age was 32 years. The ratio of females to males was approximately 4:1. Each participant had a full orthoptic evaluation while wearing appropriate refractive correction. Alternate prism and cover test was performed at 6 meters and at 1/3 meter using an accommodative target. Measured heterophorias were incorporated into the final value of fusional amplitude for each study participant, as recommended by Scobee & Green.[9]

Prior to measuring the fusional amplitudes, a script was read to ensure that all subjects received identical instructions pertaining to the goal of the test, what to expect, and their role in the test. They were instructed to concentrate on the target and keep it single, to report when it got blurry or double, and if they could get the target single again. A prism bar was used to assess the fusional amplitudes.[7] In the literature, there is some controversy pertaining to the effect of ocular dominance on vergence testing and the selection of the proper eye for fixation. Several investigators found no statistical difference when the prism bar was placed before either eye.[3,5,7,30,31] For this study, measures of fusional vergence were taken with the prism bar held in the frontal position over the non-dominant eye using the step method. Narbheram and Firth emphasized the importance of recording the blur point during the assessment of fusional amplitudes using a foveal target.[8] Although a blur point was recorded, only the break point and the recovery point values were used in the analysis.

In a modified crossover design study, convergence and divergence fusional amplitudes were assessed with the participant looking at an isolated, parafoveal-sized 20/40 (6/12) Snellen letter. The order in which the participant received each assessment was randomized into one of two sequence groups. One group received convergence assessments followed by divergence in their first session, while the second group had divergence assessed prior to convergence. The order was reversed for both groups in the second session (Table 1). Sessions 1 and 2 were completed on different days, with a minimum of 24 hours separating the sessions.

The design of this study was modified from the traditional two-period crossover design as each participant was assessed twice under experimental conditions in each session. In the first session, the initial assessment was made without encouragement, while the second assessment was made with encouragement. All first session assessments were made with the participant focusing on the target at a distance of 6 meters. The only difference was whether or not encouragement was given. For the second session, the first assessment was performed while the participant focused on the target at 1/3 meter, while the second assessment was made focusing on a distant target. All measurements obtained in the second session were performed with encouragement. The only difference was the testing

Table 1. Summary of the modified crossover design used for fusional amplitude study. Each subject was randomized into one of two sequence groups. In the first session, Group 1 received convergence followed by divergence, whereas Group 2 received divergence followed by convergence. The order of testing was reversed for both groups in the second session (see shaded area). Each subject received two assessments in each testing session. During the first session, encouragement was not given during the first assessment, but was given during the second assessment. During the second session (see shaded area), near measurements were taken prior to distance measurements.

	Sequence group				
Session	1	2	Assessment	Encouragement	Testing distance
1	C→D	D→C	1	No	6 m
			2	Yes	6 m
2	D→C	C→D	1	Yes	1/3 m
			2	Yes	6 m

C=convergence; D=divergence.

Table 2. The Stanford Sleepiness Scale is an introspective measure of sleepiness. Subjects were asked to rate their level of alertness prior to each exam by indicating which description most accurately described their current state of alertness. From: www.stanford.edu/~dement/sss.html

Degree of sleepiness	Scale rating
Feeling active, vital, alert, or wide awake	1
Functioning at high levels, but not a peak; able to concentrate	2
Awake but relaxed; responsive but not fully alert	3
Somewhat foggy, let down	4
Foggy; losing interest in remaining awake; slowed down	5
Sleepy, woozy, fighting sleep; prefer to lie down	6
No longer fighting sleep, sleep onset soon; having dream-like thoughts	7
Asleep	X

distance (Table 1). At the start of each session, the participant's level of alertness was assessed using the Stanford Sleepiness Scale (Table 2). This scale provided a quick and simple way to quantitate alertness regardless of the time of day the assessment was made.

Results

Heterophorias

Heterophorias were measured at distance and near fixation using the alternate prism and cover test. A total of 68 subjects had no measured heterophoria at distance fixation, 22 had exophoria, and 9 had esophoria. At near fixation, 15 subjects had no measured heterophoria, 57 had exophoria and 27 had esophoria. Figure 1 shows the distribution of heterophoria measurements. A total of 89 subjects (90%) were within 3Δ of orthophoria at distance, whereas a total of 63 (64%) were within 3Δ of orthophoria at near fixation. Only 6 subjects measured larger angles of ≥10Δ, each having an exophoria at near fixation. The average deviation at distance was 0.49Δ X (range of 8Δ X to 4Δ E). The average deviation at near was 2.11Δ X' (range of 20Δ X' to 7Δ E').

All measured heterophorias were incorporated into the final value of fusional amplitude for each subject. The difference between the break point with and without the phoria incorporated is plotted for both test groups from Session 2 in Figures 2-5. The data is sorted in order by age from the youngest subject to oldest to show the variability of the range of amplitude across the ages. Table 3 shows the vergence ranges organized by age categories for groups 1 and 2. The data for each group were separated to avoid biasing the final amplitude. Recall that the order of testing convergence and divergence was the same within each group. No correlation or statistical significance could be found between the heterophoria and any fusional amplitude measured when analyzed with Spearman's rank correlation (analogous to the Pearson correlation coefficient) (P values ranging from 0.0866 to 0.9122).

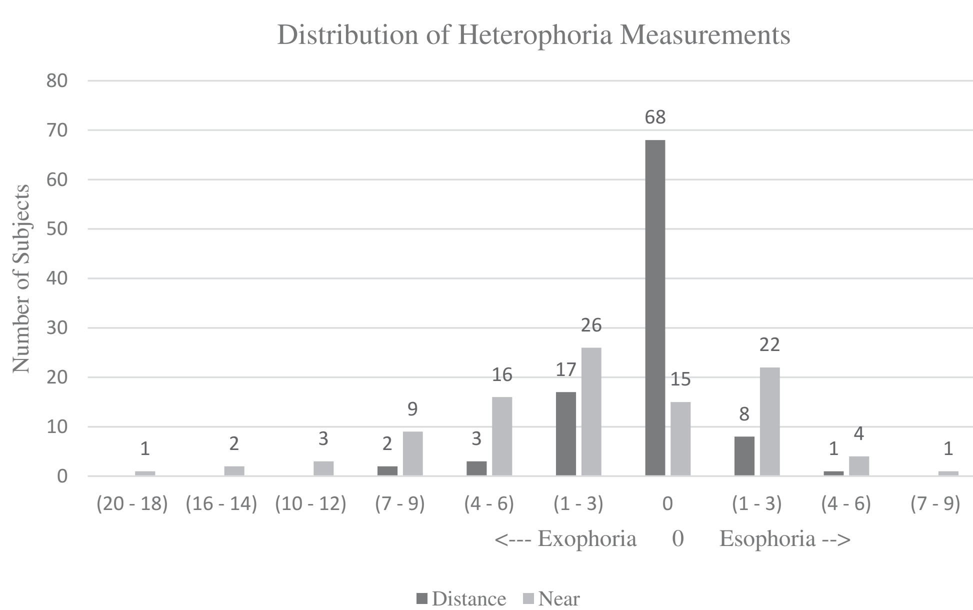

Figure 1. Distribution of heterophoria measurements (in prism diopters) at distance and near fixation. 0 =orthophoria. All exophoria measurements are to the left of 0 and all esophoria measurements are to the right of 0.

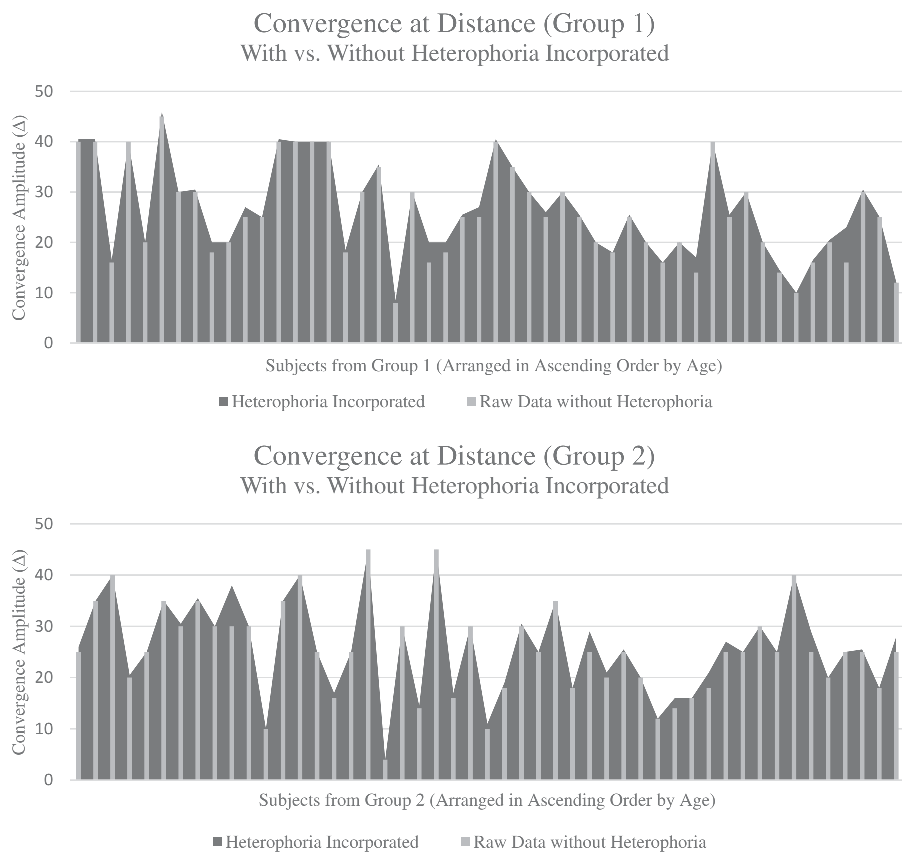

Figure 2. Convergence break points at distance fixation for Group 1 (top) and Group 2 (bottom). Measurements with heterophoria incorporated are plotted against the raw data without the heterophoria incorporated. Convergence was measured after divergence for each group. (Δ=prism diopter).

Order of Testing

To test whether or not the order of vergence testing affected the end result, data from Session 1, assessment 2 (distance fusional amplitudes only) were compared with data from Session 2, assessment 2 (distance fusional amplitudes measured after near fusional amplitudes). Wilcoxon signed-rank tests (WSRT) were used for the analysis. Convergence was not affected by order of testing (break P=0.6144; recovery P=0.7949). However, both break and recovery points for the divergence were significantly affected (break P=0.0004; recovery P=0.0003) when assessed after convergence.

Testing Distance

Wilcoxon signed-rank tests (WSRT) were used to compare convergence and divergence measures for near testing distance versus those taken with distant fixation from Session 2. Measurements at near produced significantly higher results for all of the convergence and divergence tests (P<0.0001 for all measures).

Age

The age range of study participants was 20-70 years, with 22 subjects being greater than 50 years of age. Figure 6 shows the age distribution grouped by decades. Spearman's rank correlation was used to determine if the participant's age affected the size of the amplitude measured. Using data from session one, there appears to be a significant negative correlation between age and the convergence break (P=0.011) and recovery points (P=0.0107) but no significant correlation was seen for divergence (break: P=0.8248; recovery: P=0.7305). Figure 7 plots the break and recovery points for convergence and divergence for all subjects. The data are sorted in ascending order by age from the youngest subject to oldest to show the downward trend for convergence measures and level trend lines for divergence measures.

Encouragement

Wilcoxon signed-rank tests (WSRT) were used to compare convergence and divergence measurements taken when participants were not encouraged (Session 1,

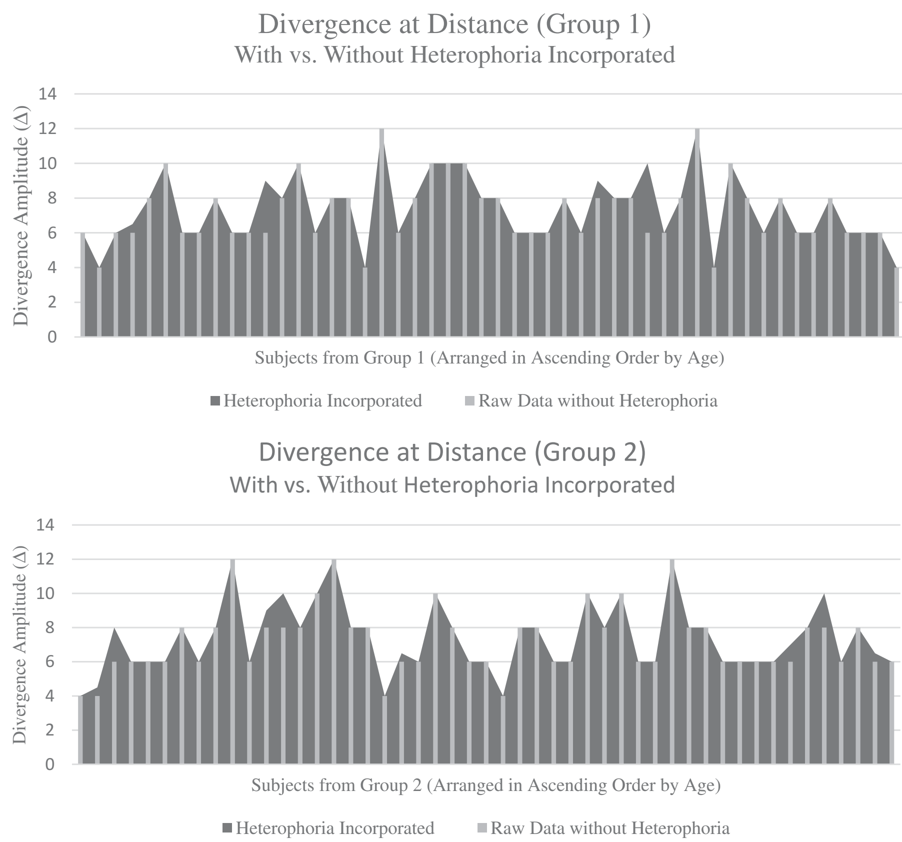

Figure 3. Divergence break points at distance fixation for Group 1 (top) and Group 2 (bottom). Measurements with heterophoria incorporated are plotted against the raw data without the heterophoria incorporated. Divergence was measured prior to convergence for each group. (Δ=prism diopter).

assessment 1) to those taken when participants were encouraged (Session 1, assessment 2). It appears that encouragement has a statistically significant effect on convergence break point ($P<0.0001$) and convergence recovery point ($P<0.0001$), but divergence measures seem to be less affected (break: $P=0.5454$; recovery: $P=0.0565$).

Alertness

Spearman's rank correlation was used to evaluate the association between alertness, as measured using the Stanford Sleepiness Scale, and convergence and divergence test results. No significance was found in the correlation (break: $P=0.2403$; recovery: $P=0.1164$) or divergence (break: $P=0.2751$; recovery: $P=0.0997$).

Discussion

Within the ophthalmic community, there are similarities in the techniques used for the assessment of fusional vergence amplitudes, but there is no agreed standard. In 1948, Scobee and Green published one of the first papers investigating fusional vergence amplitudes.[17] Since that time, a diversity of parameters pertaining to fusional amplitudes have been published. Unfortunately, the testing techniques employed were not consistent. Previously, the author studied variations in the assessment of fusional amplitudes using data from 50 subjects and presented recommendations based on the statistical significance of the data.[29] With double the cohort, the results from the current study retained statistical significance, helping to validate previous conclusions.

It is clear that the greatest influence on the clinical assessment of fusional amplitudes is the order of testing. Cridland stated that convergence suffers if tested after divergence, but divergence is not significantly affected if tested after convergence.[1] The present study comes to the opposite conclusion showing that divergence is significantly reduced if it is assessed after convergence in subjects with normal binocular functions. Thus during routine investigations of fusional amplitudes in patients with normal binocular vision, divergence should be measured prior to convergence.[32] The role for assessing the critical range first pertains to symptomatic patients with disrupted binocular vision due to an intermittent or decompensating strabismus.[6]

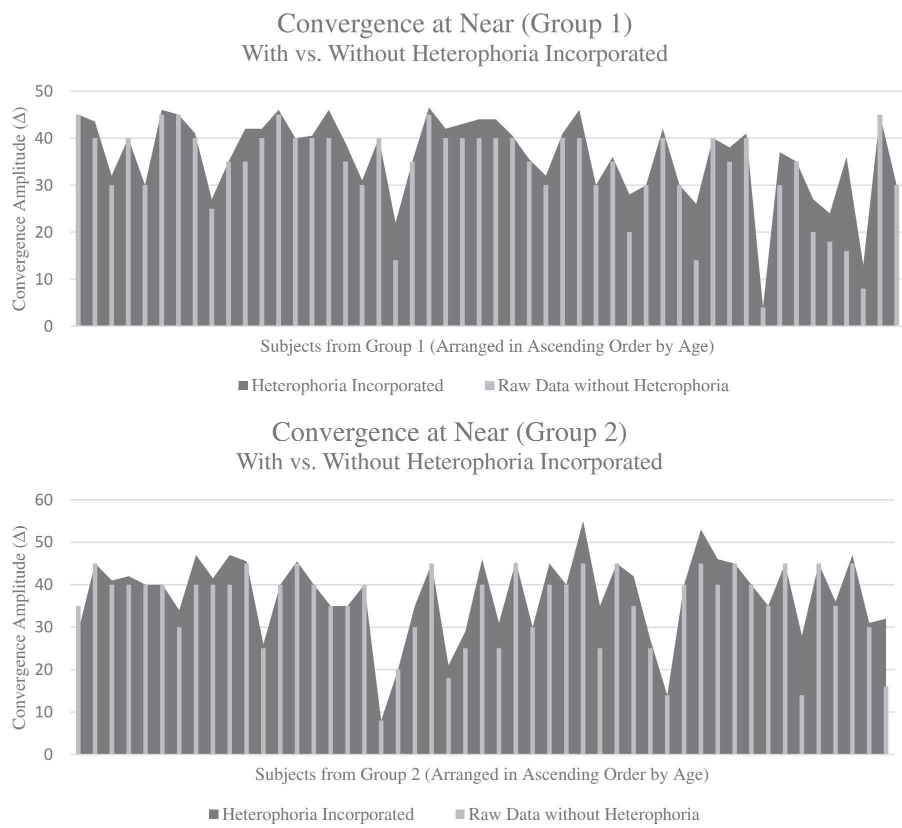

Figure 4. Convergence break points at near fixation for Group 1 (top) and Group 2 (bottom). Measurements with heterophoria incorporated are plotted against the raw data without the heterophoria incorporated. Convergence was measured after divergence for Group 1, but was measured prior to divergence for Group 2. (Δ=prism diopter).

If assessing both convergence and divergence fusional amplitudes, the symptoms of the patient should dictate the order of testing. Patients with esodeviations should have divergence assessed first, whereas patients with exodeviations should have convergence assessed first. However, divergence should be assessed prior to convergence in the asymptomatic patient.

Secondly, near amplitudes are significantly higher than distance for both divergence and convergence. If vergence assessments are done at near and far testing distances, then the distance measurement should be obtained first to reduce any bias towards the near measurements.[32] Distance measurements may be artificially reduced from fatigue due to a carryover effect from assessing the larger-sized near amplitude first. The current study was not structured to assess the vergence amplitudes with near tested after distance. This would have necessitated an additional session visit for each subject, which increased the chance for cohort attrition. Randomizing the order of vergence testing at distance and near was not done as the subjects were randomized into one of two specific sequence groups. Regardless, given the difference in the size of vergence amplitudes for distance and near, it is important to specify at what distance a measurement was taken and reference the appropriate normal values.[3,28,33]

Consideration should be given to the age of the patient when looking at normal values for fusional amplitudes.[13,14] Divergence amplitudes have been reported to be reduced with age in patients with age-related distance esotropia.[13] The current study found a significant negative correlation between age and the convergence break and recovery points, but did not find a similar correlation for divergence.

Underlying heterophorias have been reported to impact fusional amplitudes.[4,5,9,17,34] The current study failed to find a significant correlation between heterophorias and the amplitude of convergence or divergence break or recovery points. This may be related to having all measured heterophorias incorporated into the final value of the amplitude. For example, convergence is exerted to control an exodeviation, so the amplitude of an exophoria was added to the convergence fusional amplitudes for that given testing distance. Likewise, all esophorias

Figure 5. Divergence break points at near fixation for Group 1 (top) and Group 2 (bottom). Measurements with heterophoria incorporated are plotted against the raw data without the heterophoria incorporated. Divergence was measured prior to convergence for Group 1, but was measured after convergence for Group 2. (Δ=prism diopter).

Table 3. Comparison of break point values by age groups in prism diopters. Group 1 (top) was separated from Group 2 (bottom) so the order of testing convergence and divergence did not bias the final amplitude. The mean break point was calculated for each parameter with the mean recovery point recorded for reference for Group 1 and Group 2.

		Convergence at distance (BO)		Divergence at distance (BI)		Convergence at near (BO)		Divergence at near (BI)	
Age (years)	Number of subjects (n)	Raw	Phoria	Raw	Phoria	Raw	Phoria	Raw	Phoria
Group 1									
20-29	n = 20	8-45	16.5-46	4-12	4-18	14-45	22-46	12-20	12-20.5
30-39	n = 14	16-40	18-40.5	6-10	6-10	20-45	28-46.5	8-25	8-26
40-49	n = 4	14-20	16-20	6-12	6-10	14-40	26-42	14-25	16-27
50-59	n = 4	20-40	20-40	4-10	4-10	4-40	4-41	10-20	10.5-20
60-70	n = 8	12-30	10-30.5	4-8	4-8	8-45	13-45	6-18	6-20
Mean break point		**25.8**	**26.45**	**7.2**	**7.37**	**33.5**	**36.29**	**16**	**16.45**
Mean recovery point		**18.28**	**18.93**	**4.92**	**5.09**	**28.1**	**30.59**	**12.84**	**13.23**
Group 2									
20-29	n = 16	10-40	10-40	4-12	4-12	35-45	26-45.5	8-25	10-25
30-39	n = 13	4-45	4-45	4-10	4-10	8-45	8-45.5	6-18	6-20
40-49	n = 10	12-25	12-29	6-12	6-12	14-45	14-55	8-20	8.5-20
50-59	n = 8	25-40	20-40	6-8	6-10	14-45	28-47	6-18	6-22
60-70	n = 2	18-25	18 - 28	6	6-6.5	16-30	31-32	12-16	12-16
Mean break point		**25.29**	**26.01**	**7.18**	**7.38**	**35.2**	**37.76**	**13.61**	**14.6**
Mean recovery point		**18.25**	**18.97**	**5.08**	**5.23**	**31.92**	**34.67**	**10.78**	**11.77**

Raw=data without heterophoria incorporated; phoria=data with heterophoria incorporated; BO=base out; BI=base in.

were added to the divergence fusional amplitudes. Alternatively, it could be said that the small size of the average phoria measured for the study participants precluded any impact on the measured fusional amplitude. Information relating to the average vergence break and recovery points from this cohort of subjects with normal binocular functions are found in Table 3. Knowing vergence amplitudes in normal subjects can be useful to the clinician who is seeing a symptomatic patient.

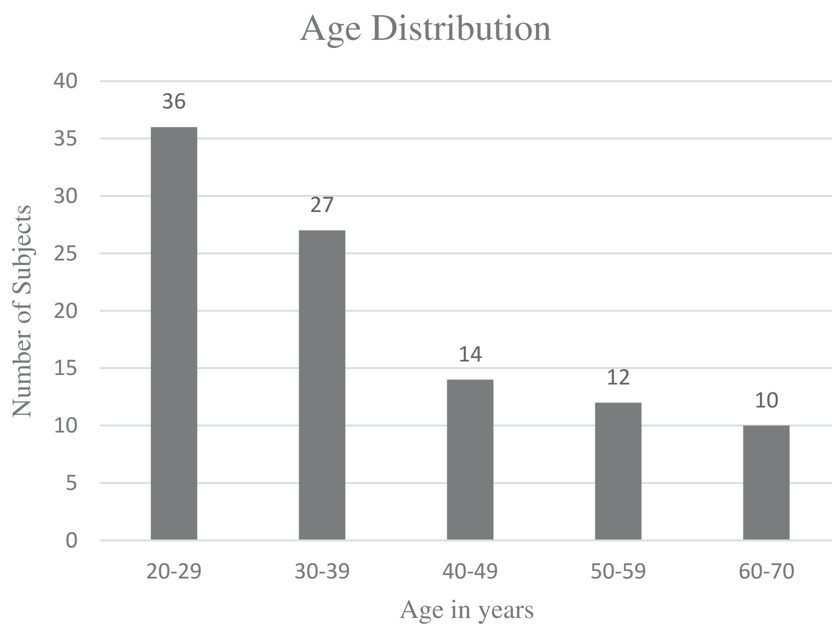

Figure 6. Distribution of subjects by age group.

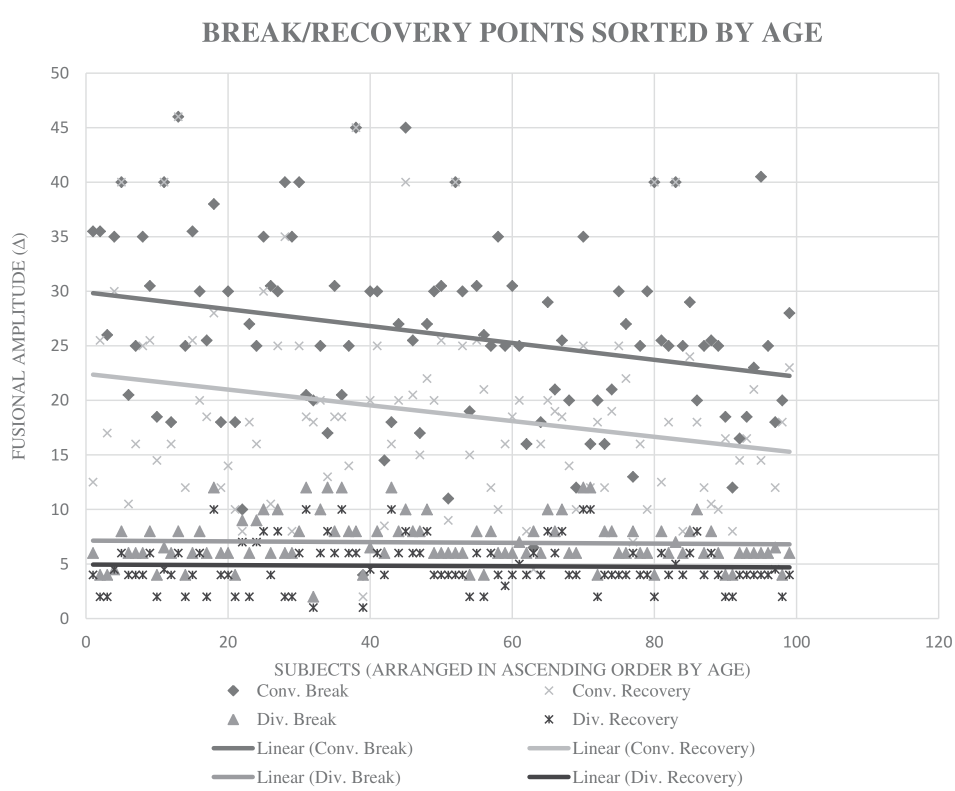

Figure 7. Break and recovery points for all subjects taken from Session 1, assessment 2 (with encouragement) for convergence and divergence. The subjects are sorted in ascending order by age. Note the downward trend for convergence break and recovery, whereas the trend for divergence remains level. Conv=convergence; Div=divergence; Δ=prism diopter.

It should be noted that the size of the target used for the vergence assessment is important when looking at normal values. Peripheral targets offer a greater stimulus to fusion over a muscle light at a distance, but the opposite is true for near as a bright light may be more dissociative for near.[3] Rowe looked at the differences between using central, parafoveal, and peripheral targets in the assessment of vergence amplitudes.[5]

Vergence ranges were reported as being higher when measured with a peripheral target compared to the smaller central or parafoveal targets. In the current study, a parafoveal target (20/40) was used as visual acuity criteria required a best corrected vision of (20/30). It was important not to have a central-sized target due to this limitation. Also, blur can be experienced when looking through a prism and the investigator didn't want the prism blur to be mistaken for blur due to increased accommodation.

The amount of effort exerted by a patient during testing can be affected by encouragement. Results from this study of asymptomatic subjects showed that convergence amplitudes are significantly affected when a patient receives inspiration by the clinician to go further. Cheering does not have the same effect on divergence. Clinicians should keep this in mind when assessing vergence amplitudes. However, there is a role for not using encouragement on an initial assessment a symptomatic patient. Narbheram and Firth noted that encouragement may help a person to exert active accommodation and increase accommodative convergence; whereas, a relaxation of accommodation may enable more divergence.[8] Thus, if the patient is made to always concentrate during testing, the clinician may not uncover the reason for the patient's symptoms. By assessing a patient without encouragement, the clinician can learn what happens when the patient is tired. By repeating the measurement with encouragement, the clinician is able to learn more about the patient's potential for fusion and ability to respond to treatment. For the current study, encouragement was scripted and all measurements were performed by one examiner (KJF). To ensure consistency in testing, the examiner objectively watched as the prism strength was altered for any refusion movement. For the second assessment (with encouragement), the same words of encouragement were used for all subjects. After the second assessment, subjects were casually asked if they noticed a difference in testing. Not one subject noticed that encouragement was given in the second assessment when it wasn't given in the first assessment. Issues that could arise from testing a patient without and then with encouragement relate to the patient becoming more adept at the test-taking and performing better with the second measurement. Alternatively, a patient may become bored or tired of the test and not perform as well with the second measurement. It must be noted that what is said and how it is said can affect a patient's response. An enthusiastic and engaging examiner may inspire a patient to perform better compared with an examiner without charisma.

Finally, a patient's alertness level should be noted when doing vergence assessments, since sleepiness or fatigue can affect performance.[33] Overall, study participants reported high alertness levels in both testing sessions, so meaningful results were not achieved when analyzing this parameter. Further studies would need to be repeated with a greater discrepancy between the alertness levels of each testing session in order to determine statistical significance. In addition, the study subjects were asymptomatic with normal binocular functions. The assessment of alertness is much more critical when examining a symptomatic patient with disrupted binocular vision due to an intermittent or decompensating strabismus.

There are limitations to this study that need to be acknowledged. There was only one unmasked examiner completing all assessments. However, care was taken by the study investigator for each second assessment to know only the sequence group and the fixing eye for each participant. The value of each fusional amplitude from the first session was not known until the second session was complete.

All participants received the same instructions prior to each session, but not all study participants were naïve to orthoptic eye exams and the assessment of fusional amplitudes. Although familiar with the topic of fusional amplitudes, the non-naïve participants did not report having had an assessment of fusional amplitudes prior to enrollment in the study. Ideally, only naïve participants should have been enrolled.[35] Although the age range of the study population was varied, it was skewed towards subjects younger than 40 years of age. This may help to explain why no correlation was found between age and reduced divergence amplitudes. The author did not analyze the influence of gender on fusional amplitudes. There was an unequal distribution of male to female participants, so any analysis would be skewed towards the female side if gender played a role in the assessment of vergence amplitudes.

The effect of refractive error was not studied. All participants were wearing their appropriate refractive correction at the time of the examination and were functionally emmetropic. The interpupillary distance was not assessed or taken into consideration. The target size used during the assessment was randomly assigned as an isolated, parafoveal target. Study protocol required a corrected visual acuity of 20/30 or better. The 20/40 target size was selected to ensure that all subjects could see the target despite mild blur induced by the prism bar placed before the non-dominant eye.

Overall, the level of alertness reported by the participants was high for both sessions. This precluded the author from obtaining meaningful data on the effect of fatigue on vergence measurements. Future studies assessing subjects on two different days with distinctly different levels of alertness are needed to analyze the effect that fatigue has on fusional amplitudes.

Conclusions

The results of this study demonstrate that divergence is significantly reduced if assessed after convergence in the subject with normal binocular function. Next, convergence is significantly affected by the use of encouragement. Measurements at near produced significantly higher results for all of the convergence and divergence tests. Finally, there is a significant negative correlation between age and convergence break point. We need to develop a standard of testing fusional amplitudes so there is consistency in the clinical assessment. This includes noting the size of the target, the distance at which the measurement is performed, the order of testing, if encouragement is used, and whether or not the underlying heterophoria is incorporated into the measurement. By using standard testing techniques, we will be able to make a more accurate comparison of vergence measures and to correlate the results from fusional amplitude studies from around the world.

Acknowledgments

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Declaration of interest

The author has no conflicts of interest to declare in relation to this study. No external funding was received for the research. This study conformed to the requirements of the US Health Insurance Portability and Accountability Act (HIPAA) and the research adhered to the tenets of the Declaration of Helsinki.

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