COMPARISON MONOCULAR VS -VJ	p-value 1	p-value 2
VS FNEBM – VJ FNEROM	0,010	
VS FNEREM – VJ FNEREM	0,001	
VS FPREM – VJ FPREM	4*10^-4	0,002
VS NPBM – VJ NPBM	0,001	0,018
VS NPBM – VJ NPBM	1*10^-5	

Table 2. Values of p-value obtained by the Wilconxon non- parametric test for comparison between monocular smooth vergences (VSs) and monocular jump vergences (VJ).

COMPARISON BINOCULAR VS -VJ	p-value 1	p-value 2
VS FNEBBI – VS FNEBBI	0,043	
VS FNEBBI – VS FNBBI	0,003	
VS FPREI – VS FPREBI	0,002	4*10^-4
VJ NNEREBI – VJ NPREBI	2*10^-4	1*10^-5
VJ NPOBBI – VJ NPBBI	0,016	
VJ NPREBI – VJ NPREBI	1*10^-5	

Table 3. Values of p-value obtained by the Wilconxon non- parametric test for comparison between binocular smooth vergences (Vs) and binocular jump vergences (VJ).

COMPARIS DISSOCIATED HETEROPHORIAS	p-value
MADDOX MODIFIED	0,0455
THORINGHTONMF VS MADDOX	
MODIFIED THORINGHTONBIF	
MADDOX MODIFIED	
THORINGHTONMN VS MADDOX MODIFIED THORINGHTONBIN	0,0062

Table 4. p-value values obtained using the Wilconxon non- parametric test for comparison between monocular and binocular dissociated heteroforias, for near (N) and far (F).

COMPARIS ASSOCIATED HETEROPHORIAS	p-value
CROSS TESTMF in open field VS	0,044
CROSS TESTBIF in open field	
NEEDL TESTMF in open field VS	0,022
NEEDL TESTBIF in open field	
MALLETMn in open field VS	0,001
MALLETBIN in open field.	
CROSS TESTMF in closed field VS	0,021
CROSS TESTMF in open field	
NEEDL TESTMF in closed field VS	0,036
NEEDL TESTMF in open field	
WESSONMn in closed field VS	0,002
MALLETMV in open field.	
CROSS TESTBIF in closed field VS	0,003
CROSS TESTBIF in open field.	
NEEDL TESTBL in closed field VS	0,019
NEEDL TESTBL in open field.	

Ta le 5. p-value values obtained using the Wilconxon non- parametric test for comparison of monocular and binocular associated heteroforias for near (N) and far (F).

For comparisons where the conclusion was that there was a significant difference, three different analyses were carried out in order to understand the type of discrepancy found in the data. With an XY dispersion graph (Figures 8-12) the two different types of measurement have been linked, assuming as a model the equality of the two measures and then the bisector of the quadrant. The value R^2, that is the % of variability of the y explained starting from the variability of the x through the linear fit, has been very small for which a great part of the variability is of random type. The results of the vergence study showed that there was a particular relevance, with overestimation, of binocular data compared to monoculars. The significant differences were found mainly for breakage and recovery data for most of the negative vergences and only slightly less for positive vergences [14].

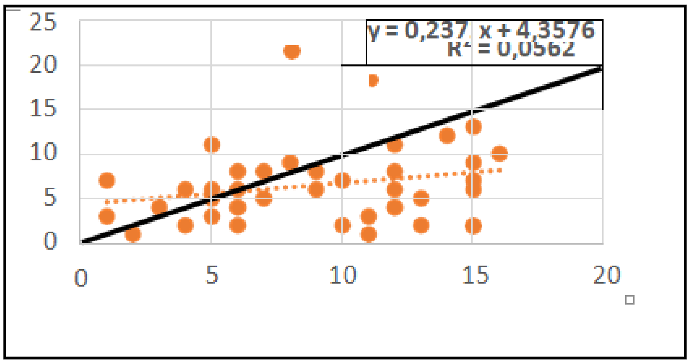

Figure 8. Smooth vergence for far, negative, rupture. Comparison of results with monocular and binocular prismatic apposition.

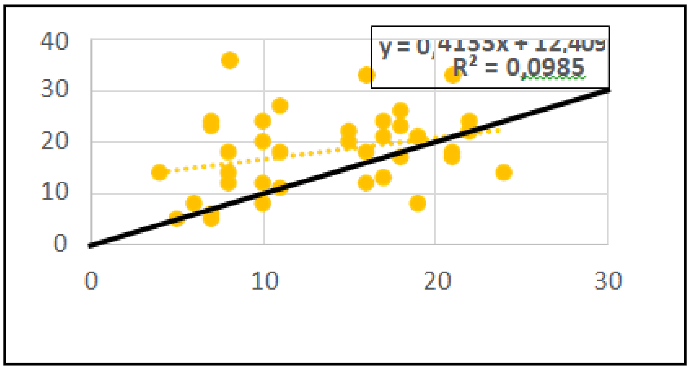

Figure 9. Smooth vergence for near, negative, recovery. Comparison between results with monocular and binocular prismatic apposition

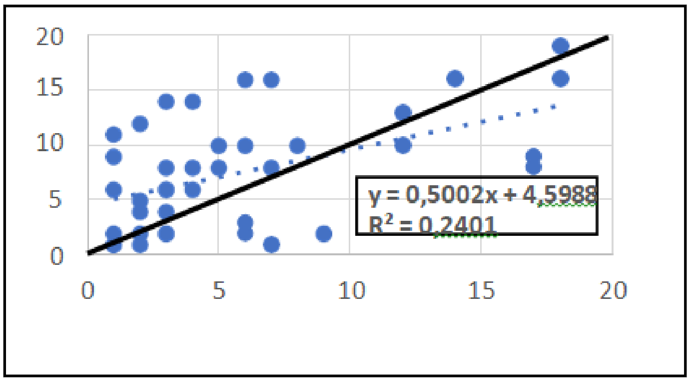

Figure 10. Smooth vergence for near, positive, rupture. Comparison of results with monocular and binocular prismatic apposition

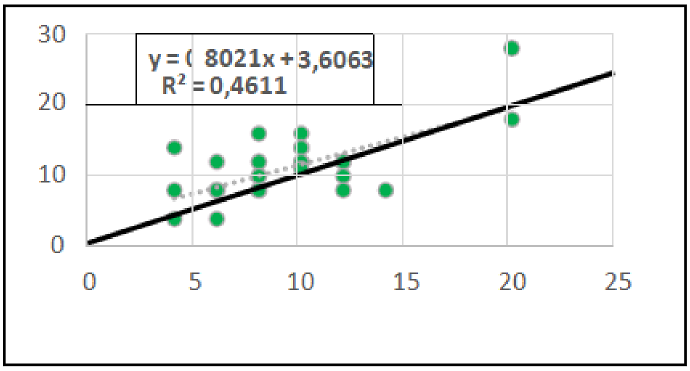

Figure 11. Vergence smooth for near, positive, recovery. Comparison between results with prismatic monocular and binocular apposition

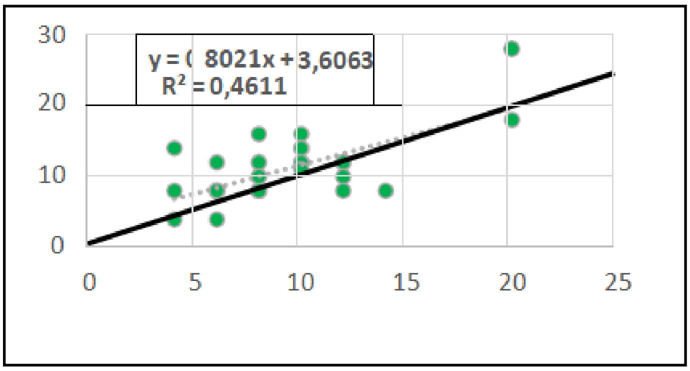

Figure 12. Jump-to-far vergence, negative, rupture. Comparison of results with monocular and binocular prismatic apposition

The Bland-Altman plot for the study of vergences reported on ascisses the semi-sum of each single data (x+y)/2 while on ordinates their difference (y-x). The points that fell within the 95% confidence interval indicated that the two methods produced consistent results, while the points outside these limits represented the cases of actual discrepancy.

In the analysis it was expected that 5% of the data could fall outside: with a sample of 40 subjects the values are at most two (40*0.05). In the study for comparison with monocular prismatic apposition only the difference between VS FNEBM-VJ FNEBM (Figure 13) and VS NPBM - VJ FPBM

Figure 14 presented three points outside the considered range. The conclusion of the non-compatibility test between the two samples remained unchanged excluding these values.

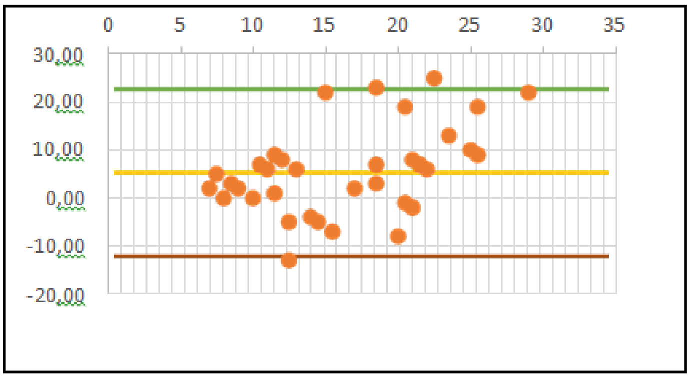

Figure 13. Bland-Altman plot for the comparison between the smooth vergence and the jump vergence: case of negative vergence, break, monocular prismatic apposition for far.

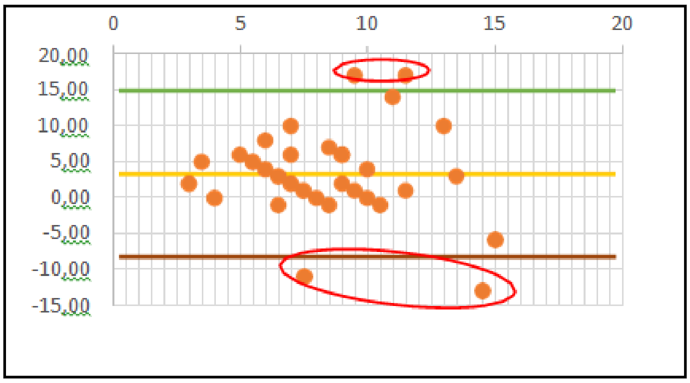

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Figure 14. Bland-Altman plot for the comparison between smooth vergence and jump vergence: positive vergence case, break, monocular prismatic apposition for far.

This last condition occurred for the comparison VS NNEBBI - VJ NNEBBI (Figure 15) in the case of binocular prismatic apposition and even in this case their elimination did not affect the compatibility of the methods. In all cases of significant difference the total average of the differences was never anything and it was possible to note an overestimation of the VJ with respect to the VS.

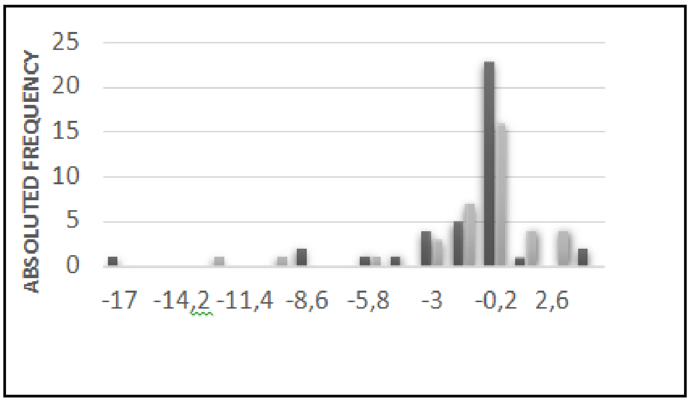

Figure 15. Bland-Altman plot for the comparison between the smooth vergence and the jump vergence: case of negative vergence, recovery, binocular prismatic apposition for close.

In the case of dissociated and associated heterophorias, comparative histograms were constructed (Figures 16-19) and showed different asymmetries (positive and negative). The distribution with tail on the left side showed a purely exophoric sample, while the distribution with tail on the right side the presence of a purely exophoric sample. The full version of the thesis shows the individual values of the asymmetries detected by the analysis with Excel.

The condition of exophoria may be due to the fact that the subject used less convergence called by accommodation, in contrast to the exophoric data, especially with regard to remote testing, where greater convergence has been induced in the event that minor fusional calls have occurred.

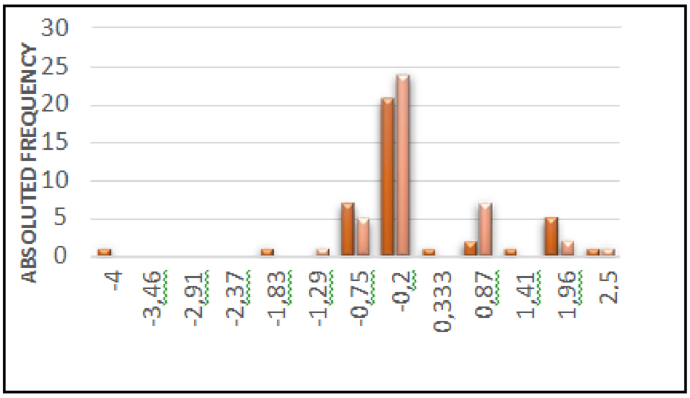

Figure 16. Comparison of monocular and binocular apposition for the Thoringhton modified Maddox test, for far (light) and for near (dark).

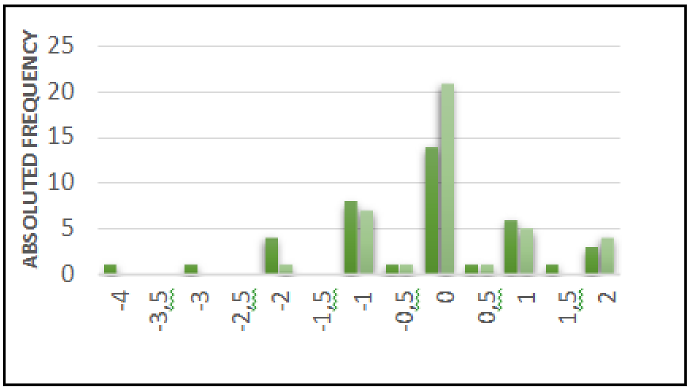

Figure 17. Histograms of differences for cross test comparison and open field needle test with monocular and binocular prismatic apposition.

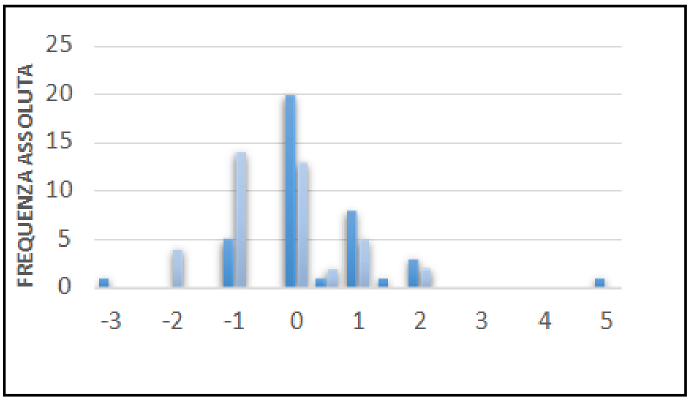

Figure 18. Histogram of differences for open field and closed field needle test comparison with monocular and binocular prismatic apposition.

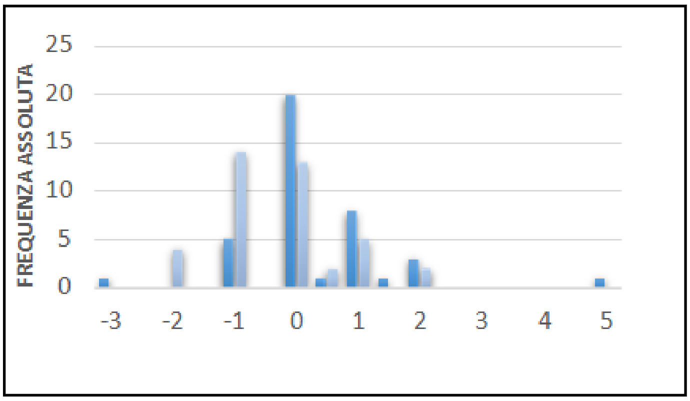

Figure 19. Histogram of differences for comparison Wesson and Mallet with prismatic monocular and binocular apposition.

CONCLUSIONS

The objective of the study was to compare different methods of measuring the binocular aspects in order to make a direct comparison between monocular and binocular prismatic apposition. Several tests have been performed to describe such aspects as dissociated, associated heterophoria and fusional differences. They differ in both the mode of execution and the instrumental apparatus.

Conclusion fusional vergences

In the case of mergers, the study in the open field has shown particular relevance, in fact, this has among the advantages the presence of a more natural environment when compared to the phoropter. The positive aspect of this measure was that it presented the subject with a more "real" condition during the measurement so that the sensory and motor aspects of the visual organs worked simultaneously. The comparison between the various monocular and binocular prismatic apposition methods has, in fact, led to satisfactory results. By means of the dispersion diagram it was possible to measure an overestimation of the binocular data with respect to the monocular data and a significant difference especially for the breakage and recovery data for most of the negative vergences and only to a lesser extent in the positive convergence. This was probably due to the fact that the negative vergences were, in fact, less extensive than the positive ones and the subject encountered more difficulties in performing the test. In addition, one reason for having significant differences in breakage data may be that the study was performed on a young sample. Costa and Rowe [2019] have specified, in fact, that one of the probable explanations of having very high values of rupture can be found in having performed the study on young adults and students, subjects therefore with a certain practicality in carrying out the test. The research in question was, in fact, conducted on 40 subjects aged between 19 and 31 years, mostly students of the University of Optics and Optometry of Turin, subjects with a certain knowledge and familiarity in the conduct of the tests to which they have been subjected.

Heterophorias dissociative conclusions

Also in the case of dissociated heterophorias the modified Maddox Thoringhton test showed that there are measurements for open field data. In contrast, the von Graefe test that was performed in the closed field showed no significant differences between comparisons. It has been hypothesized, therefore, that the adaptation to the monocular prism with respect to the binocular can vary considerably when the measurements have not been carried out to the phoropter. In this case the component that made the measure variable was presumably the different peripheral perception. Therefore, as reported in the Burian study it was possible that the presence of peripheral fusional stimuli could influence the position of the eyes during open field heterophoria testing by producing a more stable vergence response. In addition, the histograms of the differences showed mostly a negative asymmetry, detecting the presence of a sample that was shown to be predominantly exophoric, probably due to the greater contribution of accommodation and convergence required in this condition. Although some authors have argued that the measurement of dissociated heterophoria is not useful in the evaluation of disorders that decompensate binocular vision. These tests have been routinely used as part of diagnostic criteria for many abnormal conditions of binocular vision.

Associated heterophorias conclusions

Significant differences between monocular prismatic and binocular apposition for open field data have also been highlighted in the study of associated heterophorias. Overall, the comparative histograms showed positive distributions and a greater presence of exophoric subjects (negative) in monocular condition and a greater presence of exophoric subjects (positive tail) in binocular condition. It has been hypothesized that in the binocular data the accommodation was balanced by refraction according to Humpriss and therefore the data tended to move towards exophoria and not to have convergence recalled by accommodation. A different condition for the exophoric data, especially with regard to the tests from afar where greater convergence has been induced in case of minor fusional calls. The distribution of differences in the results of the Mallet test with monocular and binocular prismatic affixation also presented an exophoria condition. It was a test performed at a close distance of 40 cm in fact, according to what has already been said, this may be due to the fact that, close up, the subject used less convergence recalled by the accommodation. In the comparison between the needle test and the cross test, there were more negative monocular and binocular differences in the cross test and more positive monocular and binocular differences in the needle test. Evidently the sample in the cross test was mostly exophoric given the absence of a central fusional recall in the aforementioned, present instead in the needle test where the sample was mostly exophoric. In fact, the only test that showed no significant difference between open field and closed field measurements was the cross, which lacked the central fusional recall, which is probably why it was less susceptible to peripheral differences. It was not excluded that these exophoria values are normally more acceptable than exophoria values; this was a greater indication that the sample examined did not show any particular binocular abnormalities. Since in clinical practice the measurement of associated heterophorias is very often performed in the open field, what was obtained in this study was relevant [15].

General conclusions

Overall, it was found that for the measurement of vergences, dissociated heterophorias and associated heterophorias, the methods involving monocular and binocular prismatic apposition could yield significantly different values. This was especially relevant for open field and binocular data. Currently it may be useful to perform both measurements (with monocular and binocular prismatic apposition, in the open field and in the closed field) on the subjects to study this difference but in a future perspective it would be useful to design a study to understand what are the measures that best describe the real condition of the subject. In any case, the binocular prismatic apposition in the open field was the most optimal condition, considering that it reflects the most natural situation to which the subject was normally accustomed. For a future perspective, given therefore the significant differences, it would be necessary to probe these lines of research increasing the number of the sample and its composition as age and physical condition, in order to achieve a more specific and comprehensive understanding of the commonly used procedures for evaluating binocular vision.

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