

Agreement between three methods for measuring near point of convergence among patients with different refractive errors

Antony A. Baskaran¹, Tanuja Britto², Raja T. Sowndher³, Philip A. Thomas⁴

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Abstract

PURPOSE: To describe the agreement of three methods of Near Point of Convergence (NPC) measurement among patients with different refractive errors.

METHODS: 60 asymptomatic subjects, 18 – 25 yrs old, were included in 3 groups: emmetropes, myopes and hypermetropes. All subjects underwent NPC break point and recovery point measurement by Royal Air Force (RAF) rule, Pencil Rule (PR) and penlight with red green glasses (RG) using standard techniques. The values obtained were compared within each group by Friedman test. Bland Altman plots were constructed and Limits of Agreement calculated.

RESULTS: Hypermetropes performed poorly in RG test with significantly receded break point and recovery point values ($10.30 \pm 1.45\text{cm}$, $13.13 \pm 1.20\text{cm}$) compared to RAF test ($7.18 \pm 1.86\text{ cm}$, $10.15 \pm 2.11\text{cm}$) and PR test ($7.78 \pm 1.75\text{ cm}$, $10.75 \pm 1.44\text{cm}$). The recovery point values of the emmetropes with RG test ($10.15 \pm 2.32\text{cm}$) was significantly receded compared to PR ($9.30 \pm 1.72\text{ cm}$) and RAF test (Emm: $9.08 \pm 2.30\text{cm}$). The myopes performed better with PR test with significantly better recovery point values with PR test ($8.70 \pm 1.97\text{ cm}$) compared to RAF (9.68 ± 2.08) and RG (9.45 ± 1.73) tests. The limits of agreement were wide suggesting disagreement between the tests.

CONCLUSION: The RG test yields more receded results in hypermetropes compared to the RAF and PR tests, and the PR test yields better results than the RAF test in myopes. Thus, the results obtained by these different methods show a lack of agreement. The variability is not uniform in patients with different refractive errors.

Keywords:

Agreement, convergence, near point of convergence, pencil-ruler test, refractive errors, royal air force rule

INTRODUCTION

The near point of convergence (NPC), the nearest point at which the lines of sight intersect when the eyes converge to the maximum, is a routinely performed and very useful test in the assessment and management of convergence insufficiency. Hussaindeen *et al.*^[1] found the average NPC break and recovery points in normal Indian children to be $3 \pm 3\text{ cm}$ and $4 \pm 4\text{ cm}$ when using accommodative targets, and $7 \pm 5\text{ cm}$ and $10 \pm 7\text{ cm}$, respectively, when using penlight and red filter.

The NPC varies with the targets used and the methods employed for measurement. The

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variation with different targets used and the influence of royal air force (RAF) rule on the measurement of NPC have been well studied.^[2-5] This difference in NPC between methods is said to be due to the differential accommodative demands,^[3] presence or absence of RAF rule, experience of the observer, and anticipation.^[4]

The previous literature on variation of NPC with targets usually employed emmetropes,^[4] those who read 20/20 with habitual correction,^[2,5] and presbyopes.^[3] Ostadimoghaddam *et al.*^[6] measured NPC with an accommodative target and found hypermetropes to have receded values, as compared to myopes; however, this difference did not remain significant in multiple regression analysis.

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¹Assistant Professor, Department of Pediatric Ophthalmology, Institute of Ophthalmology, Joseph Eye Hospital, ²Professor, Department of Pediatric Ophthalmology, Institute of Ophthalmology, Joseph Eye Hospital, ³Department of Optometry, Institute of Ophthalmology, Joseph Eye Hospital, ⁴Associate Director (Research) and Professor, Department of Ocular Microbiology and Clinical Research, Institute of Ophthalmology, Joseph Eye Hospital, Melapudur, Trichy-1, India

Address for correspondence:

Dr. Antony Arokiadass Baskaran, Department of Pediatric Ophthalmology, Institute of Ophthalmology, Joseph Eye Hospital, Melapudur, Trichy-1, India.
E-mail: antomm@gmail.com

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Nevertheless, there are insufficient data regarding whether the different methods of NPC evaluation have similar variability in patients with different refractive errors. Understanding this variability may help the clinician to choose and interpret the results of orthoptic examination in a more meaningful manner.

Using Bland–Altman plots and measuring the limits of agreement (LOA) is one of the best methods to compare diagnostic tests with each other.^[7] Most of the studies on NPC have not used this statistical tool to study the degree of agreement between the different methods of NPC assessment.

By using Bland–Altman plots, the current study proposed to determine the extent of agreement between three different methods of NPC measurement in patients with different refractive errors.

METHODS

This cross-sectional observational study was done from January 2014 to August 2014 at a tertiary eye care hospital in southern India. Sixty asymptomatic South Indian subjects, ranging in age from 18 to 25 years of age, with emmetropia, or a refractive error (simple myopia or simple hypermetropia [manifest hypermetropia corrected by fogging]) with best-corrected visual acuity 6/6 in each eye, were included by convenience sampling. None of the subjects had symptoms suggestive of convergence insufficiency. The sample size was decided based on the sample size calculated in similar studies by Siderov *et al.*^[3] and Adler *et al.*^[4]

All these patients underwent static and cycloplegic refraction prior to enrollment, a cover test to check for manifest strabismus, and a stereopsis assessment with TNO cards. The break and recovery points of NPC were assessed using the RAF rule, pencil-ruler (PR) method, and a penlight with red-green glasses; the average of three consecutive values was calculated for each method. The RAF rule test was done in a standard manner. The sharp tip of a pencil was used as the target for the PR method. Red-green glasses were worn by the patient, and a pen torch was used as a target in the red-green glass method. All the tests were done on every subject by the same person and over the RAF rule to ensure uniformity of measurement between methods. The point at which the subjects appreciated diplopia of the target was considered the end point. Three readings were taken consecutively for each method and the average was calculated. The tests were performed with full room illumination. All the above tests were performed with refractive correction in place for myopes and hypermetropes.

Patients above 25 years of age, those with anterior or posterior segment abnormalities, those with astigmatism (>0.5 D cyl), anisometropia (>1 D sphere difference between eyes), amblyopia, manifest squint, and those with poor near stereoacuity were excluded.

The study followed the tenets of the Declaration of Helsinki, and approval of the experimental protocol was obtained from the Institutional Ethics Committee. Informed consent was obtained from all subjects.

Statistical analysis

The mean values of the break and recovery points of the three tests were not found to be distributed normally by Shapiro–Wilk test ($P < 0.01$) [Supplementary Table 1 and Supplementary Figure 1]. Hence, they were compared within each of the three refractive error groups by a nonparametric test for repeated measures, namely the Friedman test. Bland–Altman plots were constructed using SPSS (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.) by plotting the differences between the tests in the Y-axis with the average of the readings in the X-axis. The LOA were calculated using Excel sheet 2007 by calculating the 5th and 95th percentile values of the differences and incorporated in the Bland–Altman plot, which gives a graphical representation of the degree of agreement between the tests. The LOA are a measure of the variability of the tests, with broader limits suggestive of a high variability between two tests.

RESULTS

The demographic and baseline characters of the subjects are tabulated [Table 1]. There were 20 subjects in each group. There was no significant difference with regard to age or gender distribution between the groups [Table 1]. The mean NPC break and recovery points for the three tests for the three refractive error groups are tabulated [Table 2]. The stereopsis of all the participants was better than 240 arc sec by TNO cards.

Among emmetropes (RAF: 7.75 ± 2.23 cm; PR: 7.65 ± 1.50 ; RG: 8.03 ± 1.13 cm) and myopes (RAF: 7.00 ± 1.26 cm; PR: 6.38 ± 0.74 ; RG: 7.03 ± 1.58 cm), the break points were not significantly different between the different methods. However, among the hypermetropes (RAF: 7.18 ± 1.86 cm; PR: 7.78 ± 1.75 cm; 10.30 ± 1.45 cm), there was a significant difference in the break points yielded by the three different methods.

The recovery points measured by the three methods differed significantly, with receded values consistently noted in the RG

Table 1: Demographic factors and baseline data compared between patients and eyes in the three refractive error groups

Parameter	Emmetropes	Myopes	Hypermetropes	Statistical significance
Age (years)	19.75±2.12	19.60±1.34	20.15±2.18	$P=0.071$, Kruskal-Wallis test
Gender (male: female)	7:13	11:9	14:6	$P=0.08$, Chi-square test
Refractive error (D)	0	1.94±1.41	0.91±0.55	$P<0.01$, Kruskal-Wallis test
Stereopsis (arc s)	66±18.47	105±72.51	87±56.67	$P=0.134$, Kruskal-Wallis test

Table 2: Break and recovery points of near points of convergence in emmetropes, myopes, and hypermetropes as measured by three different methods

Refractive error group	Mean \pm SD			Statistical significance of difference between the mean values (Friedman test) (<i>P</i>)
	Break point using RAF rule (cm)	Break point using PR test (cm)	Break point using RG test (cm)	
Emmetropes	7.75 \pm 2.23	7.65 \pm 1.50	8.02 \pm 1.13	0.42
Myopes	7.0 \pm 1.26	6.37 \pm 0.74	7.02 \pm 1.58	0.08
Hypermetropes	7.18 \pm 1.86	7.78 \pm 1.75	10.30 \pm 1.45	<0.01

Refractive error group	Mean \pm SD			Statistical significance of difference between the mean values (Friedman test) (<i>P</i>)
	Recovery point using RAF rule (cm)	Recovery point using PR test (cm)	Recovery point using RG test (cm)	
Emmetropes	9.08 \pm 2.30	9.30 \pm 1.72	10.15 \pm 2.32	0.02
Myopes	9.45 \pm 1.73	8.70 \pm 1.97	9.68 \pm 2.08	0.01
Hypermetropes	10.15 \pm 2.11	10.75 \pm 1.44	13.13 \pm 1.20	<0.01

Average of three readings taken by each method mentioned. RAF=Royal air force rule; PR=Pencil-ruler; RG=Red-green; SD=Standard deviation

Table 3: Limits Of Agreement calculated for differences in the break points measured by different methods in the three different refractive error groups and in all the study subjects together

Tests compared	Difference in break points			Difference in recovery points		
	RAF/PR	RAF/RG	PR/RG	RAF/PR	RAF/RG	PR/RG
Emmetropes						
0.05	-2.1	-2.1	-2	-4	-4.1	-4
0.95	3.63	3.53	1.05	3	1.05	1.05
Median	0	-0.5	0	0	-1	-0.5
Mean	0.1	-0.28	-0.38	-0.23	-1.08	-0.85
Myopia						
0.05	-0.1	-2.15	-3.58	-1.15	-4.1	-3.675
0.95	2.53	3.03	1.1	3	4.05	3.05
Median	0	0	0	1	0	-1
Mean	0.63	-0.03	-0.65	0.75	-0.23	-0.98
Hypermetropia						
0.05	-2.05	-5.05	-4.05	-2.05	-5	-4.05
0.95	2.03	-1.28	-0.88	1.15	-1.13	-0.85
Median	-0.5	-3.5	-2.5	-0.5	-3	-2
Mean	-0.6	-3.13	-2.53	-0.6	-2.98	-2.38
All together						
0.05	-2	-5	-4	-4	-5	-4
0.95	3	3.03	1.03	3	2.58	2.05
Median	0	-1.25	-1	0	-1	-1.75
Mean	0.04	-1.14	-1.18	-0.03	-1.43	-1.4

RAF: Royal Air force rule, PR: Pencil Rule test, RG : Penlight with Red Green glasses test

Table 4: Break and recovery points (mean \pm standard deviation) with different targets compared with other studies

Studies	Refractive errors	PR		RG glasses		RAF (line)	
		Break	Recovery	Break	Recovery	Break	Recovery
Adler, 2007 ^[4] *	Significant errors excluded	4.5 \pm 2.6	8.2 \pm 3.5	6.0 \pm 5.4	10.2 \pm 6.2	8.8 \pm 8.1	10.3 \pm 9.1
Siderov, 2001 ^[3] †	Refractive errors included - BCVA 6/6	7.9 \pm 0.6	8.6 \pm 1.5	Not done	Not done	5.3 \pm 1.9	7.6 \pm 1.9
Pang, 2010 ^[2] ‡	Refractive errors included - BCVA>20/25	ND	ND	4.08 \pm 1.56	5.95 \pm 1.59	ND	ND
Schiemann, 2003 ^[5]	Refractive errors included - BCVA 20/20	ND	ND	2.38 \pm 2.11	4.35 \pm 3.26	ND	ND
Our study	Emmetropes	7.65 \pm 1.50	9.30 \pm 1.72	8.02 \pm 1.13	10.15 \pm 2.32	7.75 \pm 2.23	9.08 \pm 2.30
Our study	Myopes	6.37 \pm 0.74	8.70 \pm 1.97	7.02 \pm 1.58	9.68 \pm 2.08	7.0 \pm 1.26	9.45 \pm 1.73
Our study	Hypermetropes	7.78 \pm 1.75	10.75 \pm 1.44	10.30 \pm 1.45	13.13 \pm 1.20	7.18 \pm 1.86	10.15 \pm 2.11

*Among the three age groups in the study, the values of the age group comparable to our study population have been mentioned; †Of the two study groups included in the study, the values of the group comparable to our study population have been enlisted; ‡Transilluminator with red lens was used; the values of the control group taken for comparison. Results of other studies relevant to the methods tested in this study have been tabulated. RAF=Royal air force rule; BCVA=Best-corrected visual acuity; PR=Pencil-ruler; RG=Red-green; ND: Not done

test among emmetropes and hypermetropes. However, the PR test gave better recovery values among the myopes, compared to the other tests [Table 2].

Figures 1-3 give a pictorial representation of the differences in the break points between RAF/RG, RAF/PR, and PR/RG methods, and the relative variability of the same in the three different refractive error groups. The RG test appeared to yield consistently more receded values than did the RAF/PR tests among the hypermetropes. The PR test was found to have lesser receded values compared to the RAF test among myopes than in other groups. The LOA for the entire subset of observations were also plotted to show the values within which 95% of the differences fell.

Table 3 shows the LOA derived from the differences of the break points measured by the three methods for the three groups and all the study subjects together. LOA have to be interpreted based on the clinical scenario showing the extent of agreement between the tests. Considering all the subjects together, a difference of approximately 5 cm was found to exist between the different tests, when compared with each other.

Considering the individual refractive error subgroups, the LOA, although wide, appeared to vary symmetrically (both positive and negative differences) among the emmetropes. Among the hypermetropes, the LOA were consistently negative when the RG test was considered, suggesting that the RG test, compared to other tests, calculated receded values, especially in hypermetropes. However, among the myopes, except between

RAF and PR test, the LOA appeared to be symmetrically distributed, although wide. Comparing the RAF/PR test, the LOA (-0.1 cm to + 2.25 cm) were predominantly positive, suggesting that the myopes tended to overperform in the PR test, compared to others.

DISCUSSION

Adler *et al.*^[4] calculated the NPC using different methods among emmetropic children, while Siderov *et al.*^[3] and Scheimann *et al.*^[5] calculated it including patients with refractive errors wearing habitual correction. In spite of having normal visual acuity wearing a spectacle prescription, the orthoptic status of a subject with refractive error may not be similar to that of an emmetrope. This could be due to various spectacle-related issues, such as prismatic effects of the glasses, centration of the glasses, and alteration in image size caused by the spectacles. This is evident from the change observed in orthoptic parameters, compared to the preoperative state, following laser corrective surgery in patients with refractive errors.

Thus, the NPC tests, owing to the differential accommodative demands, may not yield concordant results in patients with different refractive errors when tested with their habitual correction. Although it may be considered an artifact of spectacle correction, it is with their habitual correction that patients study and do near activities. Moreover, most orthoptists measure the orthoptic parameters in patients using

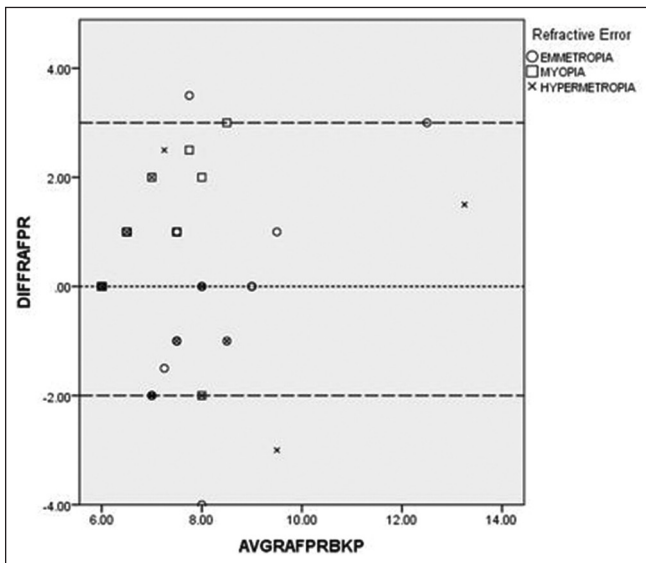


Figure 1: A Bland–Altman plot showing the difference between the royal air force/pencil-ruler break point measurements over the average of the break point of the two measurements. The large dotted lines indicate the upper (95%) and lower (5%) limits of agreement for royal air force and pencil-ruler test for all the subjects together. The small dotted line indicates the median of the differences. Most myopes were found to be above the median, suggesting that pencil-ruler yields better values compared to royal air force in myopes

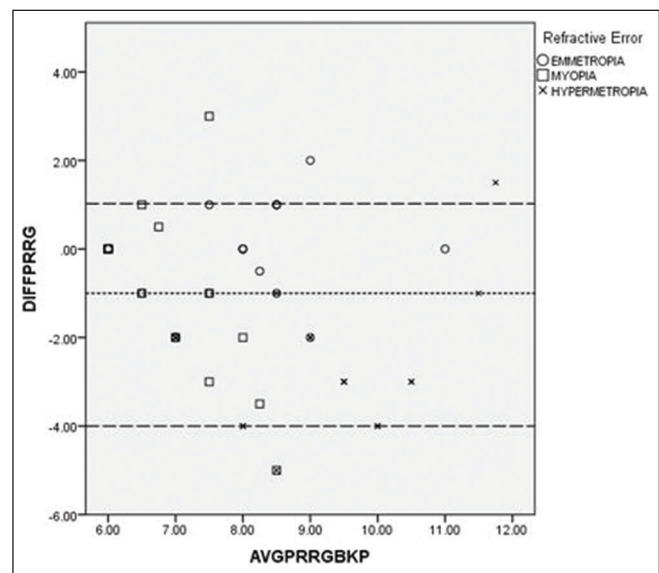


Figure 2: A Bland–Altman plot showing the difference between the pencil-ruler/red-green glass break point measurements over the average of the break point of the two measurements. The large dotted lines indicate the upper (95%) and lower (5%) limits of agreement for royal air force and pencil-ruler test for all the subjects together. The small dotted line indicates the median of the differences. All the hypermetropes were at/below the median, suggesting that hypermetropes consistently yielded more receded values with the red-green glasses test than with the royal air force and pencil-ruler tests, compared to the values in myopes and emmetropes

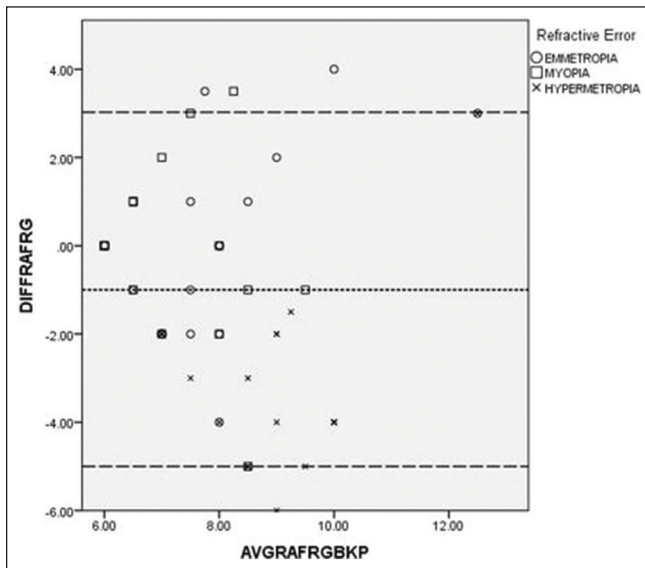


Figure 3: A Bland–Altman plot showing the difference between the royal air force/red-green glass break point measurements over the average of the break point of the two measurements. The large dotted lines indicate the upper (95%) and lower (5%) limits of agreement for royal air force and pencil-ruler test for all the subjects together. The small dotted line indicates the median of the differences. All the hypermetropes were at/below the median, suggesting that hypermetropes consistently had a receded value in the red-green glasses test than in the royal air force test, compared to the values in myopes and emmetropes

their habitual correction. Hence, the variability of these tests among patients with refractive errors has to be considered.

Among the three methods studied, PR test can be easily done with a pencil and a ruler, unlike RG test, which requires anaglyph glasses, and RAF test, which requires RAF ruler. In this study, to standardize measurements, all the tests were done over RAF ruler. Schieman *et al.*^[5] and Pang *et al.*^[2] found break and recovery points measured using penlight with red-green glasses (PLRG) to be most accurate in differentiating symptomatic from asymptomatic patients. In these studies, among asymptomatic subjects, accommodative rule, penlight, and PLRG were not found to vary significantly. However, among the symptomatic ones, the PLRG test yielded remote values. In our study, even among asymptomatic subjects, the RG test yielded significantly remote values among hypermetropes and significantly receded recovery points among emmetropes and hypermetropes. However, this variability was not found among the myopes.

Siderov *et al.*^[3] concluded that although there were differences in the NPC values obtained by different targets, the difference was not clinically significant. Although we found similar results among emmetropes, significant variations could be seen among hypermetropes. However, PLRG was not included as a target in their study.

This variation also appeared to be present on the Bland–Altman plots, where the RG test was compared with other

tests, that is, PR and RAF tests [Figures 2 and 3]; here, the majority of the hypermetropes had a “lesser than median” difference, compared to myopes and emmetropes, who were distributed symmetrically around the median. This was evident on the 95% LOA calculated among hypermetropes for RAF/RG (upper: -1.28 cm, lower: -5.05 cm) and PR/RG (upper: -4.05 cm, lower: -0.88 cm).

Possible reasons why RG tests yielded receded values among hypermetropes, and not to the same extent among emmetropes and myopes, could be the dissociativeness and the nonaccommodative nature of the test, and the probable prismatic effect of glasses in convergence.

Among myopes, the PR test yielded better break (marginal significance) and recovery points (significant difference), compared to the RG and RAF tests. When comparing the RAF/PR test, myopes tended to fall in the more positive side above the median consistently compared to emmetropes and hypermetropes [Figure 1]. The 95% LOA of the same was also more positive [lower: -0.1 ; upper: $+2.25$ cm].

The sharp tip of the pencil, being a three-dimensional object, can elicit a better convergence response.^[4] This phenomenon was markedly observed in the myopes consistently, compared to the other groups. This was possibly because of the base-out prism effect of myopic glasses when eyes converge, thereby seeing through the nasal part of the lenses rather than the center. The possible effects of glasses on measurement of NPC have also been stated by Adler *et al.*^[4]

That the values obtained using different targets are not in agreement with each other is evident from the results of previous studies^[5] [Table 4]; however, the results of the current study suggest that this variability is not uniform. The RG test showed a higher degree of disagreement among hypermetropes while the PR test showed a higher degree of disagreement among myopes.

The limitations of this study include the small sample sizes in each subgroup, the use of nonparametric methods of measurement, and the nonrandomization of the order of the tests. Notwithstanding these, the use of RAF rule for all the targets may not reflect the real-life scenario where targets are moved in free space.

Further studies using contact lenses, rather than spectacles, may have to be performed to study the influence of refractive errors/spectacle correction on the variability of NPC using different methods.

CONCLUSION

In the current study, the NPC values obtained by the three methods studied were not in agreement with each other, although this variability was less among emmetropes. In myopes, the PR test gave better values, and in hypermetropes, the RG test yielded more remote values.

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Nil.

Conflicts of interest

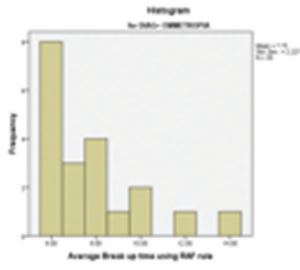
There are no conflicts of interest.

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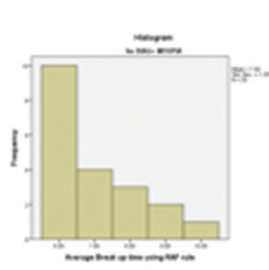
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RAF RULE

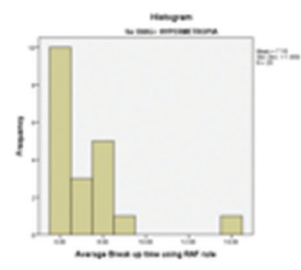
Emmetropes



Myopes

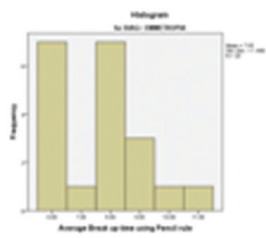


Hypermetropes

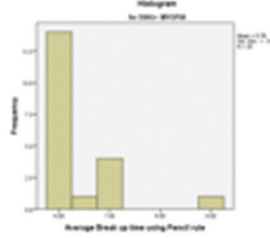


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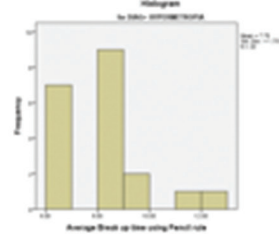
Emmetropes



Myopes

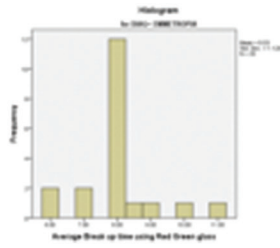


Hypermetropes

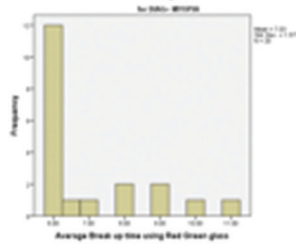


RG GLASS

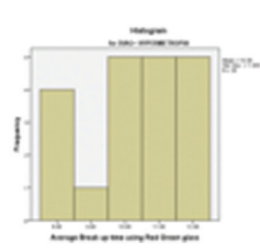
Emmetropes



Myopes



Hypermetropes



Supplementary Figure 1: Histogram of break point values measured by the three tests among emmetropes, myopes, and hypermetropes

Supplementary Table 1: Tests of normality for break point and recovery point values calculated by the three methods among patients with different refractive errors

Refractive error	Tests of normality					
	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Significance	Statistic	df	Significance
Average breakup time using RAF rule						
Emmetropia	0.216	20	0.015	0.794	20	0.001
Myopia	0.287	20	0.000	0.792	20	0.001
Hypermetropia	0.264	20	0.001	0.635	20	0.000
Average breakup time using PR						
Emmetropia	0.215	20	0.016	0.873	20	0.013
Myopia	0.394	20	0.000	0.571	20	0.000
Hypermetropia	0.249	20	0.002	0.814	20	0.001
Average breakup time using RG glass						
Emmetropia	0.309	20	0.000	0.827	20	0.002
Myopia	0.342	20	0.000	0.709	20	0.000
Hypermetropia	0.185	20	0.072	0.867	20	0.011
Average recovery time using RAF rule						
Emmetropia	0.263	20	0.001	0.818	20	0.002
Myopia	0.203	20	0.031	0.886	20	0.022
Hypermetropia	0.328	20	0.000	0.648	20	0.000
Average recovery time using PR						
Emmetropia	0.225	20	0.009	0.905	20	0.051
Myopia	0.289	20	0.000	0.823	20	0.002
Hypermetropia	0.156	20	0.200*	0.942	20	0.259
Average recovery time using RG glass						
Emmetropia	0.276	20	0.000	0.803	20	0.001
Myopia	0.173	20	0.120	0.958	20	0.504
Hypermetropia	0.369	20	0.000	0.728	20	0.000

*This is a lower bound of the true significance; aLilliefors significance correction. PR=Pencil-ruler; RG=Red-green; RAF=Royal air force rule