Title: Comparison of Near Visual Acuity and Reading Metrics in Presbyopia Correction

Running Head: Near Visual Acuity and Reading in Presbyopia

Authors: Navneet Gupta, BSc

James S. W. Wolffsohn, PhD

Shehzad A. Naroo, PhD

Affiliation (all authors): Ophthalmic Research Group, School of Life and Health Sciences, Aston University, Birmingham, B4 7ET, UK

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Corresponding Author:

Dr Shehzad A. Naroo

School of Life and Health Sciences

Aston University

Birmingham

B4 7ET

UK

Email: s.a.naroo@aston.ac.uk

Abstract

PURPOSE: Consistent measurement of near visual ability is important to allow fair comparison between different types of presbyopic correction. This study compared near visual acuity (VA) and reading metrics with different presbyopic corrections in order to provide a consistent standard for their evaluation.

SETTING: Eye Clinic, School of Life & Health Sciences, Aston University, Birmingham, UK.

METHODS: Presbyopic corrections examined were accommodating intraocular lenses (n=19), simultaneous multifocal and monovision (n=40) contact lenses and varifocal spectacles (n=38). Binocular near VA measured with different optotypes (uppercase letters, lowercase letters and words), and reading metrics assessed with the MNRead chart (reading acuity (RA), critical pint size (CPS) and CPS reading speed), were inter-correlated (Pearson's Product Moment Correlations), and assessed for concordance (Intraclass Correlation Coefficients - ICC) and agreement (Bland-Altman Analysis) for indication of clinical usefulness.

RESULTS**:** Other than CPS reading speed, all near VA and reading metrics correlated well with each other ($r>0.70$, $p<0.001$). Near VA measured with uppercase letters was highly concordant (ICC=0.78) and in close agreement (±0.17 logMAR) with lowercase letters. Near word acuity agreed well with RA (±0.16 logMAR), which in turn agreed well with near VA measured with uppercase letters (±0.16 logMAR). Concordance (ICC 0.18-0.46) and agreement (±0.24-0.30 logMAR) of CPS with the other near metrics was moderate.

CONCLUSION: Measurement of near visual ability in presbyopia ought to be standardised to include assessment of (a) near VA with logMAR uppercase letter optotypes (b) smallest logMAR print size that maintains maximal reading speed (CPS) and (c) reading speed.

The measurement of visual acuity (VA) is instinctively incorporated into any description of visual function due to its simplicity. There are several ways whereby this can be measured, with the most common being the determination of the smallest size of optotype that can just be resolved. There are however several types of optotype that can be used. Due to their face validity and familiarity, optotypes are commonly presented as uppercase letters. However, most written material in daily life is usually encountered as lowercase letters. These then form the component parts of words. Accordingly, the ability to resolve word optotypes would then appear to be a more "realistic" approach to near vision assessment.[1, 2] Indeed, reading is considered to be one of the fundamental aspects of visual function, the other being mobility,[3] and it is therefore not surprising that charts have been created for the specific purpose of assessing reading ability, through various associated metrics (reading acuity, critical print size (CPS) and CPS reading speed), as a form of near visual function evaluation.[2, 4] However, it is known that word optotypes typically yield poorer VA measures compared to single letter optotypes[5] possibly as a result of contour interaction.[6, 7] Near VA measured with word optotypes may also be influenced by the order in which the words appear, with some suggesting that the contextual elements of semantic sentences can lead to an over-estimation of the true near visual ability since it is then no longer solely a measure of visual resolution.[8, 9]

It has recently been found that there is a distinct lack of uniformity in VA reported in published studies.[10] Indeed, it is evident from Tables 1 and 2 that previous studies that have investigated near visual outcomes of various presbyopic corrections have used a variety of different notations to express near visual resolution, although the M Unit system has not been used at all. Of importance is that the continued use of non-standardised systems prevents accurate comparisons from being made, to assess for indications of benefit. It is certainly evident that the Logarithm of the Minimum Angle of Resolution (logMAR) system has many advantages over other notations for expressing near VA,[11] but it remains unclear as to the type of optotype that ought to be used, i.e. single letters (uppercase or lowercase) and/or words. This is further complicated by the desire to assess reading ability, which is typically measured using word optotypes. Therefore, the purpose of this study was to compare near VA measured with different logMAR optotypes (uppercase letters, lowercase letters and words) to various reading metrics (reading acuity, CPS and CPS reading speed) in order to determine which of these ought to be measured as a minimum standard, when assessing the near visual function conferred by different presbyopic corrections.

Method

Subject characteristics for all participants in this study are shown by the types of presbyopic correction in Table 3. Subjects implanted with the 'accommodating' IOL received a prototype design that is modelled on the 1CU 'accommodating' IOL (HumanOptics AG, Erlangen, Germany). Subjects wearing contact lenses were fitted with the Purevision™ Multifocal (Bausch and Lomb Corp., Rochester, NY., USA), which is a centre-near aspheric simultaneous vision design, whilst monovision was achieved using Purevision™ single vision lenses (Bausch and Lomb Corp., Rochester, NY., USA) with an interocular power difference equal to the near spectacle addition. The contact lens patients were younger than the other groups due to the handling and dry eye issues of wearing contact lenses with increasing age. However, this is unlikely to have affected the measures of VA in older subjects since an absence of pathology that could have reduced VA was ensured. Subjects wearing varifocal spectacles were fitted with either Varilux® Panamic® or Varilux® Physio™ lenses (Essilor Ltd., Thornbury, Bristol, UK).

All subjects in this study were required to be able to read English. In order to ensure that no visual dysfunction, other than possibly due to the type of presbyopia correction, would influence the near visual measures, all subjects were screened to ensure the absence of any binocular vision anomalies (e.g. amblyopia, strabismus or convergence problems), and the absence of any ocular pathology including cataract, age-related macular degeneration (AMD) and diabetic retinopathy.

For all subjects, near VA was measured with uppercase letter optotypes using the Early Treatment of Diabetic Retinopathy Study (ETDRS) Logarithmic Near Visual Acuity Chart 2000 (Precision Vision™, La Salle, IL., USA)[66] and with lowercase letter optotypes using a purpose designed logarithmic chart based on the design principals of Bailey and Lovie[11] (due to the lack of a commercially available alternative). The chart was created in high contrast Times New Roman font. Near word acuity, reading acuity, CPS and CPS reading speed (in words per minute - wpm) were measured using the Minnesota Near Reading (MNRead) chart (Lighthouse Low Vision Products, Long Island City, NY., USA).[2, 4]

All VA and reading assessments were conducted binocularly and at a standard consistent working distance of 40cm, under standard room illumination of 500 lux as per the recommended test conditions for the measurement of VA.[67] Subjects were instructed to read the optotypes on each chart as far down as possible, starting from the top-most line of acuity, and were stopped at a point where no more optotypes on a particular line of acuity were identified correctly. VA was then defined based on the total number of optotypes that were correctly identified, each being assigned a value of 0.02 logMAR. For the MNRead test, subjects were provided with the added instruction of reading the sentences as quickly but as comfortably as possible so that their natural reading technique would be represented. The order of testing between the charts was randomised to average any fatigue influences although subjects were given a 2 to 5 minute break between measures. During this time, subjects were asked to view a distant target so that any potential eyestrain and after-image effects would be minimised. All subjects were assessed with the best achievable vision provided by their correction type, which included best distance-corrected near vision for subjects with 'accommodating' IOL implants.

Informed consent was obtained from all subjects after explanation of the nature and possible consequences of the study, and ethical approval was obtained from the Ethical Committee of Aston University.

Statistical Analysis

Each of the near VA and reading metrics were compared to each and every other metric in a pair-wise manner by calculating Pearson's Product Moment Correlation (PPMC) Coefficients whilst linear regression was used to assess for statistical significance. A Bonferroni adjustment was applied for multiple pair-wise comparisons (significant $p<0.0033$, 15 pair-wise comparisons). Concordance of the magnitude of the near VA and reading measures was assessed for each pair-wise comparison by calculation of the Two-way Random Effects Intra-class Correlation Coefficients (ICC) (this particular model accounts for variability due to two factors: presbyopic correction and near vision metric). Finally, Bland-Altman limits of agreement (95% confidence interval) were calculated to determine the agreement between each pair of near VA and reading measures in turn.[68]

Pair-wise comparisons that yielded a weak correlation (<0.7), low concordance (<70%) or limits of agreement larger than 0.20 logMAR (selected based on the suggested minimum 95% confidence interval that represents natural variability in repeated VA measures for presbyopes[69, 70]) were taken to be indicative of additional useful clinical measures for the assessment of near visual ability in presbyopes.

Results

The mean magnitude of near VA measured with uppercase letters was lower than that measured with word optotypes, which was in turn lower than that measured with lowercase letter optotypes (Table 4). Mean RA had the lowest mean magnitude of all the near vision metrics whilst mean CPS had the highest mean magnitude (Table 4). All of the near metrics were highly and statistically significantly correlated to each other ($r > 0.70$ and $p < 0.001$ on all occasions, see Table 5) apart from CPS reading speed ($r < 0.20$ and $p > 0.0033$ on all occasions, see Figure 1). Near VA measured with uppercase letters was found to be highly concordant to near VA measured with lowercase letters, word optotypes, and to RA ($ICC > 0.70$ on all occasions) but CPS was only moderately concordant to the other near vision metrics ($ICC < 0.50$ on all occasions, see Table 6). Limits of agreement were within the clinically acceptable range of ±0.20 logMAR for comparisons between near VA measured with uppercase letters to lowercase letters (Figure 2) and to RA (Figure 3) whilst this was true for RA compared to near VA measured with lowercase letters and to word optotypes (Figure 3). Limits of agreement between CPS and the other near vision metrics (Figure 4) were greater than ±0.25 logMAR on all occasions (Table 6).

Discussion

The increasing variety of techniques that are available to correct presbyopia, such as ‘accommodating’ and multifocal IOLs and presbyopic contact lenses, has increased the importance of conducting standardised comparisons of near visual function with each, in order to obtain evidence of benefit. Near VA is perhaps the most common and well-known measure of near visual function although reading metrics such as reading acuity, CPS and CPS reading speed offer a more “real world” visual assessment. However, no previous study has investigated whether there are any differences in near VA when measured with different logMAR optotypes, or how these compare to the reading metrics, in presbyopic subjects with different corrections. It is therefore unclear whether all of these metrics are necessarily required to assess near visual function in presbyopia.

Near VA measured with uppercase letter optotypes, lowercase letter optotypes, and word optotypes, reading acuity and CPS were all found to be valid for the assessment of near visual function in presbyopes since all were strongly and statistically significantly correlated to each other. CPS reading speed however did not correlate well to any other near vision metric nor was there a statistically significant relationship with any of the other measures. This is not surprising since an assessment of reading speed is not solely an assessment of visual resolution, but is heavily dependent on other cortical and non-visual processes such as memory, comprehension and motivation.[71] However, an assessment of optimal reading speed provides a useful measure of near visual function in presbyopia, since this gives an indication of reading fluency. Indeed, reading is considered to be one of two fundamental aspects of visual ability[3] and therefore an assessment of this, in terms of reading speed, is of prime importance. Furthermore, comparisons of reading speed between two different presbyopic corrections, for example between two different types of contact lens corrections, can be made for an individual to determine the effect of, or difference in, the corrections, since this within-subject design will then cancel out the extraneous factors that influence reading speed measurements.

In this study it was found that mean magnitude of near VA measured with uppercase letters was approximately one line of logMAR acuity better than that measured with lowercase letters, with word optotypes in between. The differences are likely to have arisen partly due to factors such as disparity in font and letter legibility between the charts and optotypes. In particular, it has been shown that the presence of ascenders or descenders on lowercase letters (as is the case with the MNRead chart) improves the legibility of such optotypes.[72] Word acuity could therefore be poorer than single letter acuity since word recognition is a more complex cortical task that may also be prone to greater contour interaction effects.[73] Indeed in accordance with previous findings[5] this study found that near VA measured with single uppercase letter optotypes was better than that measured with word optotypes, with limits of agreement that were just greater than two lines of logMAR acuity. However the measures were all strongly correlated, highly concordant and had small and clinically acceptable limits of agreement suggesting redundancy of measuring near VA with more than one type of optotype when assessing the visual performance of presbyopic corrections. Since uppercase letters are the most familiar, these ought to be the optotype of choice.

Considering that assessment of near visual function with word optotypes is more representative of “real world” tasks, there ought to be some value in measuring this. However, it has now been established that near VA as assessed with word optotypes was similar to that assessed with both uppercase letters and lowercase letters (ICC >0.75 on both occasions). Similarly, it was found in this study that reading acuity was highly concordant and had small limits of agreement (approximately 1.5 lines of logMAR acuity) with near VA measured with uppercase letters, lowercase letters and word optotypes. In fact, of all the near vision metrics, reading acuity provided the lowest mean magnitude of near acuity indicating the best near visual performance. It is possible that this is an over-estimate of true reading ability, since the design of the MNRead chart requires subjects to read print of high contrast, which is very unlike the type of reading material encountered in real world reading tasks. As such, a useful assessment of the ability to resolve word optotypes is perhaps provided by measurement of the critical print size (CPS) instead.

CPS was moderately concordant to near VA measured with uppercase letters, to reading acuity and to word acuity, with large limits of agreement also observed on each occasion (approximately 2.5 to 3.0 lines of logMAR acuity). This disparity may be due to the fact that CPS is not measured to the same level of accuracy as the other metrics (0.10 logMAR as opposed to 0.02 logMAR) but, more importantly, it also represents the difference in the nature of the actual measurements. Whereas near VA, regardless of the optotype used, and reading acuity both assess near vision at the limits of resolution, CPS is representative of the most comfortable print size that can be read by the subject prior to an observed deterioration in reading speed. Based on the existence of this acuity reserve it would intuitively be expected that mean magnitude of CPS would be poorer than any other near VA measure, as is observed in this study. The importance of CPS herein is made obvious since subjects read most proficiently with letters sized at or above their most comfortable print size and therefore determination of this would certainly be of value for patient care and advice.

A similar analysis for the individual groups of presbyopic corrections were comparable to the overall group, although it was found that in subjects implanted with 'accommodating' IOLs, all of the near VA metrics and reading acuity were moderately inversely correlated to CPS reading speed. This suggests a need for such subjects to read smaller print sizes in order to achieve a consistent and maximal reading speed. This may be due to the effect concentration on smaller print sizes has in aiding in a more accurate stabilisation of the 'accommodation' response. Indeed, this adds further support for the measurement of CPS when evaluating presbyopic corrections.

In conclusion, standardised measurement of near visual ability is important to allow comparison between different types of presbyopic correction. Measurement of near VA and reading ability ought to include an assessment of (a) the smallest resolvable size of uppercase letter logMAR optotypes, (b) the smallest logMAR print size that maintains the maximal reading speed (CPS) and (c) the reading speed at this CPS.

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Figure Legends

Figure 1 Comparison of near VA, measured with uppercase letters, lowercase letters and word optotypes, reading acuity and critical print size (CPS) to CPS reading speed (n=97)

Figure 2 Bland-Altman plots comparing near VA measured with uppercase letters, lowercase letters and word optotypes reveal good agreement (n=97)

Figure 3 Bland-Altman plots comparing near VA, measured with uppercase letters, lowercase letters and word optotypes to reading acuity reveal good agreement (n=97)

Figure 4 Bland-Altman plots comparing near VA, measured with uppercase letters, lowercase letters and word optotypes, and reading acuity to critical print size (CPS) reveal only moderate agreement (n=97)

Author(s)	Aim of Study	Equivalent Snellen or Decimal	Jaeger	Points System (N Notation)	LogMAR	Reading Metrics	Other
Akutsu et al.[12]	Evaluation of reading speed with the 3M diffractive IOL				✓	✓	
Gray & Lyall[13]	Evaluation of the 3M diffractive IOL			✓			
Knorz et al.[14]	Comparison between the TrueVista bifocal IOL, 3M diffractive IOL and the Nordan aspheric varifocal IOL	✓					
Auffarth et al.[15]	Evaluation of the 3M diffractive IOL	✓					
Walkow et al.[16]	Comparison of the 3M diffractive IOL to the Array refractive IOL		✓				
Avitabile et al.[17]	Evaluation of the 811E diffractive IOL		✓				
Hayashi et al.[18]	Evaluation of the Array refractive IOL	✓					
Slagsvold[19]	Long-term results of the 3M diffractive IOL		✓				
Leyland et al.[20]	Comparison of the Array progressive refractive IOL to the TrueVista concentric IOL				✓		
Richter-Mueksch et al.[21]	Comparison of reading performance with the 811E diffractive IOL and the SA40N IOL					✓	
Shoji & Shimizu[22]	Evaluation of a concentric refractive IOL		✓				
Alió et al.[23]	Comparison between the Array refractive IOL, AcriTec TwinSet diffractive IOL and the Crystalens AT-45 'accommodating' IOL	✓	✓				
Claoué[24]	Comparison of the Array refractive IOL to the 1CU 'accommodating' IOL	✓		✓			
Pineda-Fernández et al.[25]	Evaluation of the Array refractive IOL		✓				
Nijkamp et al.[26]	Comparison of the Array refractive IOL to a single vision IOL					De Nederlanders chart	
Sen et al.[27]	Evaluation of the Array refractive IOL	✓					
Baïkoff et al.[28]	Evaluation of the Newlife bifocal IOL						Parinaud
Alió & Mulet[29]	Evaluation of an anterior chamber multifocal IOL	✓					
Schmidinger et al.[30]	Evaluation of the AcriTec TwinSet diffractive IOL				✓		
Tsorbatzoglou et al.[31]	Evaluation of the AcrySof ReSTOR diffractive IOL		✓				
Souza et al.[32]	Evaluation of the AcrySof ReSTOR diffractive IOL				✓	✓	
Chiam et al.[33]	Evaluation of the AcrySof ReSTOR diffractive IOL	✓	✓	✓			
Hütz et al.[34]	Comparison of reading ability with the Array progressive IOL, the Tecnis IOL and the AcrySof ReSTOR IOL					✓	
Schmidinger et al.[35]	Comparison of the AcriTwin asymmetric diffractive IOL with the 811E diffractive IOL and the Array refractive IOL				✓		
Vingolo et al.[36]	Evaluation of the AcrySof ReSTOR diffractive IOL				✓		
Toto et al.[37]	Comparison of the ReSTOR and the Tecnis diffractive IOLs		✓				
Mester et al.[38]	Comparison of the Tecnis diffractive IOL to Array refractive IOL				✓		

Pepose et al.[39]	Comparison of the ReZOOM refractive IOL to the ReSTOR diffractive IOL and the Crystalens AT-45 'accommodating IOL'	✓			✓	✓	

Table 1 Near vision metrics used in the evaluation of multifocal intraocular lenses (IOLs)

Author(s)	Aim of Study	Equivalent Snellen or Decimal	Jaeger	Points System (N Notation)	LogMAR	Reading Metrics	Other
Legeais et al.[40]	Evaluation of the BioComFold IOL						Parinaud
Cumming et al.[41]	Evaluation of the feasibility of the Crystalens AT-45 IOL		✓				
Küchle et al.[42]	Evaluation of the 1CU IOL	✓	✓				
Langenbucher et al.[43, 44]	Evaluation of the methods of assessing accommodation of 'accommodating' IOLs	✓					
Küchle et al.[45]	Stability of refraction and accommodation of the 1CU IOL	✓	✓				
Mastropasqua et al.[46]	Evaluation of the 1CU IOL		✓				
Küchle et al.[47]	Evaluation of the 1 CU IOL	✓					
Marchini et al.[48]	Evaluation of the performance and mechanism of action of the Crystalens AT-45 IOL		✓				
Dogru et al.[49]	Early results of the 1CU IOL	✓					
Heatley et al.[50]	Comparison of the 1CU IOL to a single vision IOL		✓			✓	
Sauder et al.[51]	Evaluation of the 1CU IOL		✓				Nieden Scale
Vargas et al.[52]	Evaluation of the 1CU IOL relative to capsulorhexis size	✓					
Kriechbaum et al.[53]	Comparison of stimulus driven and pilocarpine driven accommodation of the 1CU IOL				✓		
Koeppl et al.[54]	Evaluation of the shift of the Crystalens AT-45 IOL		✓		✓		
Schneider et al.[55]	Comparison of the 1CU IOL to a single vision IOL				✓		
Hancox et al.[56]	Comparison of IOL shift an VA of the 1CU IOL to a single vision IOL		✓			✓	
Wolffsohn et al.[57]	Evaluation of the 1CU IOL				✓ (Word acuity)		
Wolffsohn et al.[58]	Evaluation of the KH-3500 IOL				✓ (Word acuity)		
Cumming et al.[59]	Evaluation of the Crystalens AT-45 IOL		✓			✓	
Macsai et al.[60]	Evaluation of the Crystalens AT-45 IOL	✓					
Buratto & Di Meglio[61]	Short-term results of the 1CU and the Crystalens AT-45 IOLs		✓				
McLeod[62] & Ossma et al.[63]	Performance of a dual-optic IOL		✓		✓		
Marchini et al.[64]	Comparison of the performance of the 1CU and Crystalens AT-45 IOLs		✓				
Sanders & Sanders[65]	Evaluation of the KH3500 IOL	✓	✓				

Table 2 Near vision metrics used in the evaluation of 'accommodating' intraocular lenses (IOLs)

Type of Presbyopic Correction	Number of Subjects (n)	Mean Age ± SD & Range	Gender
‘Accommodating’ IOL	19	67.1±15.8years Range: 30-88 years	6 males 13 females
Presbyopic Contact Lenses	Monovision: 20	55.0±5.1 years Range: 49-67 years	11 males 9 females
	Multifocal: 20		11 males 9 females
Varifocal Spectacles	38	68.0±9.4 years Range: 49-82 years	19 males 19 females
Total	**97**	**62.5±11.4 years Range: 30-88 years**	**47 males 50 females**

Table 3 Characteristics of the subjects recruited for VA and reading metric comparisons

		Near Visual Acuity / Reading Metric					
		Uppercase Letters (LogMAR)	**Lowercase Letters (LogMAR)**	**Words (LogMAR)**	**Reading Acuity (RA) (LogMAR)**	**Critical Print Size (CPS) (LogMAR)**	**CPS Reading Speed (wpm)**
‘Accommodating’ IOL Group n=19	**Mean**	0.44	0.67	0.53	0.45	0.72	177.6
	SD	*0.12*	*0.16*	*0.19*	*0.15*	*0.13*	*29.5*
Presbyopic Contact Lens Group N=40	**Mean**	0.16	0.26	0.25	0.10	0.39	158.8
	SD	*0.13*	*0.13*	*0.11*	*0.10*	*0.12*	*19.5*
Varifocal Spectacles Group N=38	**Mean**	0.09	0.14	0.15	0.04	0.38	175.0
	SD	*0.11*	*0.09*	*0.12*	*0.11*	*0.16*	*22.4*
Overall (n=97)	**Mean**	**0.19**	**0.30**	**0.27**	**0.14**	**0.45**	**168.8**
	SD	**0.18**	**0.23**	**0.19**	**0.19**	**0.19**	**24.2**

Table 4 Means and standard deviations of the measured near VA and reading metrics by type of presbyopic correction and overall

	Uppercase Letters	Lowercase Letters	Words	Reading Acuity (RA)	Critical Print Size (CPS)	CPS Reading Speed
Uppercase Letters	-	-	-	-	-	-
Lowercase Letters	0.93 *p<0.001*	-	-	-	-	-
Words	0.83 *p<0.001*	0.88 *p<0.001*	-	-	-	-
Reading Acuity (RA)	0.90 *p<0.001*	0.94 *p<0.001*	0.92 *p<0.001*	-	-	-
Critical Print Size (CPS)	0.77 *p<0.001*	0.75 *p<0.001*	0.71 *p<0.001*	0.79 *p<0.001*	-	-
CPS Reading Speed	0.15 p=0.15	0.13 p=0.19	0.12 p=0.26	0.11 p=0.27	0.19 p=0.06	-

Table 5 Pearson's Product Moment Correlation coefficients and associated significance values for each pair-wise comparison between near VA and reading metrics (n=97). Significant results are highlighted in italic

	Uppercase Letters	Lowercase Letters	Words	Reading Acuity (RA)	Critical Print Size (CPS)
Uppercase Letters	-	-	-	-	-
Lowercase Letters	0.78 ± 0.17	-	-	-	-
Words	0.76 ± 0.21	0.87 ± 0.22	-	-	-
Reading Acuity (RA)	0.81 ± 0.16	0.62 ± 0.16	0.60 ± 0.16	-	-
Critical Print Size (CPS)	0.26 ± 0.24	0.46 ± 0.30	0.39 ± 0.28	0.18 ± 0.26	-

Table 6 Concordance (top value) and Bland-Altman limits of agreement (bottom value) for each pair-wise comparison between near VA and reading metrics (n=97)