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Near binocular visual function in young adult orthokeratology versus soft contact lens wearers

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ABSTRACT

Purpose: To compare near point binocular vision function of young adult myopes wearing orthokeratology (OK) lenses to matched single vision soft disposable contact lens (SCL) wearers.
Methods: A retrospective clinical record analysis of all OK wearers (18–30 years) presenting over an 18 month period was undertaken. Data was extracted for 17 OK wearers, with 17 SCL wearers matched for age, refractive error and duration of contact lens wear. Binocular vision data included horizontal phoria (phoria), horizontal base-in (BIFR) and base-out fusional reserves (BOFR) and accommodation accuracy (AA).
Results: The OK group was 25.8 ± 3.2 years, with a duration of wear of 45.7 ± 25 months and refractive error of R −2.09 ± 1.23D, L −2.00 ± 1.35D. Compared to matched SCL wearers the OK group were significantly more exophoric (OK −2.05 ± 2.38Δ; SCL 0.00 ± 1.46Δ, p = 0.005) and had better accommodation accuracy (OK 0.97 ± 0.33D; SCL 1.28 ± 0.32D, p = 0.009). BIFR and BOFR were not different in the two groups. Frequency histograms showed that more SCL wearers had high lags of accommodation (AA ≥ 1.50D: 8 SCL,2 OK) and esophoria (≥1Δ: 5 SCL,1 OK) than OK wearers. A positive correlation was found between refraction and phoria in the SCL group (r = 0.521, p = 0.032).
Conclusion: Young adult myopes wearing OK lenses display more exophoria and lower accommodative lags at near compared to matched single vision SCL wearers. Young adult myopes with specific binocular vision disorders may benefit from OK wear in comparison to single vision SCL wear. This has relevance to both the visual acceptance of OK lenses and in managing risk factors for myopia progression.

1. Introduction

Orthokeratology (OK) is a specialty contact lens modality used for correction of low to moderate degrees of myopia [1]. In recent years, attention has turned to the use of OK lenses to slow the progression of myopia, with recent meta-analyses of several controlled studies indicating a mean reduction in axial elongation of 45% over two to five years [2,3]. This makes the modality particularly attractive for practitioners prescribing to children [4] and young adults with progressive myopia. OK is also appealing to those with active lifestyles and/or contact lens related dry eye who wish to be independent of spectacle or contact lens correction during the day.

When compared to spectacles, the myopic single vision soft contact lens (SCL) wearer must increase accommodation and convergence effort at near [5,6], which has the potential to lead to symptoms of headache, blurred vision and asthenopia. The latter can manifest as tired, irritated and red eyes [7] which can adversely impact contact lens wear. For the young adult progressing myope, increased binocular demand with contact lens wear could exacerbate existing binocular vision anomalies associated with myopia progression – this group have demonstrated more near esophoria, increased accommodative lag, and greater variability in accommodative responses with closer near demands when compared to stable myopes and emmetropes [7–10]. Whether OK is fitted to either stable or progressing young adult myopes, it is critical to understand the effect on binocular vision function. Recent data indicates an improvement in amplitude of accommodation in children wearing OK, and a greater myopia controlling effect in those with a below-average baseline amplitude of accommodation [11].

Clinical evaluation of near binocular vision function includes measurement of accommodation and vergence accuracy, amplitude and facility. The accuracy of the accommodative response at

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near is described by accommodative lag or lead, and for vergence the near phoria. Amplitude of accommodation can be measured monocularly and binocularly through introduction of increasingly minus powered lenses, along with measurement of positive relative accommodation (response to minus lenses) and negative relative accommodation (response to plus lenses). Amplitude of vergence is measured by horizontal fusional convergent and divergent reserve response to induced prism. Facility of both accommodation and vergence is measured by alternating increased and decreased demand to measure swiftness of response [7,12].

An increase in accommodative responses to 0–5 D vergence targets in young adult myopes wearing OK for one month has been previously measured, compared to single vision soft contact lens wear. The authors measured an increase in positive spherical aberration at all vergence targets in OK wear, and their calculations of Zernike defocus indicated reduction of accommodative lags, although the latter were not directly measured [13]. One recent study evaluating accommodative changes in response to OK wear found no significant change in young adults (18–30 years) with low to moderate myopia at baseline and after three months, when compared to adults wearing other unknown corrections. Further comparison of those wearing OK for three months to an age and refraction matched group of OK wearers of at least three years duration demonstrated a significant increase in negative relative accommodation in the long term wearers, but no change in positive relative accommodation, monocular amplitude of accommodation, accommodative lag or monocular accommodative facility [14]. No assessment of vergence function at near in young adult OK wear has been undertaken.

The aim of this study was to undertake a retrospective analysis of clinical records to determine if there are any differences in near binocular vision function between young adults wearing OK compared to those wearing single vision disposable SCLs for myopia correction. Any evident differences in binocular vision function between contact lens wear modalities could affect visual acceptance and frequency of symptoms like asthenopia and headaches [7], as well as in management of binocular vision risk factors in the case of young adult myopia progression [7–10].

2. Methods

2.1. Clinical records

Consecutive clinical records of all OK wearers aged between 18 and 30 years who had presented in an 18 month period (January 2011 to July 2012) at an optometric practice in Brisbane, Australia were reviewed. All participants had given prior informed consent to allow their clinical data to be used for research purposes. The study was approved by the Queensland University of Technology, Human Research Ethics Committee and followed the tenets of the Declaration of Helsinki. The database record search and data recording were conducted by a research assistant who was masked to the purpose of the study.

2.2. OK and SCL groups

All clinical records of OK wearers aged between 18 and 30 years at their most recent presentation were accessed to evaluate available data on age, duration of OK contact lens wear, pre-OK best vision sphere refraction, and binocular vision function. The records were excluded from analysis if there was no available binocular vision data, or if binocular vision treatment had been given at any visit. A negative history for strabismus, amblyopia or ocular pathology, trauma or surgery was also required. The record was also excluded if the binocular vision data was collected when the myopia was not fully corrected (distance sphero-cylindrical refraction result must be within −0.25D to +0.50D inclusive in each eye), or if there was residual astigmatism greater than −0.75DC in any meridian [15]. All binocular vision measurements in the OK group occurred in an unaided state. The records of 17 young adult OK wearers comprised a full set of binocular vision data at their most recent presentation, satisfied all inclusion criteria, and were used in the analysis. Clinical records were searched to find 17 single vision disposable SCL wearers that matched the 17 OK wearers in terms of age, degree of myopia and duration of wear of their contact lens modality, and where the record also had a complete set of binocular vision data collected using the same methods at the most recent presentation. Clinical data was extracted and recorded in a spreadsheet (Microsoft Excel, Washington, USA).

All OK wearers had been fit with Contex E-series lenses (Contex, California, USA) according to the manufacturers fitting guidelines. These lenses are fit using an inventory set where the first lens selected is that matching the flat corneal meridian and target treatment power. If this first lens demonstrates either a tight or loose fit on the eye, the next appropriate lens is selected from the inventory set. A subsequent overnight trial determines if the ideal fit has been achieved and if the selected lens is suitable. Clinical outcomes indicating ideal and non-ideal OK contact lens fits and modification paradigms have been described elsewhere [16].

All except for one of the SCL group wore the same lens type in each eye. Eleven of the SCL group wore spherical CL and six had a toric correction, 13 wore aspheric lenses (Bausch & Lomb Purevision2, Purevision2 Toric, Soflens Toric; Coopervision Biofinity, Biofinity Toric, Proclear; Alcon AirOptix) and 4 non-aspheric lens designs (Johnson & Johnson Oasys Toric, TruEye, Moist, Moist Toric). All of the SCL group were fully corrected as per the OK group, and had only worn a single vision distance modality throughout their clinical history.

2.3. Binocular vision measures

Near point binocular vision data for each record was available in the form of horizontal heterophoria (phoria), horizontal base-in fusional reserves (BIFR) and base-out fusional reserves (BOFR) and accommodation accuracy (AA) at near. Phoria was measured using the estimated cover test at 40cm [17,18]. BIFR and BOFR were determined using the step method with a prism bar in free space, with a 6/9 acuity target at 40 cm. The break point was the prism value at which single vision was no longer maintained, and the recovery point was the prism value at which single vision was regained through fusion. The recovery value was recorded [7,12]. AA (lag or lead) was measured using the monocular estimate method (MEM) retinoscopy at 40cm [19]. These methods have shown good intra- and inter-examiner repeatability in previous studies [17,20–22].

2.4. Statistical analysis

The Statistical Package for the Social Sciences (SPSS, version 21.0, Chicago, USA) was used for statistical analysis. Each data set was evaluated for normality of distribution using Kolgov-Smirnov testing. When normality was not evident, Mann-Whitney *U*-tests of independent groups were applied. Where normality of distribution was confirmed, Student's *t*-Tests were applied. All *t*-Tests were two-tailed, independent type three (unequal variance) tests to compare means in the clinical data between groups and Bonferroni corrections for multiple analyses used to protect against Type I error [23]. Due to the different treatments applied, an independent group analysis was considered appropriate. Chi-Square was used for analysis of potential group differences in gender. Frequency histograms were plotted for binocular vision measures showing significant group differences, and Pearson's correlations were used to evaluate potential associations between spherical equivalent refractive error and binocular vision data. In all cases a p value of <0.05 was considered statistically significant.

3. Results

3.1. Participant characteristics

The mean age of the two groups was similar (OK 25.8 ± 3.2 years; SCL 25.4 ± 3.1 years, p = 0.769), as was their duration of contact lens wear in their modality (OK 45.7 ± 25.0 months; SCL 60.0 ± 36.5 months, p = 0.322). The pre-OK refraction of the OK group was similar to the current contact lens prescription of the SCL wearers, for both right (p = 0.508) and left (p = 0.401) eyes. (Table 1) There was a similar gender distribution ($X^2(1) = 0.134$, p = 0.500); 12 females in the OK group (70.6%) and 11 in the SCL group (64.7%). In the OK group, one participant was of East Asian ethnicity with the remaining 16 being of Caucasian ethnicity. In the SCL group, one participant was East Asian, one of Middle Eastern ethnicity, and the remaining 15 were Caucasian.

3.2. Binocular vision results

The OK group showed significantly more exophoria at near (phoria: OK −2.05 ± 2.38Δ; SCL 0.00 ± 1.46Δ, p = 0.005) and lower lags of accommodation (AA: OK 0.97 ± 0.33D; SCL 1.28 ± 0.32D, p = 0.009) (Table 2). A trend towards higher BIFR in the OK group failed to reach significance (p = 0.124) and BOFR at near showed no significant difference between the groups (p = 0.336). (Table 2) Paired measures analysis was also undertaken due to the methodology of pair matching the OK and SCL wearers, and the statistical outcomes were the same–the OK group again showed greater exophoria at near (p = 0.017) and a lower lag of accommodation (p = 0.028) than the SCL group, and there was no difference in BIFR (p = 0.188) or BOFR (p = 0.295) between the groups.

The frequency histogram of AA (Fig. 1) shows that more SCL wearers have high lags of accommodation than OK wearers (AA ≥ 1.50D: 8 SCL, 2 OK), and that more OK wearers have lower lags of accommodation than SCL wearers (AA ≤ 0.75D: 7 OK, 2 SCL). The frequency histogram of phoria (Fig. 2) shows that more SCL wearers are esophoric than OK wearers (phoria ≥ 1Δ: 5 SCL, 1 OK), and that more OK wearers are exophoric than SCL wearers (phoria ≤ −1Δ: 12 OK, 6 SCL).

Pearson's correlations (Fig. 3) revealed a moderate sized, significant positive correlation between SER and phoria in the SCL group (r = 0.521, p = 0.032) and a medium negative effect of SER when correlated to phoria in the OK group which was not significant (r = −0.437, p = 0.079). There was no significant relationship between spherical equivalent refractive error (SER) and AA in either the OK (r = 0.051, p = 0.846) or SCL (r = −0.057, p = 0.829) groups. Correlation between phoria and AA showed no significance in either the OK (r = 0.236, p = 0.361) or SCL (r = 0.135, p = 0.605) groups.

4. Discussion

OK wearers had a lower lag of accommodation and more exophoria than the SCL wearers in this study. In the SCL group the near horizontal phoria was positively correlated to the SER. These differences suggest that the near point binocular vision function of OK wearers can be judged as clinically similar or better [7] compared to their single vision SCL wearing counterparts. Binocular vision dysfunction at near can lead to symptoms of asthenopia in young adults [7,12], and has also be implicated in myopia progression [11,24,25]. To our knowledge this is the first examination of binocular vision function including vergence assessment in OK contact lens wear compared to SCL wear in young adult myopes.

All binocular vision function results here, with the exception of AA, fall within accepted normal ranges [7,12]. While symptomology was not quantified in this study, the results indicate visual comfort and acceptance of both modalities should be satisfactory [26]. AA results in both groups were found to be lags higher than the accepted clinical normal of +0.50 [12], likely due to the less accurate accommodative behavior of the myope as has been previously described [8–10]. A lower accommodative lag in OK contact lens wear could indicate increased visual comfort for the young adult myope compared to SCL wear [12,26]. In children, higher esophoria has been associated with reduced reading performance [27]; a similar functional effect could be extrapolated to the SCL wearing young adults in this study, particularly as tertiary studies are more common in this age group and hence near work demands are high.

In addition to the effect of binocular vision on visual function and comfort, there is a reported association between higher levels of esophoria and accommodative lag at near in myopic children and young adults as compared to emmetropes [28,29]. Progressing myopes in young adulthood have been shown to have more near esophoria, an increased accommodative lag, and greater variability in accommodative responses with closer near demands [8]. The results here show that the OK group demonstrate more exophoria and a reduced accommodative lag than SCL wearers, indicating the OK lens wearers could hold a binocular vision status of lower risk for myopia progression than SCL wearers. It has been demonstrated elsewhere that standard SCL's do not slow axial elongation associated with myopia [30]. The beneficial effect of OK on near binocular vision could partly explain OK's propensity for a myopia control effect of 45% reduction in axial elongation, as shown in recent meta-analyses [2,3]. Myopia progression status was not evaluated here–while older data indicates that population average myopia progression in young adults is low [31], newer research indicates a nearly two-fold increase in myopia frequency in a first year university population between 2002 and 2014 [32]. The risk of late onset myopia and myopia progression in young adulthood means this age group may be a burgeoning target for myopia controlling treatments in clinical practice.

Felipe-Marquez et al. [14] evaluated accommodative function after both three months and three years of OK wear in young adult myopes, but did not illustrate a difference in accommodative lag between OK and control groups. They stated that the control group

Table 1
Comparison of OK and SCL groups: age, duration of contact lens wear and refractive characteristics.

Group	n	Age (years)	Duration of CL wear (months)	Right SER (D)	Left SER (D)
OK wearers	17	25.8 ± 3.2	45.7 ± 25.0	−2.09 ± 1.23	−2.00 ± 1.35
SCL wearers	17	25.4 ± 3.1	60.0 ± 36.5	−2.41 ± 1.56	−2.46 ± 1.45
P-value		0.769	0.322	0.508	0.401

Data are mean ± standard deviation. OK = orthokeratology, SCL = soft contact lenses, SER = spherical equivalent refraction.

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Table 2
Comparison of OK and SCL groups: binocular vision parameters.

Group	Near base-in fusional reserves (Δ ± SD)	Near base-out fusional reserves (Δ ± SD)	Accommodation Accuracy at 40 cm (D ± SD) Positive = lag	Near phoria (Δ ± SD) *Negative = exophoria* *Positive = esophoria*
OK wearers	10.59 ± 1.84	25.88 ± 2.64	0.97 ± 0.33	−2.05 ± 2.38
SCL wearers	9.52 ± 2.07	24.88 ± 3.30	1.28 ± 0.32	0.00 ± 1.46
P-value	0.124	0.336	0.009*	0.005*
Effect size (r)			0.442	0.473

Data are mean ± standard deviation.
* OK and SCL groups significantly different at $p \leq 0.05$.

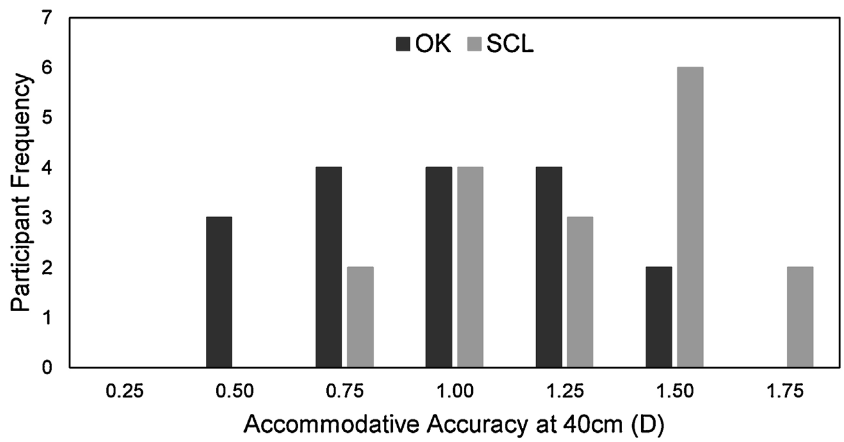

Fig. 1. Frequency histograms of accommodation accuracy (positive indicates lag) at 40 cm in orthokeratology (OK) and soft contact lens (SCL) wearers.

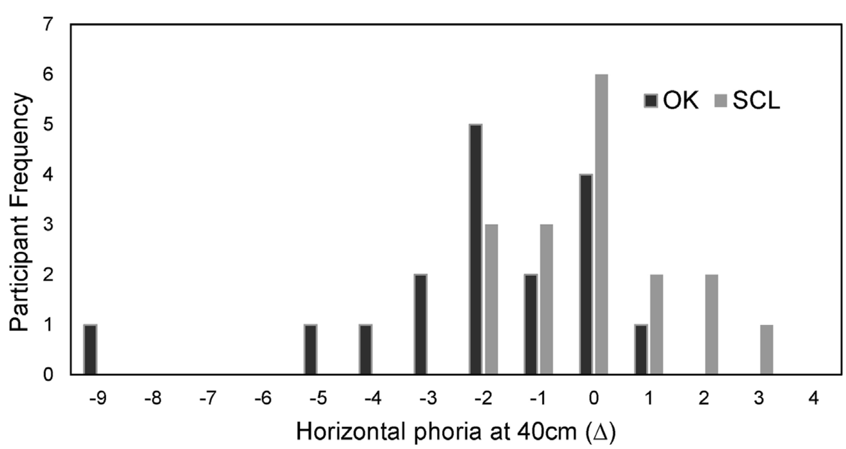

Fig. 2. Frequency histogram of near horizontal phorias (negative indicates exophoria) at 40 cm in orthokeratology (OK) and soft contact lens (SCL) wearers.

wore an unspecified ‘conventional correction’ [14]; if this included some percentage of distance spectacle lens wearers then this could describe their lack of findings. When comparing a short term (three months) with long term (three years) group of young adult OK wearers, however, these authors found a significant increase in negative relative accommodation, indicating improved accommodation function, although accommodative lag did not change. This indicates some similarity to the results found here, where the OK and SCL groups of the present study were long term wearers by similar criteria, having a mean wearing time of almost 4 (OK) and 5 (SCL) years. If Felipe et al’s study had included homogenous OK lens types and a standardised correction for the control group, its outcomes may have been in closer agreement with those found here.

Possible mechanisms for the observed reduction in lag of accommodation and higher rate of exophoria with OK contact lens wear include the differences in the peripheral optics and aberration profiles of the SCL and OK lenses. OK contact lenses have been shown to induce a myopic shift in peripheral refraction, along the horizontal meridian, equivalent to the central myopic refractive error. Astigmatism components of the refraction are not altered, and the effect is symmetrical around the horizontal visual axis [33,34]. By comparison, single vision soft contact lens correction brings about an absolute hyperopic peripheral defocus in the lower myopic powers evaluated in this study [35]. While there have been no direct evaluations of the relationship between changes in peripheral optics and binocular vision demand, SCL

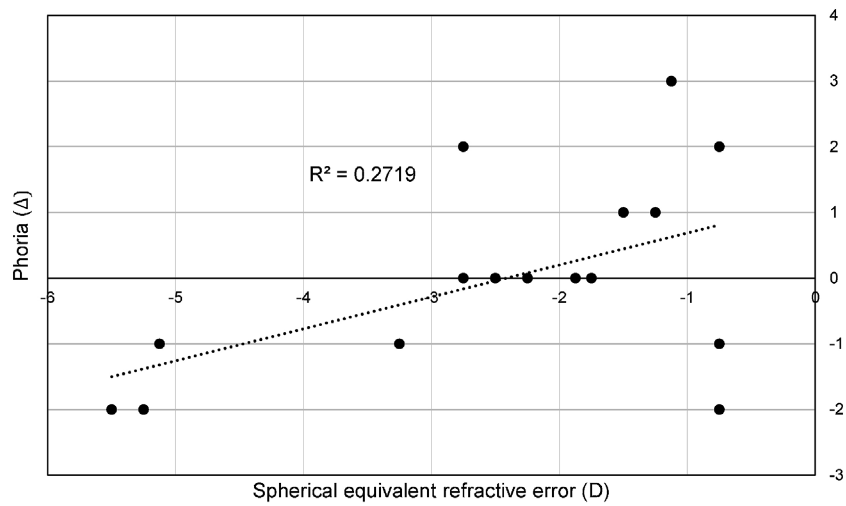

Fig. 3. Correlation of spherical equivalent refractive error and horizontal near phoria in the SCL group ($p = 0.032$, $r = 0.521$).

induced peripheral hyperopic defocus could increase accommodative demand in the myope [36], leading to an adaptive increase in accommodative lag and esophoric shift compared to OK – which is reflected in these results. Relative peripheral hyperopia in myopic eyes has been shown to be unaffected by accommodative demand [37], supporting the effect found here as a stable property of OK's impact on binocular vision function.

It is generally held that accommodation brings about a negative shift in spherical aberration (SA), with large intersubject variability [38,39]. Moreover, negatively powered contact lenses exhibit negative SA [40], which could theoretically increase accommodative demand in the myope. OK, by contrast, has been shown to increase SA in the positive direction by 4 to 8 times after only one night of wear [41,42]. A positive shift in spherical aberration could be inferred to reduce accommodative demand at near [13] and prove to be beneficial to the inaccurate myopic accommodative system by increasing depth of focus [38,39,43–46]. While a modest correlation between manifest aberrations and accommodative lag or lead has been debated [45,46], this fundamental difference between modalities could further explain effects of OK on the binocular vision system.

A previous study comparing the accommodative responses of young adult myopes in SCLs and again after one month of OK wear equated the significant positive shift in SA to increased accommodative responses, thereby reducing accommodative lags [13]. These results aligned with a study evaluating corneal versus ocular (whole eye) SA after one night and seven nights of OK wear, showing a rebalance of the internal SA through a theorised increased accommodative response [41]. Although these studies are longitudinal and short term, and the data here cross-sectional in long term wearers, results found in this study affirm a reduction of accommodative demand in OK wear compared to its SCL counterparts. The cross-linked interaction between accommodation and convergence[36]indicate that any improvement in accommodative accuracy is likely to be present with more exophoria, which is also in line with the results found here.

Correlations between spherical equivalent refractive error (SER) and the binocular vision data in each group yielded no significance for accommodative accuracy, but a significantly positive correlation with moderate effect size between SER and near phoria in the SCL group. This indicates that a less myopic refraction was related to a more esophoric posture at near. It could be expected that a more myopic refraction corrected with soft contact lenses would bring about a greater shift in negative spherical aberration [40], theoretically increasing accommodative demand [39] – this could lead to a more esophoric posture at near depending on the accommodation-convergence relationship in the individual [36]. Hence the results here are interesting and indicate a level of complexity in the covariation possibly related to time of onset from myopia. Lower myopes may have a more recent onset [47], and late onset myopes have previously demonstrated binocular vision systems more deleteriously influenced by near point demand than their early onset counterparts [48], such that a higher accommodative tone could influence phoria posture [36,49]. No significant effect of refractive error on manifest near heterophoria in young adults has been determined [50], and duration and progression of myopia was not quantified here. While not reaching significance, there was appearance of a negative correlation between SER and near phoria in the OK group, which with further investigation could reveal a clearer relationship between the change in optics created by OK and its manifest effect on binocular vision.

While accepting of the limitations of a retrospective study, the confounding effects of variation in measurement time and bias were minimised. Studies have shown the refractive effect and aberration changes after OK to be temporally stable after one month and through to one year [51,52] – the minimum OK wearing time in this group was 48 days with a mean of 3 years 10 months. Any effect of residual defocus was diminished as data was only included where an emmetropic over-refraction (−0.25 to +0.50) was evident in both OK and SCL groups. Repeatability of the clinical binocular vision measures evaluated has previously been demonstrated [17,20–22], and potential examiner bias was minimised by the data entry being undertaken by an individual masked to the purpose of the study. There is some complexity in matching the pre-OK refraction of the OK group to the current refraction of the SCL group, as the current refraction of the OK group is not known; however the attempt was made to minimise long term binocular vision and myopia stability differences between the groups through matching for age, duration of contact lens wear and myopic refraction. Further examination of a larger data set, including analysis of participants meeting exclusion criteria; along with quantification of compensation and symptomology, would enhance understanding of evident binocular visual function differences between OK and SCL wear in young adult myopes.

5. Conclusion

OK contact lens wearing young adults demonstrate a more accurate near accommodative-vergence profile compared to matched SCL wearers, with more exophoria and reduced accommodative lag. While symptomology was not quantified, this could indicate improved visual comfort and acceptance of OK over SCL wear for specific binocular vision dysfunctions, as well as explain a mechanism of OK's myopia control effect.

Conflicts of interest

None.

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