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Comparison of the uniocular field of fixation assessed objectively and subjectively using the Goldmann perimeter

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Abstract

Aim: **The uniocular field of fixation (UFOF) may be assessed using the Goldmann perimeter subjectively and objectively. Haggerty *et al.* in 2005 proposed a technique examining six axes corresponding to the primary field of action of each extraocular muscle (EOM). Comparative evidence on subjective and objective assessment and the effect of target size is unclear. The purpose of this study was to determine the effect of subjective and objective assessment and target size upon the mean total EOM excursions and individual muscle excursions using the Haggerty technique in normal subjects.**
Methods: **Volunteers were recruited with right visual acuity of 0.10 logMAR or better, no manifest strabismus, full ocular motility, and no ocular pathology. Subjective and objective UFOF using two fixation targets (1Ie and 1IIe) were plotted for the right eye by one examiner using the Haggerty technique on the Goldmann perimeter.**
Results: **Twenty-four participants (22 females, 2 males) with a mean age of 20.3 ± 1.6 years were included. The mean total EOM excursions performed objectively using target 1Ie and 1IIe were $288.2 \pm 4.7°$ and $288.5 \pm 5.7°$, and subjectively were $290.7 \pm 4.8°$ and $299.4 \pm 7.2°$. The mean total excursion comparing objective and subjective assessment was not affected by target size. Increasing the target size produced a significant enlargement in total EOM excursions when assessed subjectively but not objectively. As regards individual muscle excursions, the inferior rectus excursion showed the greatest difference when comparing subjective and objective assessment ($p < 0.0001$). A significant difference was also found for the inferior oblique using target 1Ie. Only the inferior oblique was affected by increasing target size when assessed subjectively ($p = 0.007$). Bland-Altman analysis showed large variation comparing objective and subjective assessments and for increased target size.**
Conclusion: **The degree of excursion obtained performing objective and subjective assessment can vary for individual EOMs. Target size may also influence the mean total EOM excursion. Standardised method of assessment is vital when assessing the UFOF to avoid misinterpretation of change caused by a different methodology.**

Key words: Goldmann perimeter, Objective, Subjective, Target size, Uniocular field of fixation

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Introduction

The uniocular field of fixation (UFOF) is defined as the field of uniocular excursion whereby foveal fixation is maintained.[1] Examination of the UFOF establishes the limit of uniocular excursion in different positions of gaze. A method of quantitatively measuring uniocular excursion is invaluable in the diagnosis and management of ocular motility disorders. A number of quantitative assessment techniques have been employed in eye clinics including the synoptophore,[2,3] cervical range of motion device,[4] Aimark perimeter[3] and the Goldmann perimeter.[5–9]

A wide variety of mechanical, neurogenic and myogenic disorders affect ocular motility. Thyroid-associated ophthalmopathy, orbital trauma, myasthenia gravis, chronic progressive external ophthalmoplegia, nerve palsies and iatrogenic disorders caused by strabismus or retinal detachment may benefit from repeated UFOF assessment. It is, however, essential that the technique employed is accurate and repeatable to establish whether there is stability or any improvement or deterioration in a patient's condition.

Haggerty *et al.*[7] proposed a technique examining six axes corresponding to the primary field of action of each extraocular muscle (EOM) using the Goldmann perimeter. The choice of fixation target was based on the visual threshold of the individual. The smallest target discernible on the fovea, starting with target size 0Ie, was chosen. Loss of central fixation was determined subjectively by asking the participant to report when this occurred, and confirmed by the examiner objectively. Good repeatability to within 4° was shown in healthy individuals when examined by the same observer, and inter-observer repeatability to within 7.9°. Greater variability was noted in patients with Graves' ophthalmopathy, and Haggerty *et al.* advocated that clinically only a change of 8° or more should be considered significant. They also recommended the same examiner assess the patient on consecutive visits to minimise variability.

The advantage of using the Haggerty technique is that it can be performed relatively quickly and thus minimise

Table 1. Mean excursion of individual extraocular muscles and mean total extraocular muscle (EOM) excursion

Method	Mean excursion of muscle ± SD (°)						Mean total EOM excursion ± SD (°)
	LR	SR	IO	MR	SO	IR	
Objective 1Ie	49.7 ± 4.7	35.4 ± 5.7	45.8 ± 6.3	53.9 ± 5.4	53.9 ± 4.3	49.6 ± 6.5	288.2 ± 20.0
Objective 1IIe	49.1 ± 5.7	35.2 ± 4.3	45.9 ± 7.5	53.7 ± 6.1	53.7 ± 5.8	50.9 ± 7.5	288.5 ± 21.8
Subjective 1Ie	47.5 ± 4.8	33.0 ± 4.2	41.5 ± 6.6	51.0 ± 7.0	54.7 ± 7.6	63.0 ± 9.8	290.7 ± 22.2
Subjective 1IIe	49.5 ± 7.2	33.5 ± 4.7	43.4 ± 6.4	51.5 ± 6.1	54.7 ± 5.9	66.7 ± 10.0	299.4 ± 24.3

LR, lateral rectus; SR, superior rectus; IO, inferior oblique; MR, medial rectus; SO, superior oblique; IR, inferior rectus.

patient discomfort. It is standardised, reliable, and allows for interpretation of restriction of each EOM[7,8]. Rowe and Hanif[9] described how this technique has become widely used in many orthoptic clinics in the UK.

Using the Goldmann perimeter EOM excursion can be assessed purely objectively or subjectively, or subjectively with the observer verifying the loss of central fixation. Whilst objective methods have been described as accurate and repeatable,[6] others suggest that subjective methods are more accurate in reliable individuals.[7] Comparative evidence of subjective and objective assessment is lacking.

The choice of fixation target when plotting the UFOF varies between studies. Haggerty *et al.*[7] chose the smallest target visible for an individual. Other studies[5,6] have used standard-sized targets such as 4Ie and 4IIIe. To our knowledge, there is no published literature comparing the effect of target size upon the UFOF.

The purpose of this study was to establish the effect of subjective and objective assessment and target size upon the overall size of the UFOF and the individual EOM excursions using the Haggerty technique in healthy individuals.

Methods

This was a prospective repeated measures study undertaken at the University of Sheffield with University departmental ethics approval.

Participants

Volunteers were recruited from the student population of the University of Sheffield. All participants received verbal and written explanation of the experimental procedures and written consent was obtained. Testing was performed on the right eye only, with the left eye occluded. Inclusion criteria were a visual acuity of 0.10 logMAR or better in the right eye, no manifest strabismus, full ocular motility, and no ocular pathology.

Procedures

The subjective and objective UFOF using two fixation targets (1Ie and 1IIe) were plotted for the right eye by one examiner using the Haggerty technique[7] on the Goldmann perimeter in a darkened room. Six axes corresponding to the primary field of action of each EOM for the right eye were used: lateral rectus 0°, superior rectus 67°, inferior oblique 141°, medial rectus 180°, superior oblique 216° and inferior rectus 293°. Head movement was limited by using a chin rest and head strap. Order effect was minimised by randomisation. Two minutes' rest was given between each UFOF measurement to reduce the effects of fatigue. When assessing the range of uniocular excursions subjectively, the participant followed the target from the centre outwards along each of the six axes in a random order. Each endpoint was established using an audible signal from the participant when they felt central fixation was lost. For the objective assessment, the examiner determined the endpoint of central fixation via the central telescope. Two subjective and two objective UFOFs were performed using the 1Ie and 1IIe targets.

Analysis

Two-factor ANOVA was carried out to compare the effect of subjective and objective assessment and different target sizes upon the mean total EOM excursion. A paired Student's *t*-test was performed to compare the effect of subjective and objective assessment and target size upon a single EOM excursion, and combined excursion of antagonist muscle pairs. Sidak's adjustment was applied to avoid type 1 errors, which set the significance level at $p < 0.008$. Agreement between the testing methods was analysed using Bland-Altman analysis.[10]

Results

Twenty-four participants (22 females, 2 males) with a mean age of 20.3 ± 1.6 years were included. Mean visual acuity was −0.03 ± 0.1 logMAR in the right eye. Seventeen subjects were emmetropic and 7 wore a contact lens in the right eye. Participant 17 produced anomalous data and was excluded from the analysis.

The mean total EOM excursions performed objectively using targets 1Ie and 1IIe were 288.2 ± 20.0° and 288.5 ± 21.8°, and subjectively were 290.7 ± 22.2° and 299.4 ± 24.3°, respectively (Table 1). The mean total excursion comparing objective and subjective assessment was not affected by target size 1Ie ($p = 0.61$) or 1IIe ($p = 0.06$). Increasing target size had no effect upon mean total excursion assessed objectively ($p = 0.93$) but enlarged it significantly when assessed subjectively ($p = 0.008$).

The individual mean EOM excursions assessed objectively and subjectively using target 1Ie and 1IIe are shown in Table 1. The mean excursions for the lateral rectus were similar using all four assessment methods. The mean excursions for the superior rectus and medial rectus were slightly greater when performed objectively than subjectively using either target, but the difference did not reach statistical significance. The inferior oblique also displayed a greater degree of excursion when assessed objectively than subjectively, but this difference was only significant when using target

Table 2. Combined excursion of antagonist muscle pairs

Method	Target	LR/MR	SR/SO	IR/IO
		Mean ± SD (°)	Mean ± SD (°)	Mean ± SD (°)
Objective	1Ie	103.6 ± 8.0	89.2 ± 6.9	95.4 ± 9.0
	1IIe	102.8 ± 9.2	88.8 ± 6.5	96.8 ± 11.0
Subjective	1Ie	98.6 ± 9.4	87.6 ± 8.4	104.5 ± 10.2
	1IIe	101.0 ± 10.4	88.3 ± 7.3	110.1 ± 10.6

LR, lateral rectus; SR, superior rectus; IO, inferior oblique; MR, medial rectus; SO, superior oblique; IR, inferior rectus.

1Ie ($p < 0.0001$). The opposite was the case for the superior oblique and inferior rectus excursions, which showed a greater degree of excursion assessed subjectively. These differences were only found to be significant for the inferior rectus, which showed a greater degree of excursion when assessed subjectively than objectively with both targets ($p < 0.0001$). Increasing target size did not significantly affect the degree of excursion for the individual muscles except for the inferior oblique when assessed subjectively ($p = 0.007$).

Inadvertent head movements can alter the excursion achieved for the individual muscle.[6] For example, a minor head adjustment to the left will serve to favour the excursion of the medial rectus whilst putting excursion of the lateral rectus at a disadvantage. This effect is eliminated when combining the antagonist muscle pair.[7] Table 2 illustrates the combined excursion of antagonist muscle pairs. Only small differences were found between objective and subjective assessment for combined lateral and medial recti excursions and combined superior rectus and superior oblique excursions, which did not reach statistical significance. However, a significant difference between objective and subjective assessment was observed for combined inferior rectus and inferior oblique excursions for both target 1Ie ($p = 0.001$) and target 1IIe ($p = 0.0004$).

Agreement between objective and subjective assessment and increasing the target size was examined employing Bland-Altman analysis. The mean difference, or bias, and standard deviation of the difference, comparing subjective against objective methods and increasing target size, are shown in Tables 3 and 4 respectively. Using target 1Ie, the mean bias between subjective and objective assessment was within 4.3° for all EOM excursions except the inferior rectus, for which the mean bias was 13.4°. A similar pattern was found when increasing the target size to 1IIe: the mean bias was within 2.5° for all EOM excursions except the inferior rectus, for which the mean bias was 15.8°. The largest standard deviation of the difference was noted for inferior rectus excursion, measuring 11.2° and 10.3° using targets 1IIe and 1Ie, respectively; followed by the lateral rectus, measuring 7.0° using target 1IIe; and 6.7° for the superior oblique using target 1Ie. The smallest standard deviation of the difference was found for the inferior oblique, measuring 4.3°, and the medial rectus, measuring 3.9°, fixating target 1Ie and 1IIe, respectively. Bland-Altman plots of the two EOMs with the largest and smallest standard deviation of the difference fixating target 1Ie are shown in Figs. 1 and 2, respectively. Variation can be seen for both the inferior rectus and inferior oblique excursions but the 95% limit of agreement is strikingly greater for the inferior rectus compared with the inferior oblique.

When the target size was increased the mean bias was less than 1.5° assessed objectively but increased to within 4° when relying on subjective responses. The greatest standard deviation of the difference was observed for superior oblique excursion assessed objectively, which measured 7.1°, and for lateral rectus assessed subjectively, which measured 7.0°. The smallest was found for superior rectus and inferior oblique, which both measured 3.2° assessed subjectively. When assessed objectively, the superior rectus again showed the smallest difference of 4.1°.

Figs. 3 and 4 are Bland-Altman plots of the superior oblique and the superior rectus excursions. These muscles showed the largest and smallest standard deviation of the difference, respectively, when assessed objectively.

Discussion

The mean total EOM excursion performing the Haggerty method using the Goldmann perimeter in young healthy adults was slightly less when assessed objectively

Table 3. Agreement between subjective and objective assessment with target sizes 1Ie and 1IIe using Bland-Altman analysis

Target size	LR		SR		IO		MR		SO		IR	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1Ie	−2.2	5.2	−2.5	4.7	−4.3	4.3	−2.9	6.2	0.9	6.7	13.4	10.3
1IIe	0.4	7.0	−1.6	4.8	−2.5	5.9	−2.2	3.9	1.1	5.4	15.8	11.2

Mean difference (bias) and standard deviation of the difference (SD) are displayed in degrees.
LR, lateral rectus; SR, superior rectus; IO, inferior oblique; MR, medial rectus; SO, superior oblique; IR, inferior rectus.

Table 4. Agreement between using target sizes 1Ie and 1IIe for subjective and objective assessment using Bland-Altman analysis

Method	LR		SR		IO		MR		SO		IR	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Subjective	2.0	7.0	0.6	3.1	1.9	3.1	0.5	4.4	0.04	4.6	3.7	6.9
Objective	−0.7	5.0	−0.1	4.1	0.2	4.6	−0.3	5.6	0.1	7.1	1.4	5.0

Mean difference (bias) and standard deviation of the difference (SD) are displayed in degrees.
LR, lateral rectus; SR, superior rectus; IO, inferior oblique; MR, medial rectus; SO, superior oblique; IR, inferior rectus.

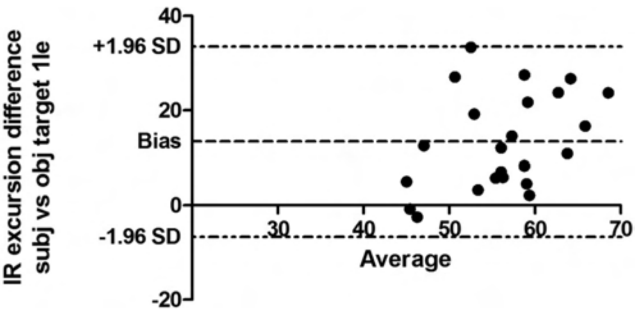

Fig. 1. Bland-Altman plot of the inferior rectus (IR) excursion comparing subjective against objective assessment using target size 1Ie.

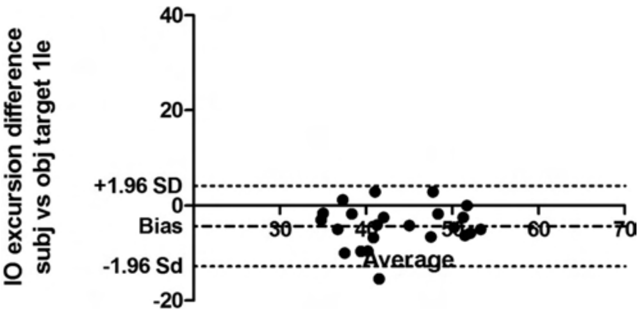

Fig. 2. Bland-Altman plot of the inferior oblique (IO) excursion comparing subjective against objective assessment using target size 1Ie.

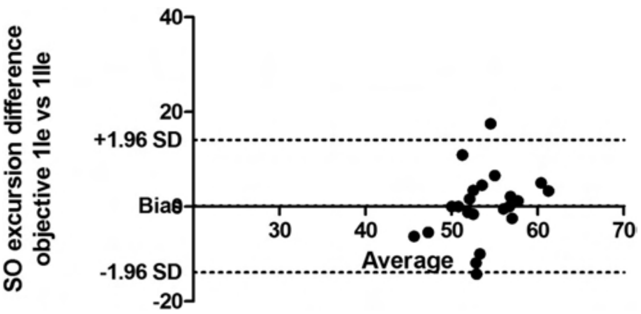

Fig. 3. Bland-Altman plot of the superior oblique (SO) excursion assessed objectively using target size 1Ie and 1IIe.

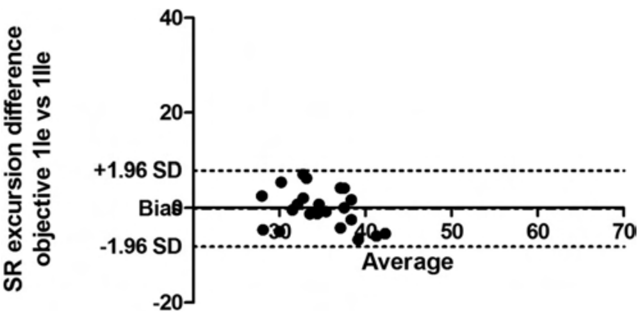

Fig. 4. Bland-Altman plot of the superior rectus (SR) excursion assessed objectively using target size 1Ie and 1IIe.

Table 5. Comparison of mean data of the individual muscle excursion and the mean total extraocular muscle (EOM) excursion from this and previous studies

	Mean excursion of muscle (°)						Mean total EOM excursion (°)
	LR	SR	IO	MR	SO	IR	
This study ($n = 23$) Age 18–26 years, mean 20 years							
Objective 1Ie	50	35	46	54	54	50	288
Objective 1IIe	49	35	46	54	54	51	289
Subjective 1Ie	48	33	42	51	55	63	291
Subjective 1IIe	50	34	43	52	55	67	299
Haggerty *et al.*[7] ($n = 13$) Age 20–29 years	53	45	47	51	47	61	303
Richardson *et al.*[8] ($n = 35$) Age 21–59 years, median 38 years	53	43	46	51	49	62	–
Rowe and Hanif[9] ($n = 20$) Mean 37 years	52	43	44	49	50	61	–

LR, lateral rectus; SR, superior rectus; IO, inferior oblique; MR, medial rectus; SO, superior oblique; IR, inferior rectus.

compared with subjectively, but this difference was not statistically significant. The scores obtained for subjective responses were in close agreement to Haggerty *et al.*'s[7] findings. Their measurements relied on subjective responses which were verified objectively by the examiner. The objective estimate was recorded only if subjective responses were deemed unreliable, but they reported all excursions recorded were subjective responses.

Increasing the target size did significantly influence the mean total EOM excursion assessed subjectively but not objectively. To our knowledge, no previous studies have examined the impact of changing target size. It is evident from our study that if the UFOF is assessed relying on subjective responses then care must be taken to standardise the choice of target when repeat testing is performed, to establish true improvement or deterioration of a patient's disease.

The degree of excursion for individual EOMs was dependent upon the method of assessment and target size. In general, the mean degree of excursion of an individual EOM was greater when measured objectively compared with subjectively, except for the superior oblique and inferior rectus muscles where the opposite was the case. This difference was particularly noticeable for the inferior rectus muscle. The individual EOM excursions compare well with those previously reported for healthy individuals[7–9] (Table 5), although the inferior rectus excursion measured objectively in this study is less than in previous studies whilst the subjective assessments are very similar. The earlier studies[7–9] relied on subjective responses. The lesser degree of inferior rectus excursion estimated objectively may be explained by the upper lid obscuring the endpoint on downgaze, which leads the examiner to underestimate the full extent of the excursion. This difference was not found for the superior oblique, which may be due to the participant's nose limiting the degree of excursion before the upper lid impeded the examiner's view. Taping up the lid may improve the examiner's view. When choosing the technique to measure the UFOF, the examiner must be aware of the risk of underestimating the inferior rectus excursion if this is assessed objectively. Some ocular diseases commonly have inferior rectus involvement, such as thyroid-associated ophthalmopathy and blow-out fracture of the inferior wall. In these patients subjective assessment or a combination of objective and subjective assessment should be considered.

Using the smaller fixation target 1Ie a significant difference was elicited between the subjective and objective assessment for the inferior oblique excursion, the objective measurement being larger than the subjective. There is a possibility that the examiner consistently overestimated the excursion. Testing by different examiners, taking inter-examiner variability into account, would clarify this finding.

In this study the mean excursions of the superior rectus muscle using different methods of assessment and target size were similar, and ranged between 33° and 35°. Other studies found greater degrees of excursion ranging between 43° and 45° (Table 5). Unintentional small head movements during testing can change the excursion obtained for the individual muscle and disadvantage one muscle whilst favouring the excursion of the antagonist muscle.[6,7] This effect can be eradicated by combining the antagonist muscle pair.[7] It may be that the lesser excursion of the superior rectus is due to positioning of the head on the forehead and chin rests in such a way as to favour the excursion of the superior oblique whilst putting the superior rectus at a disadvantage. This suggestion is supported by the mean combined superior rectus/superior oblique data obtained by Rowe and Hanif.[9] The mean combined lateral rectus/medial rectus excursion in our study was in good agreement with previous studies performed subjectively[9] and objectively.[6] The mean combined inferior rectus/inferior oblique excursion was significantly smaller when assessed objectively compared with subjectively in this study. The degree of excursions measured subjectively was in good agreement with a previous study.[9] The effect of changing head position does not account for the discrepancy between the inferior rectus and inferior oblique observed when measured objectively and subjectively.

This study only included a young adult population, whereas other studies have included adults with a greater range of ages.[3,7,8] The effect of age upon the degree of EOM excursions is controversial. A decrease with increasing age has been reported,[6,11,12] while another study was unable to confirm an age-related decline although a trend towards superior rectus reduction was observed.[7] Further studies with larger sample sizes are required to establish whether age affects the degree of excursion.

Considering the agreement between subjective and objective assessment methods using both target sizes, the mean difference (bias) was less than 4.5° for all the EOMs except the inferior rectus, for which the bias was 13.4° and 15.8° using target sizes 1Ie and 1IIe, respectively. The standard deviation of the difference ranged between 3.9° and 11.2° with the majority being greater than 5.0°. Substantial variation in the degree of excursion was observed for the individual muscles but to a much larger extent for the inferior rectus, as is shown in Fig. 1. Haggerty *et al.*[7] examined the repeatability of the individual EOM excursions performed by two different examiners. They calculated the coefficient of repeatability (variability) as 2× standard deviation of the difference to establish the degree of variability which should be expected clinically. Based on their findings, they proposed that only a change of 8° or greater could be deemed clinically significant. Employing the same formula for this study, comparing subjective and objective assessment methods resulted in a change of at least 22° being required to represent a significant change, due to the large standard deviation of the inferior rectus excursion. Better agreement was found when the size of the fixation target was increased from 1Ie to 1IIe, performing the same assessment method. In this case the ranges of the standard deviation of the difference were much narrower, at between 3.1° and 7.1°. However, a greater than 14° change would still be required to represent a significant change. These findings reveal the variation which can be obtained if different fixation targets and assessment methods are employed, and highlight the importance of standardised assessment techniques on repeated testing of a patient.

This study has found a high degree of variation in the amount of individual EOM excursion in healthy individuals. In general, the measure of the UFOF is performed to investigate any deterioration or change on repeated visits. This study is limited in the fact it did not investigate the reproducibility of the assessment methods. Previous literature[5,7] reported good reproducibility relying on subjective responses which were verified by the examiner. Gerling *et al.*[6] stated objective assessment to be highly reproducible but they only measured horizontal ductions and direct elevation and depression. Interestingly, independent of the assessment technique all the above-described studies[5–7] noted that the coefficient of repeatability was larger in patients with restricted ocular motility compared with healthy individuals. Further studies comparing reproducibility of subjective and objective assessment would be of value to decide the most appropriate technique.

A limitation of this study was that gender was not controlled, so there was an unequal number of males and females, although the data collected showed no difference between the sexes. Data was confined to a group of young adults and the findings may have been different in older age groups.

Orthoptic clinics that use the Goldmann perimeter to quantitatively measure the UFOF are faced with the problem that this instrument is no longer manufactured. This is also the case for the Aimark perimeter. In recent years, the semi-automated Octopus perimeter has been developed and advocated as a direct replacement of the Goldmann perimeter.[13] One study[9] has compared the degree of EOM excursions achieved using the manual Goldmann and semi-automated Octopus perimeters. Differences for individual EOM excursions were found between the two perimeters but were within 5° if the speed of the fixation target chosen for the Octopus was 10°/second. The difference increased to 10° with slower speed of the fixation target at 3°/second. The authors concluded that the speed of the fixation target influenced the comparability of the two instruments. Reaction times decrease with age.[14] The reaction time of the participants and speed of fixation target may have influenced the agreement between the Goldmann and Octopus perimeters.

Conclusion

In summary, this study found that the mean total EOM excursion was not affected by whether assessment was objective or subjective, but subjective assessment was influenced by the size of the fixation target. The degree of excursion of an individual EOM was influenced by whether it had been assessed objectively or subjectively, and to a lesser extent the size of fixation target chosen. Objective assessment resulted in a slightly greater degree of excursion for most of the muscles except the inferior rectus. Involuntary lowering of the upper lid on downgaze may impede the examiner's view and cause underestimation of the degree of excursion. Therefore it is recommended that examiners rely on subjective responses when testing inferior rectus excursion. Large variation was found between objective and subjective assessments. The variation was less for both subjective and objective assessments when the target size was increased. It can be concluded that when monitoring a patient it is important to record and standardise whether the UFOF is performed objectively or subjectively, and also the choice of target size, to avoid misinterpretation of differences which are due to methodology.

Competing interests: The authors declare they have no competing interests.

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