THE COVER TEST
is there anything more to learn ?

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Introduction

The cover test is probably the most widely used test of ocular motor balance enabling the practitioner to determine the presence and measure the amplitude of heterophoria and strabismus. The cover test requires only an occluder and a trained observer/practitioner. It enables the practitioner to make a rapid assessment of the ocular motor balance with patients fixating at different distances and in different directions of gaze. Apart from the patient being required to maintain fixation on a target, there is usually no other subjective input by the patient. In this respect the cover test may be described as objective although it is the practitioner's subjective observations that are recorded.

The "cover test" and the "alternate cover test"

There is some anecdotal confusion amongst clinicians as to exactly what is meant by the term "cover test." There is a tendency in ophthalmology to equate "cover test" with what might be more fully described as the *alternate cover test* whereas in optometry the term is often used to mean the *cover-uncover test* or *unilateral intermittent occlusion.* For the purposes of this discussion, whenever the term "cover test" is employed, it is used to describe the *cover-uncover test.*

The cover test is the most commonly performed and most important test relating to binocular vision and enables the clinician to detect the presence of heterophoria or hetereotropia and to measure the size of the deviation (Barnard & Thomson, 1995a; Franklin, 1997). An investigation of eye movement characteristics during the cover test forms a large component of this thesis.

The alternate cover test is usually used to assess phoria amplitude. The patient fixates a target at the required distance and an occluder is placed before one eye for a short period of time and then rapidly moved in front of the fellow eye without giving any time for binocular vision to occur. As the cover is removed from the eye, any movement is noted. This process is repeated until the practitioner is satisfied with the observation. Evans (1997) described the *alternate cover test* as a transfer of the cover from one eye to the other and back several times. von Noorden (1990) described it as a test used in conjunction with prisms to neutralise the movement observed during this alternating covering procedure. This technique reportedly produces a larger amplitude of phoria as compared to the *cover-uncover test.* Cooper (1992) and Evans (1997) also suggested that the degree of deviation usually increases during the alternate cover test allowing 'the full extent of the deviation to be seen'.

Cooper (1992) discussed the clinical implications of vergence adaptation in terms of the cover test and observed that with repeated alternate occlusion, the angle of deviation often increases and that the increase in the angular measurement is dependant on:

(1) the size of the initial deviation,
(2) the duration of the occlusion, and
(3) the strength of vergence adaptation.

Earlier researchers have distinguished between fast and slow fusional vergences by the time course for ‘relaxation’ of convergence following occlusion of one eye. Ludvigh et al (1964) found that when convergence is stimulated for a short period of time (5 sec) fast fusional vergence relaxes within 10-15 seconds after one eye is occluded. The time course of relaxation has been described as a "decaying exponential " (Krishnan & Stark, 1977; Toates, 1974).

Cooper (1992) proposed that the increase in the angle during alternate occlusion is due to the rapid decay of fast fusional vergence by occlusion followed by a longer delay of slow fusional response. Stated another way, a measurement which increases with repeated alternate occlusion represents an initial elimination of fast fusional vergence followed by a subsequent elimination of slow fusional vergence. Conversely, removal of an occluder during a unilateral cover test permits fusion to reoccur. This results in stimulation of the fast fusional vergence system that feeds into the slow fusional vergence system. Repeated occlusion with unilateral cover testing results in the elimination of fast fusional vergence signals with minimal effect on slow fusional vergence signals because slow fusional vergence has a long time constant. Therefore, the deviation measured with the alternate cover test is usually larger than the amount measured with a unilateral cover test. The former is the result of the sum of the fast and slow fusional vergence system whereas the latter is a measure of the fast fusion system.

The cover test – a review of the literature

Method

The patient is asked to fixate a target at a known distance. The cover is introduced before one eye and the other eye is observed to detect any movement suggesting the presence of a heterotropia. In the presence of heterophoria, the occluded eye will deviate to what is assumed to be a “physiological position of rest”. The occluded eye is then uncovered whilst the practitioner checks for any heterophoric recovery movement in that eye. The direction of the recovery movement determines whether the phoria is an esophoria, exophoria or hyperphoria. With practise, an observer can estimate the amplitude of the phoria and will make subjective judgements concerning the speed and quality of the recovery movement or movements. Alternatively the movement can be neutralised with prisms in order to assess the amplitude (Franklin, 1997) but this requires repetitive occlusion and there is the possibility of introducing prism adaptation artefacts. The procedure is then repeated for the other eye. The measure of amplitude is generally assumed to be the same for each eye.

Evans (1997) suggested that when undertaking the cover-uncover test it is useful to hold the occluder a few centimetres from the eye so that the observer can ‘peep’ round the edge and see the covered eye. However, Evans also acknowledged the importance of occluding "most of the visual field". Stidwill (1990) also suggested observing the eye under the cover by placing oneself in the monocular temporal field of the covered eye and stresses that patients must not be allowed to use their binocular field during the cover period. However it should be noted that even very brief periods of peripheral stimulation of the binocular visual field can instigate a fast fusional response which will prevent the complete decay of slow fusional vergence (McCormack et al, 1991; McCormack & Fisher, 1996; Larson, 1992). Cridland (1964) observed that, during the uncovering period of the cover test, the occluded eye often moves to take up fixation long before the image of the fixation object can have fallen upon its retina. This was particularly apparent when the dominant eye was being uncovered. Cridland postulated that binocular cues gained from peripheral visual field may be sufficient to initiate the recovery movement.

There have been suggestions that the nature of recovery eye movements following the cover test may depend upon factors such as the size of the heterophoria, eye dominance, visual acuities and the presence of suppression (Pickwell, 1973). Stidwill (1990) stated that a rapid recovery movement indicates a compensated heterophoria. Lyle & Wybar (1967) observed that recovery may be rapid when the occluder is removed from one eye and slow when removed from the other eye. However, these suggestions are mostly anecdotal or observational in nature.

Eye movements during the cover test

Both latency (reaction time) and velocities of version and vergence eye movements have been studied extensively (Westheimer 1954; Rashbass & Westheimer 1961; Krishnan et al,1973Bahill et al,1975a; Bahill et al, 1975b; Bahill & Stark 1979; Enright, 1984; Semmlow et al, 1986; Erkelens, 1987; Erkelens et al, 1989a; Erkelens et al, 1989b; Semmlow et al, 1993; Hung et al, 1994; Tam & Ono,1994; Collewijn, et al 1995). One aim of this present study was to quantitatively measure both latencies and time for recovery following the cover test to investigate some of the anecdotal claims mentioned above.

It is often assumed that the eye that is not occluded retains fixation during the cover-uncover procedure, i.e. there is an asymmetric vergence or version movement. However, it has been noted that the “fixing” eye often moves, particularly during the recovery phase, that the amplitude of this movement is usually about half that of the movement of the eye being uncovered and is greater when the dominant eye is covered (Pickwell, 1973). Peli & McCormack

(1983) noted similar movements of the “fixing” eye and observed significant differences in the responses of the two eyes, especially for subjects with clear ocular dominancy. The movement made by the fixing eye has been named an “irrelevant” or “flick” movement (Pickwell, 1972).

Anecdotal observations have also suggested an association between a blink and a refusion movement of the deviating eye in intermittent exotropia (Stella, 1968). This is also noted during the cover test procedure when, on removing the cover, there is no immediate recovery response but a subsequent blink appears to precipitate a recovery movement. Stella (1968) reported this association to be purposeful initiation of a fusion movement.

More recently it has been suggested that the amplitude of phoria may not be an important clinical measure in terms of symptoms (Jenkins et al, 1989). Nevertheless, the relationship between speed of recovery and compensation of a phoria will also be investigated. If there is a relationship as described by Stidwill (1990) then one might expect changes in the time for recovery to be observed when an associated phoria is alleviated by treatment.

Optimum duration for occlusion

Another question to be addressed relates to the length of time that an eye should be occluded during the cover test. It would be useful for the practitioner to know what the optimum period of occlusion should be and to have some further understanding as to what type of fusion is being investigated by the relatively short-term dissociation provided by the clinical cover test.

‘Conventional wisdom’ suggests that each eye should be covered in turn for a brief period and then uncovered. The suggested duration of the occlusion has been variously described as brief (von Noorden, 1990), about one second (Stidwill, 1990) and one or two seconds (Evans, 1997). Evans (1997) stated “this enables the response to momentary dissociation to be observed and that the effect of longer dissociation can be observed by employing the *alternate cover test’.*

Lyle & Wybar (1967) suggest covering one eye and then making the fellow eye follow the test target, which is moved from side to side and then up and down, finally returning to the “centre” before removing the occluder. This perhaps suggests a recommended occlusion period of longer than one or two seconds.

Perhaps the most intriguing reference, appertaining to the length of time that the occluder should be applied is that of Earnest Clarke who, in his book *Eyestrain*, published in 1893 stated,

> “ *if a person with normal vision be directed to look at an object in the distance, and one eye be covered for twenty or thirty seconds, if there is any latent deviation it becomes (as a rule) manifest, and on removal of the*

> *hand there will be diplopia for a brief space of time, and the covered eye will have to move, in order to fuse the two images - in, if there was latent divergence, and out, if convergence."*

Percival (1928) suggested an even longer period of occlusion, recommending holding a card over the eye "for at least a minute".

As will be seen in due course, Clarke's twenty seconds or even Percival's minute, is likely to provide a more 'useful' result than the 1 - 2 seconds that is recommended by clinicians of more modern times.

Calvin et al (1996) described a study in which the cover test was compared to the von Graefe test. The duration of occlusion used in the cover-uncover test was "about 1 second". Other descriptions of the cover test technique (Hugonnier & Clayette-Hugonnier, 1969; Pigassou-Albouy & Jones, 1978; Mallett, 1988) make no mention of the time period of occlusion.

Rosenfield et al (1997), using a dissociation test combined with subjective responses, suggested that a more accurate assessment of phoria amplitude may be obtained by maintaining dissociation for 25 minutes. If this is the case, then the normal practise of occluding for about 2 seconds during the conventional cover test may be providing the practitioner with an underestimation of the 'true' amplitude of phoria. This has been alluded to already by Barnard & Thomson (1995a).

Effect of target characteristics

The type of fixation target used during the cover test varies from practitioner to practitioner. It is important that the patient fixates and accommodates as accurately as possible throughout. Even when fixating, the eyes are not completely stationary. The effect of target contrast on these involuntary eye movements occurring during fixation has been investigated (Caifa & Hebbard, 1967). Using a target subtending 11.45' visual angle, they reported that as the contrast of the fixation target was decreased below 50 per cent there was an increase in the standard deviation of the eye position during fixation and a highly significant increase in the mean amplitudes of the involuntary saccades. For target contrasts between 50 and 100 per cent, the mean amplitude of the saccades and mean standard deviation of eye position did not change with contrast. It is therefore advisable for the clinician to use a high contrast target as a fixation target.

A high contrast letter at the end of the line seen by the eye with the poorest vision or visual acuity on the Snellen chart is often used for fixation during the distance cover test. If the acuity of the poorest eye is below 6/18 a spotlight may be used but whenever possible a target stimulating accommodation is preferable (Franklin, 1997). For the near cover test, the target is usually a fine high contrast letter on a hand held near chart. A penlight should never be used as a fixation object (von Noorden, 1990) as this is an inadequate stimulus for accommodation. For both distance and near the surround and target will provide a stimulus for binocular lock when the eyes are uncovered.

For younger children, Hugonnier & Clayette Hugonnier (1969) suggest that the target should be a luminous spot. It may be argued however that this is not as good a stimulus to accommodation as a fine letter target. Other targets may be used for children and it is with some incredulity that this author noted that Pigassou-Albouy and Jones (1978) described a fixation target in the form of a doll smoking a
cigarette !

Accuracy

Ludvigh (1949) and Romano & von Noorden (1971) studied the minimum amplitude of eye movement that could be detected objectively. Ludvigh's subjects were experienced observers and he found that under optimal conditions of illumination and with co-operative patients, the smallest observable change in eye position is approximately 2^{Δ}. Romano & Von Noorden (1971) found similar results.

An Investigation of Eye Movement Characteristics during the Cover Test

Equipment

Eye movements were recorded during a distance (340 cm) and near (40 cm) cover test. High contrast black targets (+ 0 +) were used to provide both a fixation target (0) and paracentral "binocular lock". Each symbol subtended 0.3 degrees and were separated by 0.6 degrees. The distant target was mounted on uniform white background subtending visual angle 40 x 40 degrees and there was an average luminance 65 cdm^{-2}. The near target was identical but displayed on a high resolution monitor.

Binocular eye movements recorded using an infra-red limbal-tracking system interfaced to a PC (Dell 486P/50).

Eye movement signals digitised using a 10 bit A/D converter sampling at 200 Hz Calibration via recessed LEDs for distance and small crosses displayed on screen for near produced a linear response up to approximately +/- 10 degrees.

Eye position during subsequent recording was ascertained by means of linear interpolation between calibration points. Resolution of the system was approximately 0.1 degrees and with the use of dental bite to restrain head movements the accuracy was of the order 0.2 degrees (= 12 minutes of arc or approximately 0.4 prism dioptres).

Polystyrene covers were driven by two independent stepper motors modified to rotate at 1500 degrees per second. The time to obtain complete occlusion = 34 ms.

The system was controlled by two networked computers. Computer 1 was used to acquire eye movement data and computer 2 to control stepper motors, calibration LEDs and the display screen for near fixation target.

Method

A dental bite was made for each subject to eliminate head movements Calibration of eye movement recorder was carried out for both distance and near cover test routines. Subjects were asked to fixate the target while eye movements were recorded for 34 seconds:

- 4 seconds binocular fixation (BF)
- 10 seconds RE occluded
- 6 seconds BF
- 10 seconds LE occlusion
- 4 seconds BF

Data were stored on computer disc for analysis and a Windows-based program was used to display and analyser data.

Subjects

100 “normal” subjects meeting the following criteria were examined:

- emmetropic
- no symptoms
- no history of BV anomalies or ocular disease
- aged 16 to 35 year

A further 30 patients referred because of symptoms attributed to heterophoria/convergence anomalies were examined.

Eye movement characteristics during the cover test

Parameters analysed

- The maximum phoria amplitude reached during the 10 seconds of occlusion
- The amplitude of phoria after 2 seconds occlusion
- The amplitude of phoria after 10 seconds of occlusion
- The time at which the maximum phoria amplitude was reached

- The time at which the amplitude measured at 10 seconds was reached
- The latency, following uncovering the eye, from when the occluder theoretically passed across the visual axis, to the commencement of a recovery movement (latency for recovery)
- The time taken for recovery of the occluded eye
- The number and type of eye movements during the recovery process
- The size of each of these recovery movements

The data was recorded in Microsoft Excel for analysis using Excel and Unistat software.

A summary of some of the results

A larger number of conclusions were made from this study. A small number are discussed below.

Relationship between right and left eye phoria amplitudes

- There was a strong correlation between each eye whether measured at 2 seconds, 10 seconds or as the maximum phoria during 10 seconds of occlusion for both distance and near cover test.

What happens to the eye under the cover*…*

…does it vary between subjects ?

- The eye movement profiles under the cover are varied. In some subjects the eye moves rapidly to a position of rest and the amplitude remain stable until the cover was removed at 10 seconds. In other cases the eye would gradually drift with the amplitude increasing at a slower rate.

… and how about the right and left eye of each subject… ?

- … there was no linear relationship between the right and left eyes of subjects for the time taken to reach the phoria amplitude measured at 10 seconds for both distance (R^2 = 6%; n = 78 subjects) and near (R^2 = 6%; n = 82 subjects)

***How long should a practitioner occlude an eye during the cover test* ?**

Is one or two seconds long enough ? A univariate analysis of variance for repeated measures of amplitude of phoria at 2 and 10 seconds show a significant statistical difference ($p < 0.001$) between the phoria amplitude at 2 and 10 seconds for individuals for both the distance and near cover test.

How long does it take an eye to reach the 10 s position?

There was no significant difference between groups for distance and near and between “normals” and “referred subjects”

Mean times for each group were

Normals distance	= 4.36 s (SD = 3.27 s)
Normals near	= 4.96 s (SD = 3.48 s)
Referred distance	= 4.27 s (SD = 3.39 s)
Referred near	= 4.50 s (SD = 3.07 s)

What about recovery eye movements ?

There are two main phases during recovery following the cover test:

1. Latency period before eyes commence recovery movement(s)
2. Followed by recovery movement(s) which may be saccades and/ or vergence movements

Saccade or vergence ?

63.8% of all esophoric eyes (distance or near) commenced recovery with a saccade whereas 63.7% of all exophoric eyes (distance or near) commenced with a vergence movement. There was a significant difference between exophores and esophores (Chi squared $p = 0.006$).

Latency

Of the 400 possible measurements, 187 latencies were obtained from the recordings (72 for distance & 115 for near). The mean latency = 0.29 s (SD 0.58 s) with an *apparent* minimum = 0.07 s and a maximum = 6.78 s. There was no significant difference between distance and near ($p = 0.58$).

Esophoric versus exophoric latency

For distance there was a significant difference between latencies in the esophoric and exophoric groups ($p = 0.04$). For near there was no significant difference ($p = 0.55$) .This should be viewed with caution because of the small number of near esophores.

How many eye movements for recovery ?

For the normal group distance cover test the median number of movements was 2 (range = 1 to 5; mean = 1.7;SD = 0.8). For near it was also 2 (range =1 to 8; mean of 2.8; SD = 1.0).

There was however, a significant statistical difference between exophores and esophores for the number of eye movements to achieve recovery following near cover test (Mann-Whitney $p = 0.001$; 95% confidence interval = 0.00 to 1.00)

Recovery characteristics of near exophores

For the normal group, the mean number of eye movements to recovery = 2.9 (SD = 1.1). For the group referred to study because of symptoms associated with BV anomalies, the average number of eye movements to recovery = 3.9 (SD = 1.7). There was a significant difference between the two groups ($p = 0.001$).

Recovery time

For near exophores, the mean recovery time for exophores was 0.76 s (SD = 0.15 s) compared to the mean of 1.12 s (SD = .10 s) for the referred group ($p = 0.024$.

Does recovery time relate to associated phoria ?

Subjects from "normal group" and "referred group" sorted into two categories
(a) with no associated phoria
(b) with associated phoria (eso/or exo) in one or both eyes

The mean recovery times for subjects with no associated phoria was 0.87 s (SD = 0.61) compared to 1.21 s (SD = 1.22) for those subjects with associated phoria ($p = 0.091$).

Does large phorias take longer to recover ?

There was a very weak linear relationship between 10s amplitude and recovery time for:
distance esophores R^2 = 1%
distance exophores R^2 = 4%
near esophores R^2 = 26%
near exophores R^2 = 12%

Relationship between recovery time and number of movements

A Kruskal-Wallis one way ANOVA showed a significant difference between groups (Right-Tail Probability for 5 degrees of freedom $p = 0.00$). Important differences are between 1 movement and 3 or more movements to achieve recovery.

Conclusions

- The age old assumption that one phoria measurement does for both eyes is probably correct.
- Practitioners should cover each eye for 4 to 5 seconds (not 1 -2 seconds)
- For near exophores, the highest symptom scores occur for “intermediate” recovery times.
- However, the number of recovery movements is not a good predictor of symptoms

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