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An explicit *no* response instead of *time-out* in automated visual-field testing

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Abstract *Background:* To evaluate the effect of response-acquisition technique on psychometric performance in visual-field testing, the conventional *one-button yes/time-out* method was compared with a *two-button yes/no* method for responding whether or not the stimulus was detected. There are a number of situations in which the single-button technique leads to ambiguous results. In this study, we thus expected the *yes/no* method to reduce tendencies towards habituation and automatic responding. Our hypothesis was that the two-button technique could reduce the rate of erroneous responses. *Methods*: Luminance-difference sensitivity for bright stimuli (32′) on a photopic background was evaluated at 26 locations within the central visual field (30°) using a specially equalised video display unit and a modified 4/2-dB staircase strategy (six reversals, maximum-likelihood threshold estimation). Sixty-one ophthalmologically normal subjects (aged 20–30 years) were examined twice with each method. *Results:* Mean sensitivities with the *two-button yes/no* method were found to be, on average, 0.13 dB above those measured with the *one-button yes/time-out* technique – a difference without clinical relevance. Within-subject variability did not differ between the two methods. However, the less intuitive *two-button yes/no* method had a slightly higher number of false responses in catch trials. *Conclusion:* Compared to the conventional *one-button yes/time-out* method, the *two-button yes/no* method in normal young subjects thus showed little difference in mean sensitivities and equivalent within-subject variabilities. Concerning our initial hypothesis, the *yes/no* method is of somewhat higher complexity and is not able to reduce the rate of erroneous responses. The *one-button yes/time-out* method fared a little better in error rate. In summary, the *yes/no* method is an alternative and additional possibility of response acquisition in visual-field testing, which is worthy of being tested in a clinical study with elderly subjects.

Introduction

The way in which subject responses are obtained in perimetry has largely developed through convention and has received little critical attention. In standard automated perimetry, the subject holds a single button which she or he presses within a prespecified time window upon the detection of the stimulus. This allows the quick and reliable acquisition of a large number of responses in normal and impaired subjects and is well suited for clinical use. There are a number of situations, however, in which the single-button technique leads to ambiguous results. Often, normal subjects complain about the shortness of the time in which they have to decide whether they have seen a stimulus or not. This time-constraint stress may provoke many false responses, depending on

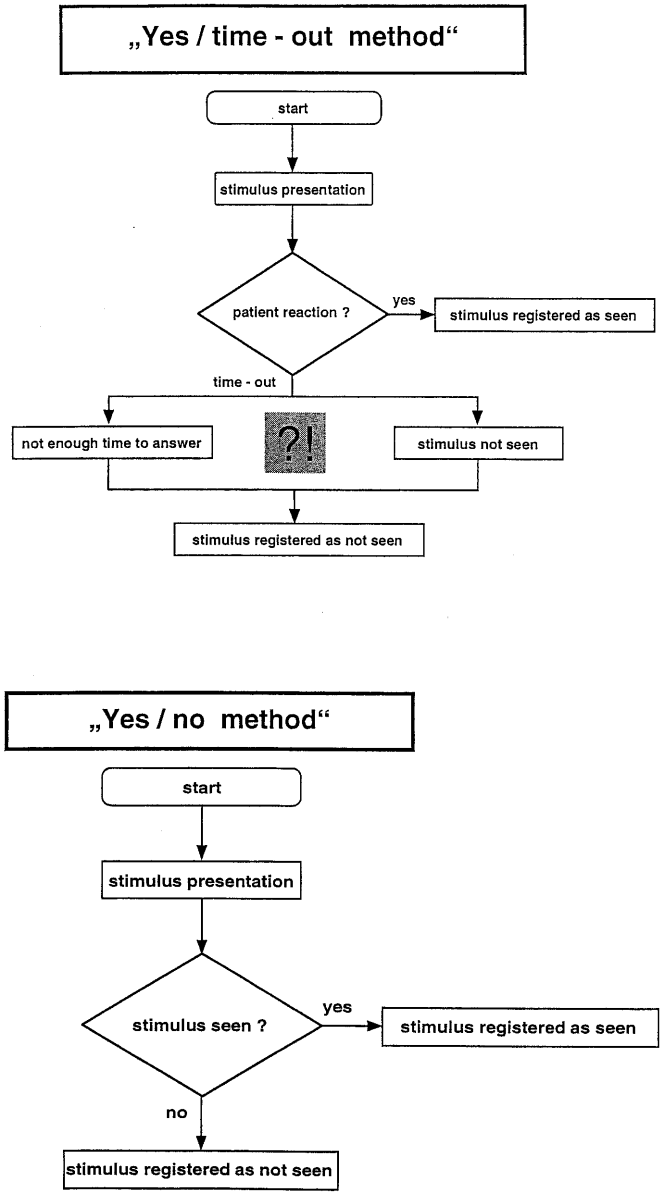

Fig. 1 Flow chart of response acquisition in visual-field testing, using the conventional one-button *yes/time-out* method (*top*) and an alternative two-button explicit *yes/no* technique (*bottom*)

the number of questions asked. The accommodation to subjects showing slow or unreliable response behaviour, as is often the case in brain-injured or mentally impaired patients, is a major problem in response acquisition.

Another problem is that of the influence of the subject's alertness on the percentage of trials reported as seen. The monotonous rhythm of stimulus presentation adversely affects vigilance and motivation, resulting in fatigue, lack of concentration, erroneous responses and reduced patient compliance. Figure 1 (top) shows the algorithm used in the conventional technique (named the *yes/time-out* method here). In this method, which is used in nearly all automated computer perimeters, patients concentrate on the "*yes*" button. An acoustic signal is often presented along with the visual stimulus, so that the patient soon becomes conditioned to press the button on hearing the signal. The rate of false-positive responses can thereby be increased; "catch" trials are usually included to assess that rate.

A further problem of the method is that signal detection paradigms cannot be applied because it is not clear whether a non-response represents a miss. Stimuli are counted as "not seen" if there is no response within a specific time after presentation, but it cannot be decided whether the patient really did not see the stimulus or whether the time was just too short.

The development of a new, computer-based campimetry method [35] has raised the question of the best means of response acquisition anew and has led us to study its effect systematically.

In view of the problems described above, the present study analyses the effect of response-acquisition techniques on psychometric performance using an explicit *yes/no* method in which there is a separate button for the "*no*" response (Fig. 1, bottom). The next stimulus is presented only after the subject has responded by pressing one of the two buttons. The interval between stimulus presentations therefore depends on the subject's response interval, i.e. is under the subject's control, thus taking away the time-constraint stress of the conventional method. The extra time allowed for the response is of particular clinical relevance in the case of patients with neurological diseases, such as brain injuries or mental impairment. With the *yes/no* method it is possible to decide whether the patient really has a scotoma or is just being slow in responding. Compared with the *yes/time-out* method, we thus expected that the *yes/no* method would reduce tendencies towards habituation and automatic responding. Our hypothesis was that the *two-button* technique would reduce the rate of erroneous responses.

Reaction time is another important response variable in a psychophysical measurement. An increase in reaction time is known when the luminance or contrast of the presented signal decreases [12, 13, 14, 16, 20, 21, 22, 26, 33]. Increasing reaction time, therefore, indicates convergence on the perceptual threshold. With an explicit *yes/no* method it is possible to register reaction time to each stimulus presentation. A systematic change in reaction time can objectify and validate threshold measurement.

An explicit *two-button yes/no* method might serve as an alternative or additional response-acquisition technique in clinical visual-field testing, particularly for patients with slow or unreliable responses. It was the aim of the study to examine the alternative *yes/no* method and to compare it with the conventional *yes/time-out* within a homogeneous group of young and healthy sub-

jects. There has been little research on methods of response acquisition in the context of visual-field testing [5, 25]. In a previous study [35], we compared luminance-difference sensitivities for bright and dark stimuli. The present study extends those results by comparing the *yes/no* method and the conventional *yes/time-out* method with regard to (1) mean sensitivity, (2) within-subject variability, (3) examination time, (4) responses in catch trials and (5) responses to fixation checks.

Subjects and methods

Exclusion criteria

After history-taking and ophthalmological examination, 61 healthy subjects (34 women and 27 men, aged 20–30 years) were enrolled in the study. Informed consent to participate in the study was obtained from all subjects. The following were grounds for exclusion:

- Ametropia of >± 6 D sph and >± 2 D cyl
- Corrected visual acuity (distance and proximity) <1.0
- Lang Stereotest (I): Not all figures correctly perceived
- Intraocular pressure >20 mmHg
- Strabismus
- Impaired ocular motility
- Anisocoria and/or existence of a relative afferent pupillary defect (swinging flashlight test)
- Pathological findings in the anterior segment (slit lamp)
- Pathological alteration of the fundus (direct and indirect ophthalmoscopy in miosis)
- History of trauma, operation, inflammation of the eye, amblyopia, lesion of the visual pathway

Study design

Each subject was examined with both response-acquisition techniques on each of two different days. A 10-min break separated the two examinations on each day, and the subjects were allowed to rest for 2 min during each examination. To minimise the effects of training and fatigue, the 61 subjects were divided into four groups with sequentially randomised orders of examination: 17 subjects: A-B-A-B, 13 subjects: A-B-B-A, 15 subjects: B-A-A-B, 16 subjects: B-A-B-A, with A denoting the *yes/time-out* and B the *yes/no* method.

Only the leading eye of each subject was examined; it was identified by means of Rosenbach's "Visierversuch" [29]. Forty right eyes and 21 left eyes were tested. Each subject was allowed to choose in which hand to hold the *"yes"* and in which to hold the *"no"* button. At the end of the examinations, the subject's right- or left-handedness was determined by means of the Edinburgh Handedness Inventory [28].

Questionnaire

After the second examination on each of the two days, the subjects filled out a questionnaire in which they were asked to rate the *yes/time-out* method as better, worse, or equivalent to the *yes/no* method with respect to the following characteristics: pleasantness, strenuousness, complicatedness, ease of response, number of stimuli perceived, and number of false responses.

Campimetric device

The examinations were carried out on a campimetric set-up composed of a standard personal computer (Power Macintosh 6100/66) and a second, high-quality monitor for stimulus presentation (BARCO, model Calibrator; 75 dpi, 1024×768 pixels, 21-in. diagonal, max. luminance L=64 cd/m^2) driven by the computer's 24-bit video card (Apple). Fixation during the examination was assisted by four red fixation marks (24.0 min diameter, 1° eccentricity, L=17.75 cd/m^2) in the centre of the screen. The subject's eye was brought into the appropriate position in front of the stimulus-presentation monitor by means of a chin-forehead rest, with an integrated infrared camera for fixation control (the eye being visible on a third small screen). At the viewing distance of 30 cm the screen subtended 68°×50° of visual angle. The screen background luminance was kept constant at 10 cd/m^2 at all screen locations by means of a specially developed equalisation procedure described in a separate report [6].

Psychometric strategy

The luminance-difference sensitivity (LDS) for bright stimuli (32′) was measured at 26 test locations within the central 30° of the visual field. Figure 2 shows the test grid.

A modified 4/2 staircase strategy was used for sensitivity measurement: Stimulus luminance was first varied in steps on the grey scale corresponding to 4 dB, then after the first reversal of response category in grey-scale steps of 2 dB, and thereafter in steps of single grey-scale values with four further reversals at the single grey-scale step level. LDS was measured in decibels according to

$$\mathrm{LDS\ (dB)} = 10 \times \log(1000 / \Delta l)$$

where Δl is the difference (in cd/m^2) between background and stimulus luminance. This is a device-independent version of Flammer's formula [8].

Each trial started with an acoustic signal. Sixty milliseconds after this signal, the stimulus was presented for 200 ms. In the *yes/time-out* examinations the next stimulus started after a fixed interval of 1200 ms, independent of the subject's response; in the *yes/no* examinations the next stimulus was presented only after the subject had pressed one of the two buttons, with a minimum interstimulus interval of 1200 ms (see Fig. 1).

Additionally, the two types of catch trials commonly used in visual-field testing were integrated into the algorithm in order to evaluate the quality of subject responses [19]:

- Catch trials for false-positive responses (acoustic signal only)
- Catch trials for false-negative responses (stimulus with maximum luminance at a test location known from previous presentations to be "normal")

Approximately 8% of the total number of trials per examination were used in each type of catch trial per single examination, and approximately another 4% of the total number of trials per examination were used to control fixation. The corresponding stimuli were presented in the exact centre of the screen with a luminance of 5 dB above the central LDS threshold. The number of perceived control stimuli correlates with the goodness of a subject's fixation. This method of checking fixation is, remarkably, an unconventional technique. The conventional method, usually integrated in the most automated perimeters, is the fixation control of Heijl and Krakau, presenting a stimulus of high luminance in the blind spot [7, 18, 36].

All catch trials and fixation controls were randomly presented between proper stimulus presentations.

As is common in automated perimetry, the sequence of screen positions for the individual stimuli was randomised such that the staircases were intertwined. All presentation and response data, including subject reaction times, were stored on disk.

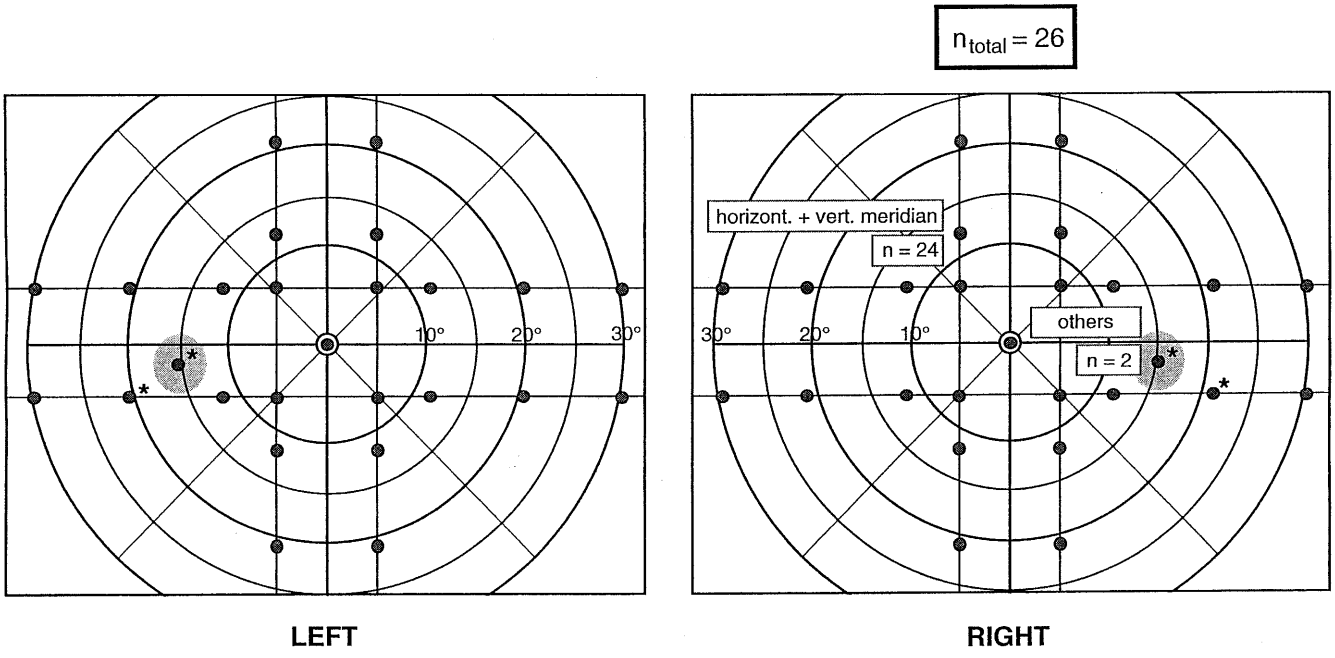

Fig. 2 Test grid with 26 test locations in the central 30° of the visual field. *Asterisks* mark the two test locations situated in or near the blind spot

Data processing and statistical methods

Calculation of target variables

A logistic function, with threshold and slope as free parameters, was fitted to the response data for each of the 26 test locations by the maximum-likelihood method ("logit analysis" [4]; see also [34]). Threshold was defined as the point of inflection. In our tasks (which are both yes/no tasks), this is the point where the stimulus is seen with a probability of 50%. It corresponds to the ED_{50}. Mean sensitivity in decibels was then calculated from the 26 LDS threshold values.

Examination times were log-transformed in order to normalise the distributions. The ratio between examination times for both response-acquisition techniques was then given by the anti-logarithm. Due to the log-normal distribution of the examination times, the geometric mean of the ratio of the examination time in *yes/no* versus *yes/time-out* is an estimate of the ratio of the median examination times.

Target variables

The mean sensitivity for each subject, at each of the four examinations, and the examination time were considered the primary target variables. Responses in catch trials and responses to fixation controls were the secondary target variables.

Statistical hypotheses

Luminance-difference sensitivities, within-subject variabilities and examination times do not differ between the two response-acquisition techniques.

Statistical analyses

Mean sensitivities and log examination times were analysed by analyses of variance (ANOVA, using the SAS version 6.12 package, Procedure MIXED; SAS, Boneville, Minn., USA), using *day*, *examination*, interaction between *day* and *examination*, and *method* as fixed effects, and *subject* as random effect. Variance components for between-subject variability and within-subject variability were estimated by restricted maximum-likelihood estimation (REML), separately for both methods (SAS version 6.12 package, Procedure MIXED). Mean differences were tested on the 5% level. Estimation of the mean differences of both methods was given, including the 95% confidence interval. Secondary target variables were analysed by descriptive statistics and were tested by the Wilcoxon signed-rank test.

Results

Comparison of mean sensitivities

Two of the 26 test locations were in or near the blind spot and were excluded from the analysis. Mean sensi-

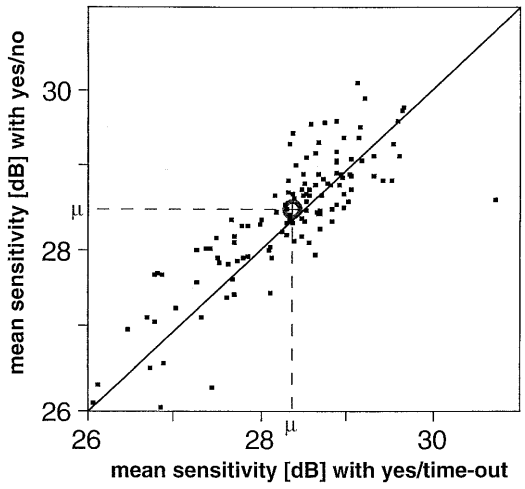

Fig. 3 Scatter plot of mean sensitivity (dB) obtained with the two techniques of response acquisition, *yes/time-out* and *yes/no*. Each data point represents the mean sensitivity of one subject at one examination. The mean difference between the two methods was 0.13 dB (P=0.005; n=122; $\mu_{yes/time\text{-}out}$=28.33 dB, $\mu_{yes/no}$=28.46 dB). The *diagonal* corresponds to equal sensitivities between the two methods

tivity over the remaining 24 test points was calculated separately for each of the four examinations and for each subject. Figure 3 shows a scatter plot of mean sensitivities over both examinations obtained in the *yes/no* method and in the *yes/time-out* method for each person tested. The majority of the points (76 points) are slightly above the identity line, such that the mean sensitivities with the *yes/no* method are, on average, 0.13 dB above those measured with the *yes/time-out* method. Due to the large number of measurements, the difference is statistically significant (*P=0.005*; 95% confidence interval [0.04, 0.23]) but is not of practical relevance.

The interaction between *examination* and *day* in the ANOVA showed an increase of the mean sensitivities between the first and the second examination on the first day, for both methods. Within the two examinations on the second day, there was no statistical difference in sensitivity (Table 1).

Within-subject variability

Within-subject standard deviation was estimated by variance component analysis as described in "Data processing and statistical methods", being 0.39 dB for the *yes/time-out* and 0.34 dB for the *yes/no* method. The difference between the two values was not statistically significant (P=0.28). Using these estimates of within-subject variability, the 95% reference interval for individual differences (i.e. the interval within which 95% of the individual values lie; this is not the 95% confidence interval [2]) can be estimated as [-0.6 dB, 0.9 dB].

Comparison of the examination time

The geometric mean of the ratio of the examination time in *yes/no* versus *yes/time-out* was 1.06, with a 95% confidence interval of [1.04, 1.09]. This means the *yes/no* method is slightly more time consuming (P<0.0001). The geometric mean of the examination time was 11.1 min, against 11.8 min for the *yes/time-out* and *yes/no* method, respectively.

Comparison of subject responses in catch trials

Catch trials were analysed separately for each method. Concerning the total number of catch trials per examination, there are only small absolute differences between the two methods [*yes/time-out:* 32.9±4.5 catch trials for false-positive responses (mean ± SD), 27.7±4.3 catch trials for false-negative responses; *yes/no:* 33.6±4.6 catch trials for false-positive responses, 28.1±4.4 for false-negative responses]. Out of these total numbers of catch trials, there were only 1.8±2.5 (mean ± SD) wrongly answered catch trials for false-positive responses and 0.2±0.7 for false-negative responses per examination within the *yes/time-out* method. With the *yes/no* method the absolute numbers of wrongly answered catch trials per examination are comparable, with 2.6±2.4 for false-positive responses and 0.3±0.7 for false-negative responses. In both methods, the percentage of wrong an-

Table 1 Mean sensitivity values (dB) of the first and the second examination on the two days of examination for both methods. The interaction between *examination* and *day* showed for both methods an increase in the mean sensitivities between the first and the second examination on the first day

Method	Mean sensitivity (dB)			
	Day 1		Day 2	
	Examination 1	Examination 2	Examination 1	Examination 2
Yes/time-out	28.17	28.27	28.37	28.52
Yes/no	28.25	28.52	28.65	28.44

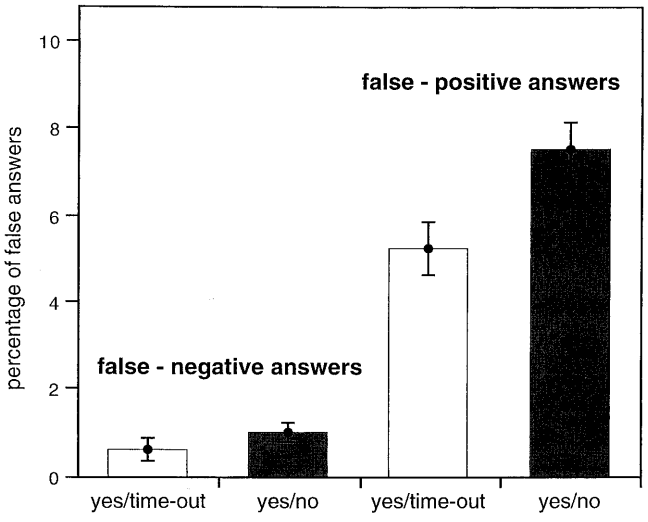

Fig. 4 Comparison of responses to catch trials. The *yes/no* method resulted in slightly more false responses to both types of catch trials, with the increase in false-positive answers being a little greater: 5.3±0.6% (mean ± SE) false-positive answers with the *yes/time-out* method versus 7.6±0.6% with the *yes/no* method, and 0.6±0.3% false-negative answers with *yes/time-out* versus 1.0±0.2% with *yes/no*

swers was markedly higher for false positives (5–8%) than for false negatives (0.6–1%), i.e. subjects tend to respond rhythmically even when there is no stimulus. For both types of catch trials, the *yes/no* method had somewhat more false responses than the *yes/time-out* method, with an average of 7.6% false positives (compared with 5.3%) and 1.0% false negatives (compared with 0.6%) (Fig. 4). Both differences between the methods are statistically significant ($P<0.05$; Wilcoxon signed-rank test).

Comparison of subject responses to fixation controls

There was no difference in the goodness of fixation between the two techniques, with 12.0% of the fixation-control stimuli being missed in the *yes/time-out*, and 12.0% in the *yes/no* method. The average number of fixation-control trials was 16.1±2.3 (mean ± SD) per examination with the *yes/time-out* method and 16.6±2.3 with the *yes/no* method.

The average total number of trials per examination was 425±29 (mean ± SD) for each subject with the *yes/time-out* method and 429±32 with *yes/no*. The difference between the two methods was not significant ($P>0.05$; one-sample Student's *t*-test).

Questionnaire results

The Edinburgh Handedness Inventory revealed 57 (93%) of our 61 subjects to be right-handed and four (7%) to be left-handed. In both examinations, left-handed subjects always held the *"yes"* button in their left hand. Of the right-handed subjects, 51 always held the *"yes"* button in their right hand and four always in their left; two changed hands between examinations.

Subjectively, 29 (48%) of the 61 subjects found the *yes/time-out* method more pleasant, 19 (31%) the *yes/no*, and 13 (21%) had no preference. A slight majority of subjects regarded the *yes/no* method as more strenuous (36/61, 59%) or more complicated (41/61, 67%). A similar proportion (36/61, 59%) felt it easier to respond in the *yes/time-out* method. When asked in which method they thought they had perceived the most stimuli, 20 subjects (33%) had no preference, 22 (36%) preferred *yes/no* and 19 (31%) *yes/time-out*. Neither method was clearly felt to result in more false responses than the other: Twenty-seven subjects (44%) felt they had more errors in the *yes/no* method, 20 (33%) in the *yes/time-out* and 14 (23%) were undecided.

Discussion

In conventional automated perimetry there is one standard technique of response acquisition: the *one-button yes/time-out* method. In the psychophysical literature it is sometimes referred to as a go/no-go method; it can be considered a simplified version of a classical *yes/no* task [3, 23], since it corresponds to a *yes/no* method where the *"no"* response is replaced by a *time-out*. The method is well suited for clinical use, because it allows the quick and reliable acquisition of a large number of responses within a short examination time. In alternative perimetric procedures, such as high-pass resolution perimetry (ring perimetry) [9, 10, 11], short-wavelength automated perimetry (colour perimetry) [30, 31, 32] or dark-stimulus perimetry [1, 27, 35], responses are obtained by the same method.

As mentioned above, the *yes/time-out* method has certain problems and can lead to ambiguous results. The goal of the present study was to differentially evaluate the classical *yes/no* task of psychophysical measurement as an alternative to the standard method of response acquisition in automated perimetry.

Theoretically, the *yes-no* paradigm can be treated within signal detection theory [15, 24]. Such an analysis, for example, allows its comparison with forced-choice paradigms. However, since the two tasks considered here are treated equivalently by signal detection theory – the *time-out* corresponding to a *no* – no such analysis was carried out here.

Yes/no versus *yes/time-out* – two methods of equal value?

The present study aimed at varying the patient response without changing the conventional *yes/no* test procedure. It was of interest whether a true *yes/no* would minimise automatic responding and conditioning and thus give higher priority to the decision-making on the part of the subject.

Our main finding is that the sensitivities with the two methods of response acquisition are essentially the same. Even though mean sensitivity was higher by 0.13 dB with *yes/no*, and this difference is statistically significant due to the huge number of responses, the difference is negligible in comparison with the intraindividual variance in a standard measurement, and is clinically irrelevant. With respect to sensitivity, the two methods of response acquisition can thus be used interchangeably.

Further, examination times were compared. Examination with *yes/no* took a little longer than with *yes/time-out* [about 0.7 min (geometric mean) out of 11.8 min total time), most likely because of additional demands on decision making. The additional information in an explicit "no" therefore comes at a certain price. Again, however, the difference is small and is of little practical relevance.

Remarkably, the parameters of quality and validity were somewhat lower for the alternative *yes/no* method: It led to higher proportions of both false-positive and false-negative responses in catch trials than did the *yes/time-out* method. False-positive responses increased from 5.3% to 7.6% and false-negatives from 0.6% to 1.0%. Especially the increase in false-positive responses reflected the tendency of the subjects to press the *"yes"* button more frequently within the explicit *yes/no*. This bias might be the reason for the slightly higher mean sensitivities found with the *yes/no* method.

What are the reasons for the false responding to catch trials?

Independent of the method and the kind of false response, there is always an influence of a subject's inattentiveness or lack of concentration, vigilance, motivation or compliance. Regarding false-positive responses, the subject might assume that she/he has missed the stimulus presentation (thus answering "yes") in both methods. This corresponds to the classical kind of response bias. Additionally, in the one-button case, false-positive responses may indicate a conditioned readiness to press the button after hearing the acoustic signal. In the two-button *yes/no* method, there are another two possible reasons for a false-positive response: First, the subject can confuse the two buttons. Second, owing to its greater readiness the dominant hand might react when it should not. Most (90%) of our 61 subjects held the *"yes"* button in their dominant hand.

As for false-negative responses, a false negative certainly occurred in the one-button method when there was no response to a maximum-luminance stimulus because of missing the stimulus presentation. There is an additional possibility: The subject sees the stimulus, but the reaction is too late or the time for responding too short. Not seeing because of scotoma plays no part, because the presentation of catch trials for false-negative responses only happens at test locations known from previous presentations to be "normal". In the *yes/no* method the subject replies false negatively by pressing the *"no"* button, because of missing the stimulus presentation. A further possibility for responding false negatively is confusion between the two buttons. These hypothetical reasons for false responses are summarised in Table 2.

There are two possibilities for false-positive and two for false-negative responding with the *yes/time-out* method, compared with three possibilities for false-positive and two for false-negative responding with *yes/no.* The generally higher rate of false-positive than of false-negative responses in both methods can probably be ex-

Table 2 Hypothetical reasons for false answers

Answer	One-button method	Two-button method
False-positive (acoustic signal only; no stimulus, answered with "yes")	1. Subject assumes she/he has missed stimulus presentation (thus answering "yes"; (lack of concentration, vigilance or compliance) 2. Conditioned readiness to press button after hearing acoustic signal	1. Subject assumes she/he has missed stimulus presentation (thus answering "yes"; (lack of concentration, vigilance or compliance) 2. Confusion between two buttons 3. Greater readiness of dominant hand to react
False-negative (stimulus with maximum luminance; answered with "no")	1. Subject missed the stimulus presentation (thus answering "no"; (lack of concentration, vigilance or compliance) 2. Reaction too late or time for responding too short	1. Subject missed stimulus presentation (thus answering "no"; (lack of concentration, vigilance or compliance) 2. Confusion between two buttons

plained by a conditioned readiness to press a button upon hearing the acoustic signal. Between the methods there are slightly more false-positive responses in *yes/no*, because of the higher number of ways of making that mistake. The *yes/no* response acquisition technique seems generally to be of higher complexity, comparable with the experience of Heijl et al. [17]. The use of both hands in the *yes/no* technique leads to confusion of the two buttons and reduces control by the dominant hand. This reduces the subject's concentration on stimulus perception. Most subjects regarded the *yes/no* method as more strenuous or more complicated, and many reported the two buttons were easily confused.

In conclusion, compared with the conventional *yes/time-out* method of response acquisition in standard perimetry, the alternative *yes/no* method shows little difference in the characterising parameters tested: sensitivity, reliability, examination time, error rate and fixation.

The *two-button yes/no* method relieves the subject from the time-constraint stress of responding within a given time and can be accommodated to the patient's individual response behaviour. At the same time, it is of somewhat higher complexity, it leads to confusion between the buttons and it depends on the subjects' handedness. The *one-button yes/time-out* method fared a little better regarding error rate and was a little quicker. With regard to our initial hypothesis the *yes/no* method is not able to reduce the rate of erroneous responses. Therefore, in the clinical routine where short examination times are highly beneficial, the standard *yes/time-out* method of responding will remain the method of choice. In situations where an explicit "no, not seen" is of interest, however, the alternative *yes/no* method can be substituted for the other without further problems. In summary, the *yes/no* method is an alternative and additional possible means of response acquisition in visual-field testing of young and ophthalmologically normal subjects which merits being tested in elderly subjects and in a clinical study with patients. It would then be of interest whether the gains in individualisation and stress reduction improve perimetric reliability in those with slow or unreliable responses or reduced vigilance, as is seen in brain-injured or mentally impaired patients or in patients of greater age.

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