The Effect of Attention on Conventional Automated Perimetry and Luminance Size Threshold Perimetry

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Purpose. To investigate the effects of divided attention on conventional automated perimetry (CAP) and luminance size threshold perimetry (LSTP).

Methods. Ten healthy subjects, ages 27 to 65, with two perimetry types (CAP and LSTP) were tested in random order. At a later session, these tests were given with a mental workload to simulate the effect of anxiety or distraction on subjects performing visual field testing, also in random order. The mental workload, the Paced Auditory Serial Addition Test (PASAT), was first administered to each subject, and the score was recorded. During the visual field testing, the PASAT was again administered continuously. Each subject was instructed to attend primarily to the PASAT while taking each visual field test.

Results. CAP was affected by the addition of the PASAT, with a worsening of sensitivity from an average of 30.0 ± 0.67 to 24.2 ± 7.4 dB with a range of −0.04 to −23.2 dB ($P = 0.04$). LSTP showed a generalized reduction in threshold 1.71 ± 0.22 to 2.35 ± 0.72 dB with a range of 0.12 to −2.17 dB ($P = 0.25$). The percentage of correct responses on the PASAT was not significantly different between CAP (76.9%) and LSTP (74.8%). False-positive and -negative catch trial responses were increased during CAP with PASAT testing ($P = 0.009$). A substantial increase of fixation losses occurred during CAP with PASAT (3.7–16.2, $P = 0.002$). LSTP with PASAT showed increases in localization error ($P < 0.001$) and reaction time ($P = 0.004$).

Conclusions. Divided attention significantly affects performance on conventional automated perimetry with its fixed size stimuli and when the stimuli are scaled (LSTP). The deficits may simulate nerve-fiber-bundle–like defects. (*Invest Ophthalmol Vis Sci.* 2004;45:342–350) DOI:10.1167/iovs.03-0594

Perimetry is a psychophysical test designed to give a quantitative estimate of the function of the visual field. To measure differential light sensitivity thresholds accurately in clinical perimetry, an attempt is made to isolate the subject to the task at hand and ask for a response to the presence of a light stimulus appearing from a dimmer background. Despite attempts to control the testing conditions, many factors can affect the outcome of a visual field test. Test instructions and the associated response bias,[1] learning effect,[2–5] and fatigue[3] have all been shown to affect the test outcome. In addition, patients in a clinical setting may have anxiety from many potential sources. Headache and eye pain are not uncommon in patients undergoing perimetry. These factors, anxiety and pain, may cause patients to divide their attention between ongoing thoughts and the demanding perimetric test they are attempting to complete. Although clinical perimetry attempts to minimize these effects, it is not always successful.

Efforts to measure the visual field during divided attention tasks have become popular in the vehicle crash prediction literature.[6,7] The useful field of view (also called the functional or occupational visual field) is the spatial area or visual field extent that can be monitored by a subject while performing another task.[8] Unlike clinical perimetry, suprathreshold stimuli are commonly used, binocular vision is tested, and stimulus recognition, rather than simple detection, is required. The effects of attention on the useful field of view have been shown to be considerable.[9–12]

Although a large body of literature has evolved regarding the useful field of view, studies investigating the effects of attention on clinical perimetry are limited. Tschopp et al.[13] used the false-negative response rate and the slope and goodness of fit of the psychometric function in children as an indirect assessment of attention effects in clinical perimetry. They found these attention-related measures were better predictors of visual thresholds than age. Fujimoto and Adachi-Usami compared the mean sensitivity between conventional automated perimetry (CAP) programs with different numbers of test locations and different test field sizes. They assumed a smaller test field would allow more focusing of attention. They reported that the mean sensitivity was significantly higher when fewer test locations were used and when a smaller test field size was administered.[14]

CAP uses a small fixed-size stimulus, and light intensity is varied. Although these stimuli easily attract attention near fixation, they are less efficiently seen with increasing eccentricity.[15,16] In 1857, Aubert and Foerster[17] first demonstrated that the lower visual acuity of peripheral vision could be compensated for by increasing stimulus size. Because large stimuli in the periphery are more salient, it is possible that these larger stimuli would be more resistant to the effects of divided attention.

Therefore, to evaluate the effects of divided attention on clinical CAP and perimetry where thresholds are measured to different sized stimuli (threshold is defined as the smallest sized stimulus seen), we measured visual thresholds in the standard way and then with the subject performing mental arithmetic using the Paced Auditory Serial Addition Test (PASAT). Our goal was to investigate the effect of divided attention on visual thresholds of fixed and scaled stimuli.

Methods

Subjects

Ten subjects were recruited from employees and students at the University of Iowa. The study was approved by the University of Iowa Investigational Review Board and adhered to the tenets of the Declaration of Helsinki. Each subject met the following criteria for inclusion

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in the study: (1) best corrected Snellen visual acuity of at least 20/20; (2) refractive error no greater than 6 D sphere and 3 D cylinder; (3) undilated pupil size of at least 3 mm; and (4) no history of eye disease other than refractive error in the selected eye. Two subjects represented each decade from the third to seventh decades, with the mean age 45.3 years. One half of the subjects had little or no experience with visual field testing; the other half was experienced (having tested three or more times). All subjects gave informed consent and were compensated for their participation in the study.

Apparatus and Stimuli

Conventional Automated Perimetry. We used the full-threshold test of the Humphrey Field Analyzer (model 750, program 24-2; Carl Zeiss Meditec, Dublin, CA) with a white Goldmann size III stimulus varying over a 4-log unit range. This white background was calibrated to 31.5 apostilb (asb). Each subject's appropriate near correction was used with an additional refraction performed at the perimeter. Threshold values at test locations throughout the central 24° field were determined with a 4-dB/2-dB staircase procedure. For each subject, the number of false positives (responses when no stimuli were presented), false negatives (no response to a 9-dB brighter stimulus than had previously been seen), fixation losses, and short-term fluctuation at selected test locations were calculated by the test instrument. On completion of the full field threshold test, each subject was given a minimum of a 5-minute rest before the second threshold test was performed simultaneously with the PASAT.

Luminance Size Threshold Perimetry. Luminance size threshold perimetry (LSTP) was performed in a darkened room using an IBM-compatible 486-MHz computer with software we have developed.[18,19] The subjects' appropriate near correction was used. Care was taken to prevent lens rim artifact by asking whether the subject could see each corner of the video display while looking at the fixation target. The number of false positives (responses when no stimuli were presented) and false negatives (no response to a maximum size stimulus in an area with vision) were tabulated by the test software.

Stimulus presentation was randomized among the preselected test loci. Fixation was monitored by the visual field technician. We tested 44 locations that match the 24 -2 Humphrey perimetry test points (6° spaced grid) except for absence of the top and bottom rows ($y = 21°$ and $-21°$) and the two points along the nasal horizontal ($x = -27°$). The stimulus was a light gray, filled, circular patch of 80 asb; the background was a uniform darker gray with a luminance of 50 apostilb. The targets were of 18 sizes, with a diameter step factor of 10^{-1}. The angle subtended by the targets ranged from 0.13° to 8.46°. A stimulus size threshold was found.

Valid responses were defined by (1) a reaction time greater than 110 ms from stimulus onset and less than 1 second and (2) a localization error (described later) of no more than 10° from the center of where the target was actually presented. The testing distance from the screen was fixed at 22 cm by a lens holder attached to the monitor. The monitor sat on an adjustable-height table and was adjusted so the test subject was comfortably seated looking slightly down. The 17-inch diagonal monitor (Multisync 5FG; NEC, New York, NY) gave a 21° test field (42° × 42° total).

The subject began the trial by touching the light pen to the box at the bottom center of the screen. As the subject fixed on a central cross, an auditory cue was given. After a 275-ms delay, a stimulus was displayed. The subject lifted up the light pen and touched it to the monitor at the position on the screen where he or she perceived the center of the target. The reaction time was calculated from the time the target was displayed to when the subject lifted up the light pen from the screen.

The localization error was calculated using the trigonometric distance from the x and y pixel coordinates of the target center to the x and y pixel coordinates of where the subject touched the screen with the light pen. The subject received feedback of the localization error at the end of each trial. The relative localization error was calculated by using the Pythagorean theorem to find the error relative to center. This is either an undershoot (negative number) or an overshoot (positive number) of stimulus localization. To help maintain interest during the baseline test, reinforcement was given as a computer-simulated fireworks display if the subject came within three pixels of the target center. No reinforcement was given during the test with PASAT, to keep the subject on task. The test time for the 44 test loci was approximately 15 minutes.

Paced Auditory Serial Addition Test. The PASAT is a neuropsychological tool to assess attention, information processing, and working memory. The task requires subjects to add consecutive digits together in a specified timeframe. It was originally used in cerebral concussion research to measure information processing during recovery from a closed head injury.[20] Normative data have been published,[21] and although a learning effect can be demonstrated, the interrater and intrarater reliability scores are excellent.[22] It is now commonly included in batteries of attention tests.

We administered the PASAT, using a portable cassette tape player. The voice on the cassette was male with an Australian accent. A short description of the test, followed by test instructions, was given before the practice test was administered. The tape was then stopped, the instructions were discussed, and questions were answered. The practice session, which consisted of 10 presentations of random numbers ranging from 1 to 9, was then administered. The subject was expected to add the first number to the second number, give the answer verbally, add the third number to the second number (not the answer of the first plus the second), verbally state the answer, and so on. The rate of presentation for the practice session and the test sessions was 2.4 seconds. The baseline test was presented exactly like the practice test, except that it was longer, using 61 trials of number presentations instead of 10 and lasted approximately 2.39 minutes. The portion of the PASAT used in conjunction with visual field testing was the same 2.39-minute segment modified in length to play continuously until the test was completed. Each subject performed a baseline PASAT.

Testing Strategy. Each subject performed five tests in a sequence. Forced and elective breaks were given, and care was taken to minimize fatigue effects. The five tests were (1) a modified version of the PASAT; (2) CAP (24-2 full threshold) administered in the usual manner; (3) a second CAP test with a second PASAT (modified in length to play through the completion of CAP) performed simultaneously; (4) LSTP; and (5) a third PASAT, administered continuously during performance of a second LSTP.

The PASAT was explained, and instructions were given to the subject. The volume was adjusted to a comfortable level for each subject. A practice test was administered. Subjects were encouraged to practice the PASAT using the recorded practice test until they had a good understanding of the test and felt comfortable taking it. All questions about the test were answered and the instructions were clarified. A baseline PASAT was then administered, and responses were recorded for each subject. Responses were also recorded during the simultaneous performance of the visual field tests.

CAP was then administered. Instructions were given, the foveal threshold was obtained, and the gaze-tracking monitor was initialized. The test was paused once for each subject, to lessen possible fatigue affect. A 30-minute break was given, and then CAP and PASAT were administered together. The same procedure was followed for the second CAP. The foveal threshold was obtained, and the gaze-tracking monitor was initialized. Instructions were then given, the blind spot was localized, and the threshold test was started. As soon as the subject responded to the first stimulus on CAP, the PASAT was started. The subject's responses to the PASAT were recorded, and fixation was monitored. The test was paused approximately every 5 minutes, or sooner if the subject requested a break.

Next, LSTP was administered. The perimetrist demonstrated the test and gave instructions. Once the subjects understood the test they were given a practice session. After approximately 25 practice trials, the test was restarted. Subjects were given a short rest break midway

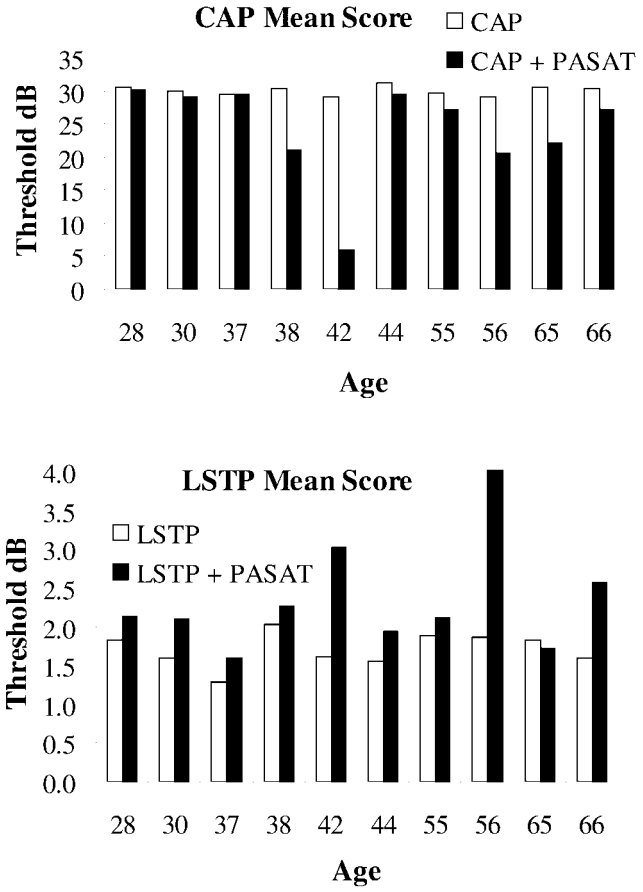

FIGURE 1. Mean scores of the two tests of a patient with CAP (*top*) and LSTP (*bottom*).

through the test. A 30-minute break was given, and then LSTP and PASAT were performed together. The subject was again given instructions, and the test was started. After the subject responded to the first target, the PASAT was started. Again, the test was paused approximately every 5 minutes, or at the request of the subject.

Statistical Analysis

Threshold values comparing each visual field test alone and with the PASAT were analyzed with paired *t*-tests. Wilcoxon signed rank tests were used when the data were not normally distributed or there was inhomogeneity of variance. The recorded responses from the baseline PASAT and two perimetry tests were also analyzed with paired *t*-test. The impact of the PASAT on sensitivity for four concentric zones in CAP and LSTP were analyzed with a 2 × 4 (test, zone) repeated-measures ANOVA.

RESULTS

Threshold values comparing each visual field test alone and with the PASAT were analyzed with paired *t*-tests. CAP was affected by the addition of the PASAT ($P = 0.04$), with a worsening of sensitivity from an average of 30.0 ± 0.67 dB (± refers to 1 SD) to 24.2 ± 7.4 dB with a range of −0.04 to −23.2 dB. LSTP showed a generalized reduction in threshold with the addition of the PASAT, 1.71 ± 0.22 to 2.35 ± 0.72 dB with a range of 0.12 to −2.17 dB ($P = 0.25$). The mean scores for CAP and LSTP, with and without the PASAT are shown in Figure 1. LSTP results are a size threshold (smallest size stimulus at each test location) and the log of the total area of the stimulus size in pixels is used.

During CAP with PASAT testing, compared with performance on the single CAP test, false-positive and -negative responses were increased (from 1.9% to 8%, $P = 0.028$; from 1.9% to 20.5%, $P = 0.011$), fixation losses were increased (i.e., from 3.7 to 16.2, $P = 0.002$), and test time was lengthened by 5.08 minutes ($P < 0.001$).

With LSTP, relative localization error increased by 13% with the addition of the PASAT, but the result did not reach statistical significance ($P = 0.187$). However, all 10 patients had prolonged reaction times the PASAT was added ($P = 0.004$); the mean increase was 93 ms. Localization error was increased by 0.58° of error ($P = 0.02$). With LSTP, false-positive responses increased (from 2.4% to 10%, $P = 1.000$), but false negative responses decreased (from 18.33% to 16.6%, $P = 0.916$). With CAP, false positives increased by 7% and false negatives by 19%. Six patients had more false-positive responses with PASAT, and seven had more false-negative catch trials with PASAT. All 10 had a larger mean localization error with the concurrent PASAT. Performing simultaneous PASAT and LSTP tests increased the average test time for the LSTP by 2.33 minutes ($P = 0.009$).

The fraction of correct responses on the PASAT (baseline, 80.7%) was not significantly different when performed at the same time as the CAP test (77%) compared with simultaneous performance with LSTP (75%).

Concentric zone analysis for CAP showed a loss in sensitivity when PASAT was added ($P = 0.035$). Concentric zone 1 (cecocentral) is located around fixation, followed by zones 2 (pericentral) and 3 (midperipheral) to zone 4 (peripheral), located at 21°. The concentric zones in LSTP were not significantly affected, but generalized loss of sensitivity was present (Fig. 2). LSTP with PASAT showed a generalized increase in localization error, in the periphery only, from 0.20° to 0.30° ($P < 0.001$).

Some examples of the effects of the PASAT on CAP results are found in Figures 3 and 4. Figure 3 shows a typical result in a patient with a normal findings in the standard Humphrey Field Analyzer 24-2 threshold test. The effect of addition of the PASAT is shown in Figure 3B with a generalized reduction of sensitivity, along with some relative localized defects. A more dramatic example is shown in Figure 4, with a markedly depressed visual field in Figure 4B measured during the PASAT. Note how the abnormalities simulate nerve fiber bundle defects. The frequency of visual field defect types with the two types of perimetry, with and without the PASAT is shown in Figure 5.

DISCUSSION

We tested 10 normal subjects with a mental workload to simulate the effect of anxiety or distraction on subjects performing visual field testing. We found that a divided-attention task during perimetry significantly raised thresholds across the visual field. This finding was true whether the stimuli were of fixed size or scaled, and it has significant implications for CAP. Although it is assumed that patients have a single task, various factors may be present that violate this assumption. For example, headache, anxiety, worry about a recently received diagnosis, and deficits in attention may make visual field testing results abnormal and may simulate disease.

In addition to a higher threshold, a divided-attention task significantly increases catch trials, time of examination, and with LSTP, the localization error. Little consideration has been paid to these effects in the perimetry literature.

As expected, the majority of subjects (9 of the 10) had loss of sensitivity with CAP or LSTP when the PASAT was added. CAP showed more visual field defects and fewer normal visual

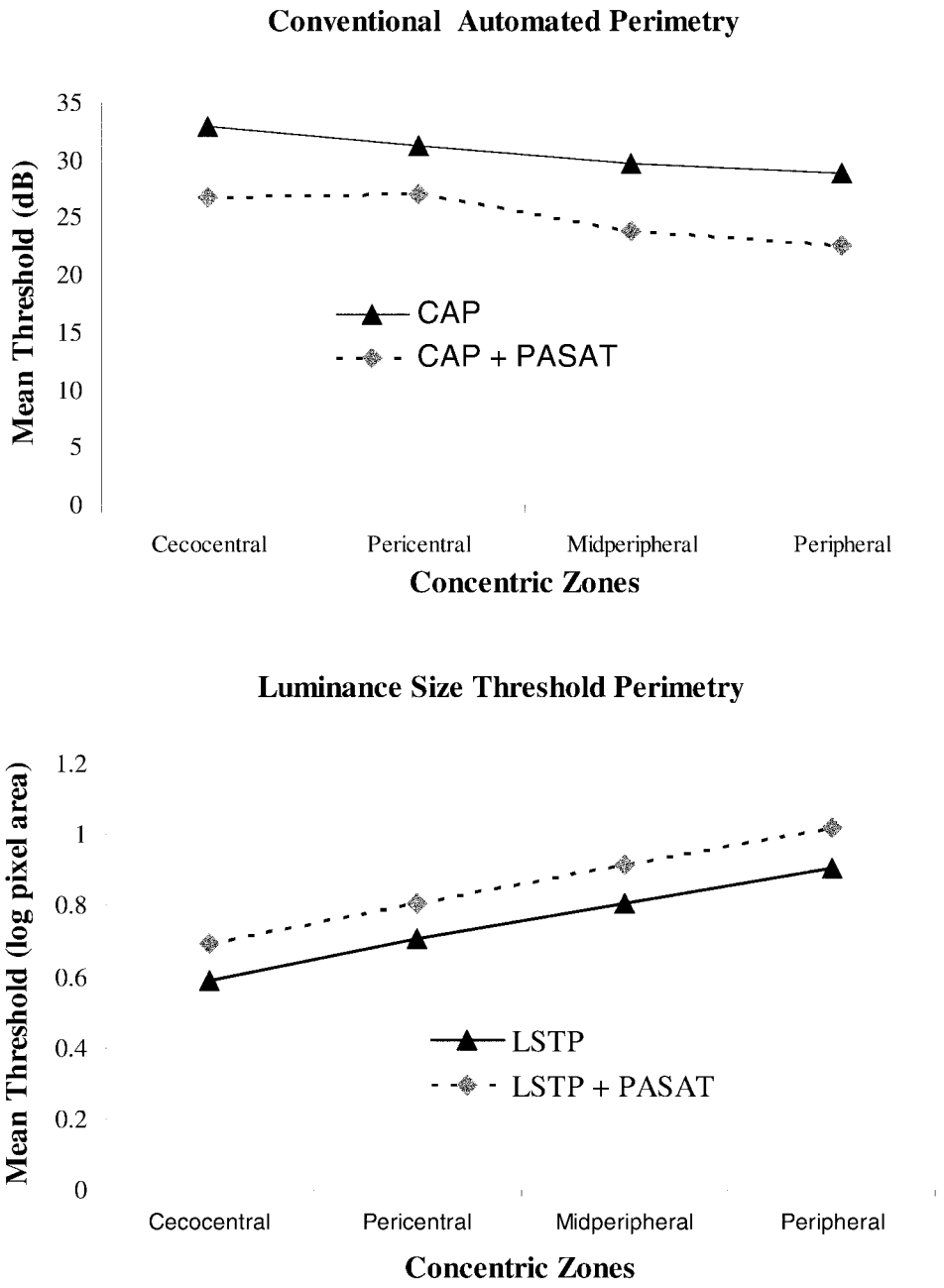

FIGURE 2. Reduction of sensitivity occurred in the four concentric zones of CAP with PASAT compared with CAP (*top*) and LSTP (*bottom*). There was a constant eccentricity effect with either test, with or without a foveal loading task. The four zones are at approximately 3°, 9°, 15°, and 21° eccentricity (*left* to *right* on the *x*-axis).

fields than did LSTP (Fig. 5). The most frequent defect was a generalized depression of the visual field but nerve-fiber-bundle–like defects were also noted. Although the different scales of the two tests make comparisons problematic, there appeared to be a similar pattern across the visual field and percentage of decrement with the two tests. We anticipated that using larger scaled stimuli in the periphery would provide a more salient stimulus and lessen the effect of divided attention. Our results do not support this notion.

The finding that the dual task significantly increased the test time and false-positive and false-negative responses in CAP indicates a loss of reliability. CAP is a demanding test to take, requiring prolonged concentration. Due to factors such as response indecision and fatigue, subjects may have difficulty performing CAP. In these conditions, anxiety and resultant loss of attention may further affect the outcome of the test.[23,24]

It is well known that concurrent presentation of a foveal task raises peripheral light sensitivity thresholds.[25,26] Plainis et al.[27] measured luminance thresholds at 5°, 10°, 20°, and 30° during conditions of no foveal load and low-, medium-, and high-load conditions. They found that the increase in threshold, between 5° and 10°, from the foveal load was greater than at more peripheral eccentricities. They also found the effect of the magnitude of the foveal load was less dependent on eccentricity beyond 10° eccentricity. We, like others, found a constant increase in luminance threshold with eccentricity, with and without a foveal load.[28,29] However, our percentage increase in thresholds using a high-load auditory stimulus task gave a similar increase in luminance threshold.

Rantanen and Goldberg[30] investigated the change in threshold with two levels of an auditory tone counting task in 13 normal subjects, by using a Goldmann perimeter. With the tone counting tasks, participants were required to keep track

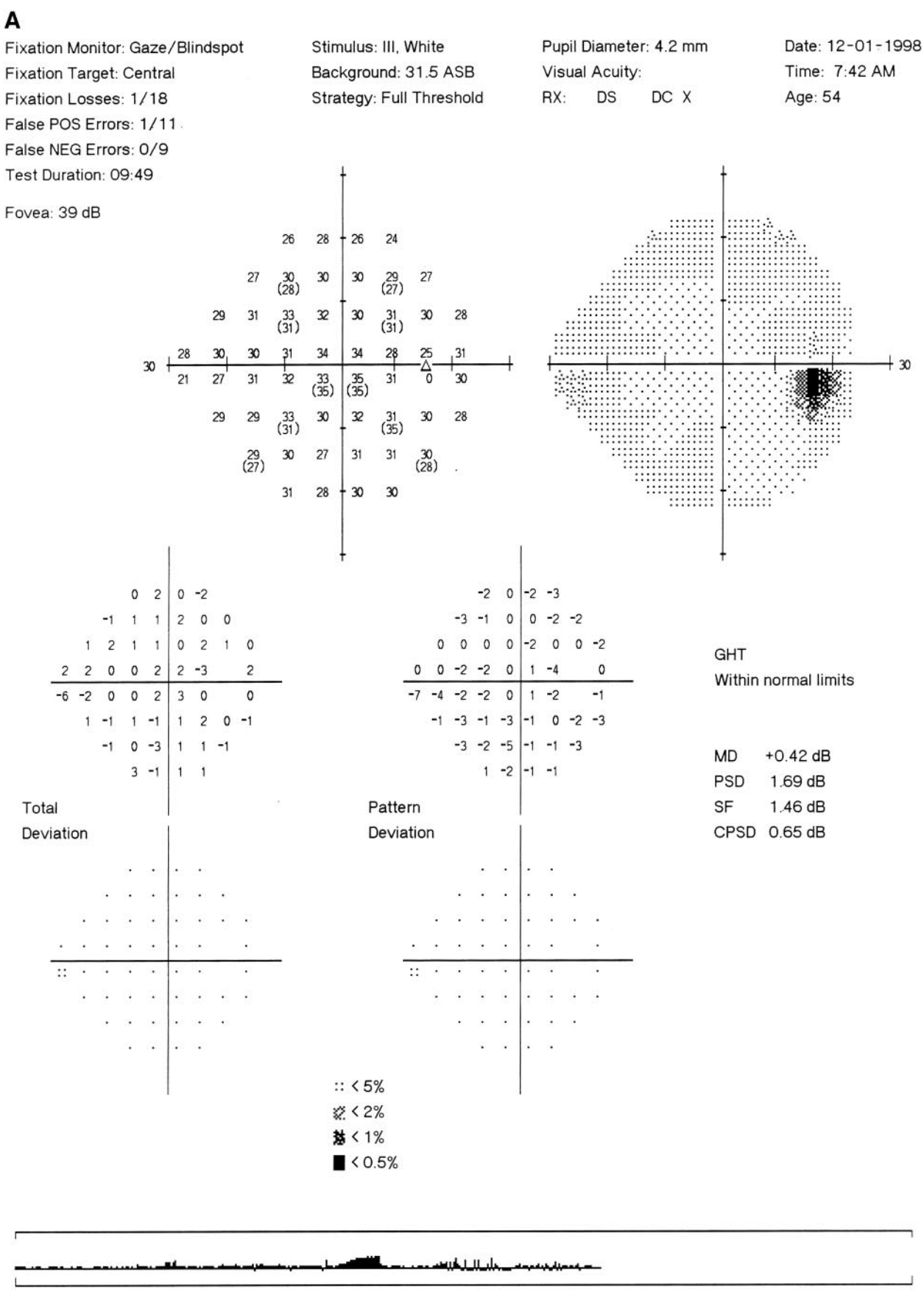

FIGURE 3. Typical example of a patient with the baseline visual field shown in (**A**) and the same patient with concomitant administration of the PASAT in (**B**). Note the generalized reduction in sensitivity (mean deviation = −2.10 dB) with irregularities simulating visual field defects.

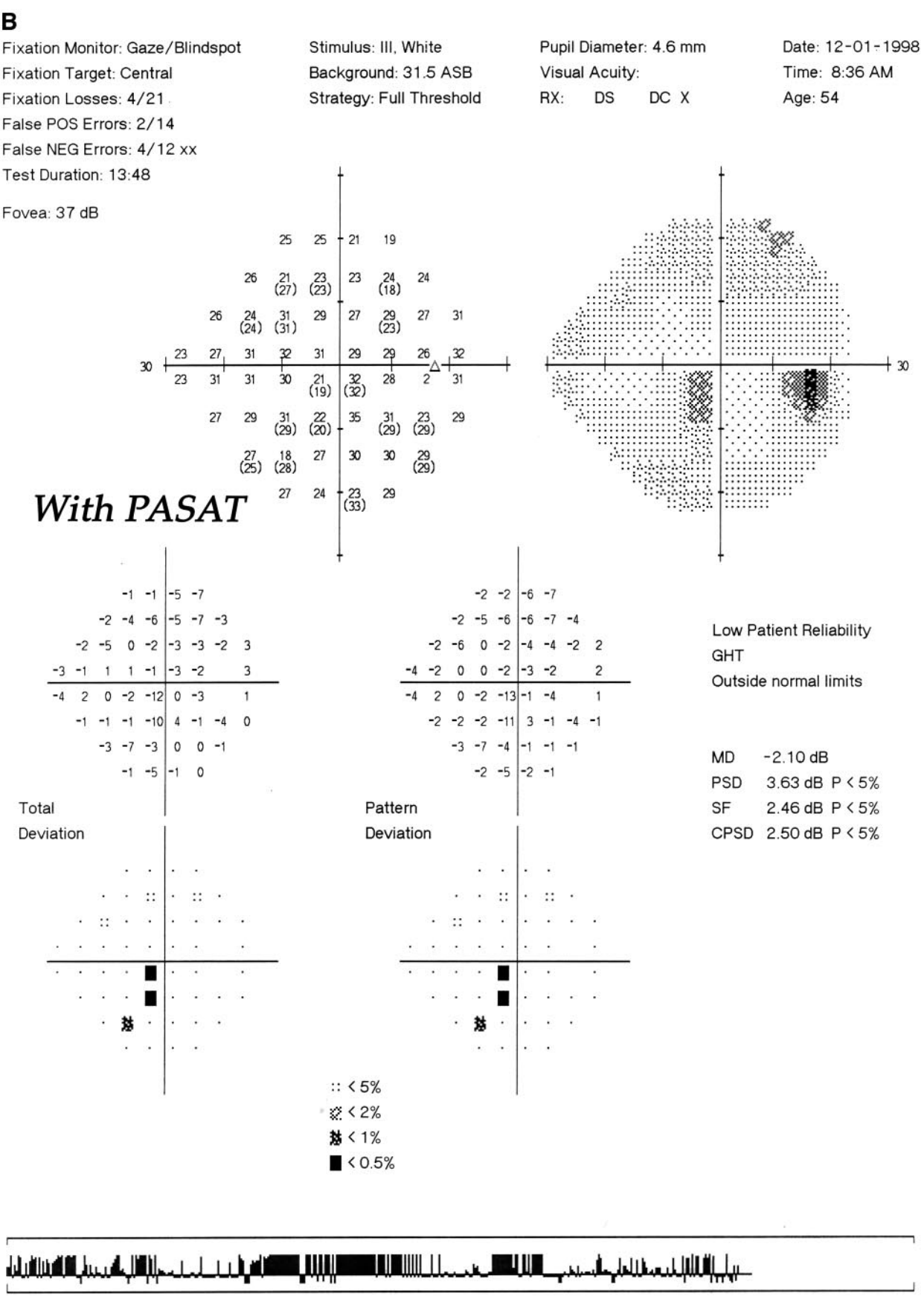

FIGURE 3. (*Continued*).

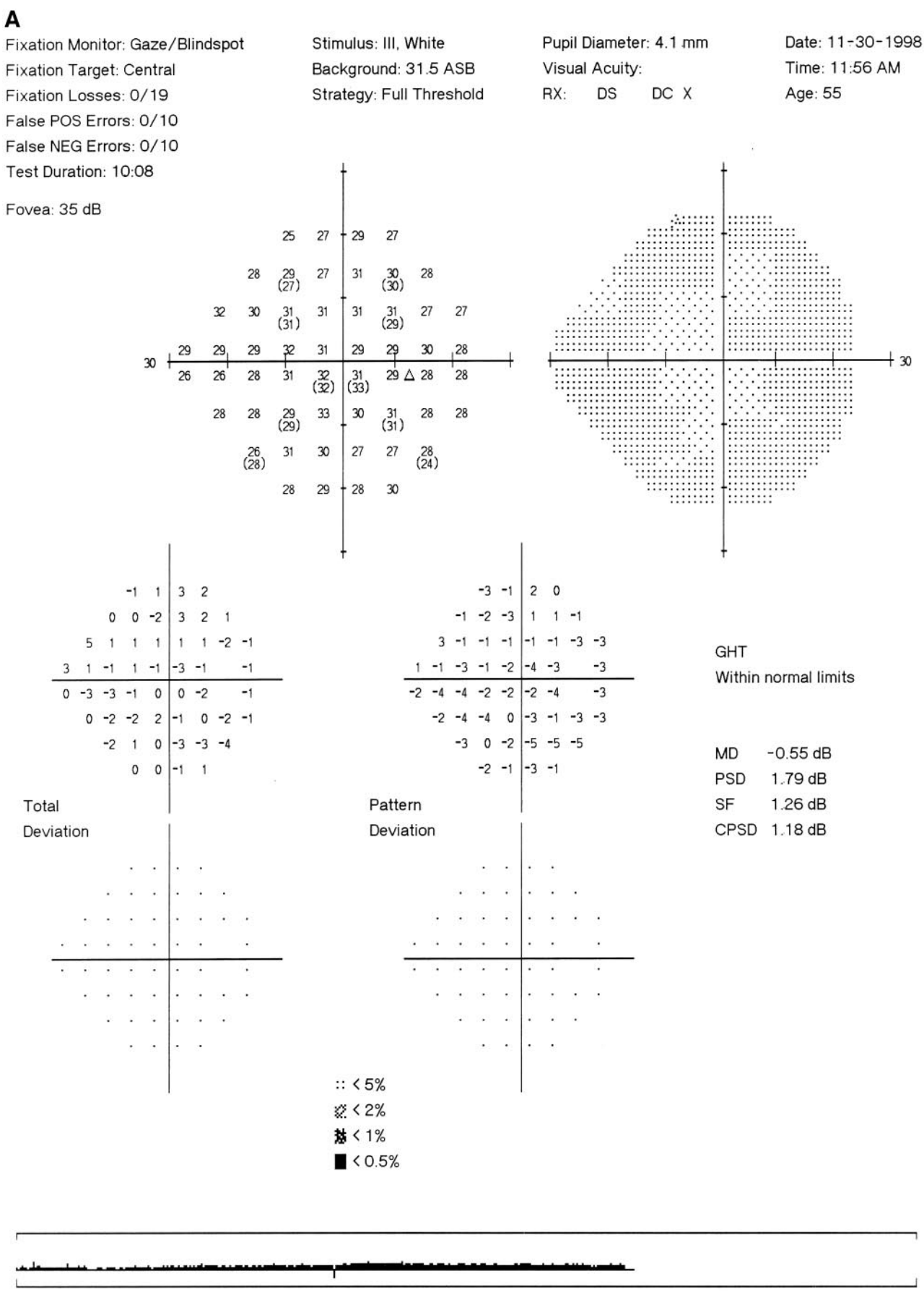

FIGURE 4. An example with a more pronounced effect of the PASAT can be seen by comparing (**A**) without PASAT and (**B**) with PASAT. Note the almost constant eye movements recorded on the gaze tracker at the *bottom* of (**B**). This commonly occurred during administration of the PASAT.

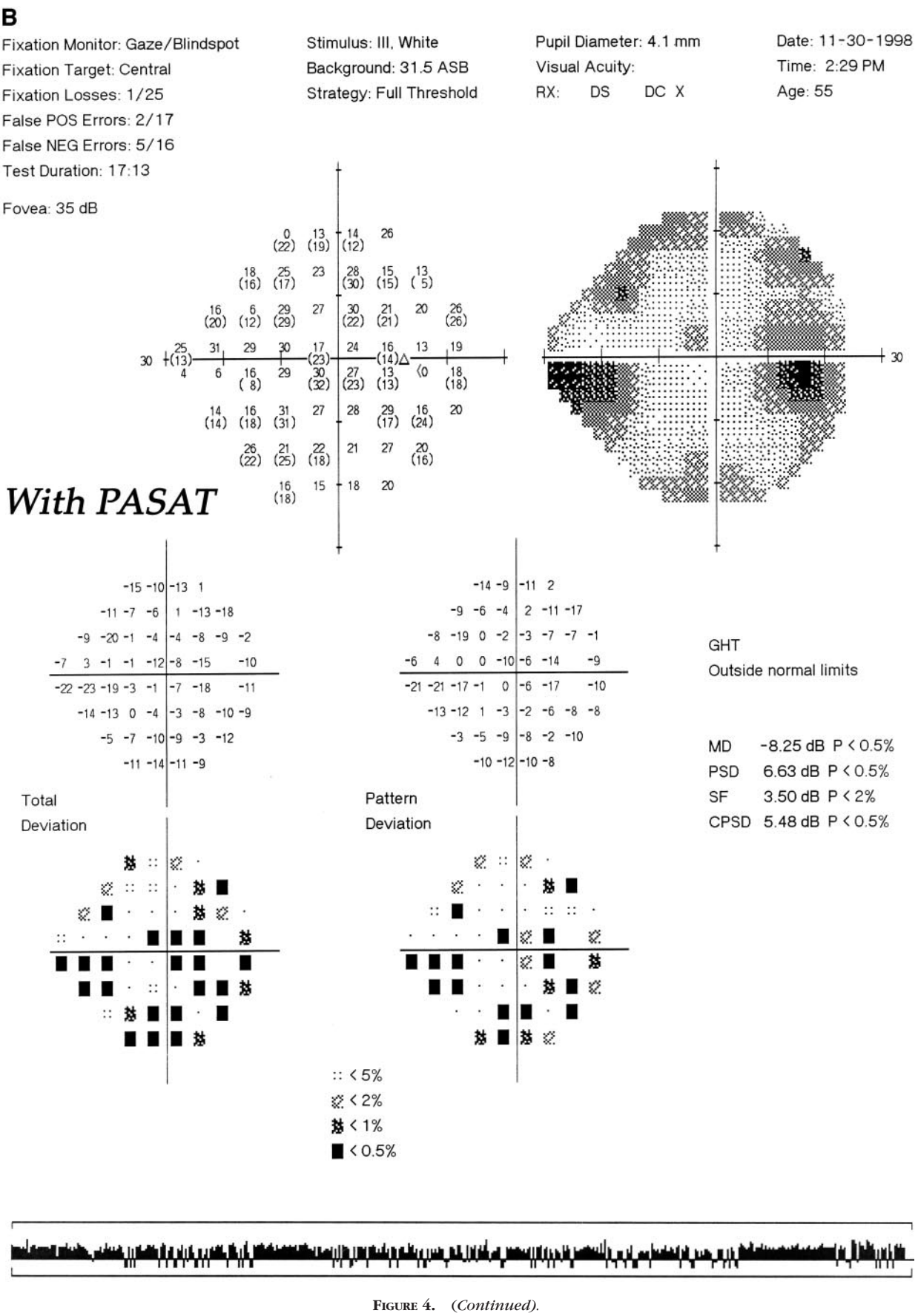

FIGURE 4. (*Continued*).

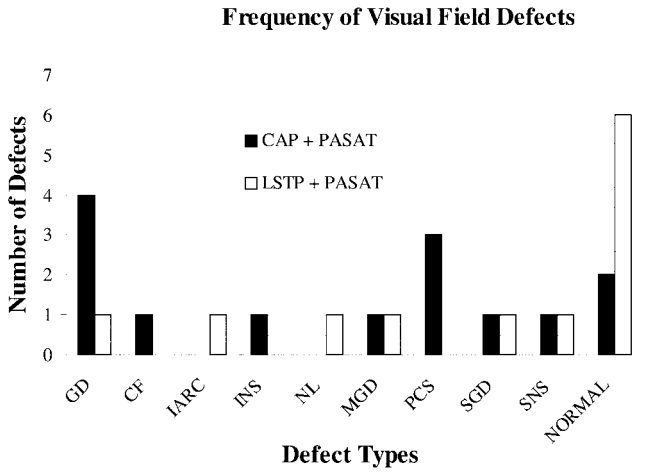

FIGURE 5. Frequency of defects found in CAP and LSTP when tested simultaneously with PASAT showing that CAP had fewer normal and more visual field defects than LSTP. GD, generalized depression; CF, contracted field; IARC, inferior arcuate; INS, inferior nasal step; NL, nasal loss; MGD, mild generalized depression; PCS, paracentral scotoma; SGD, severe generalized depression; SNS, superior nasal step.

of one of three auditory frequencies and count tones of a specified frequency while Goldmann perimetry was performed. For the moderate workload condition, subjects were asked to respond to every fifth tone of the lowest frequency. For the high-workload condition, subjects had to keep track of two frequencies and respond. These investigators found the mean area of the visual field was reduced to 92.2% with the medium workload and to 86.4% with the heavy workload.[30] Our results are similar. Also, the visual field constriction in the Rantanen and Goldberg study, like the one in ours, was not uniform and resulted in shape distortion of isopters. In addition, they reported greater relative constriction of vertical compared to the horizontal dimension of the isopter.

Rantanen and Goldberg[30] found a 4% decrement in auditory task performance with the moderate loading task and a 19% decrement with the difficult loading task. We found a 3% to 5% decrement in correct answers on the PASAT during perimetry, suggesting that our loading task was of the moderate mental workload variety.

Our results show that divided attention with a moderately difficult auditory task significantly affects performance on conventional differential light threshold perimetry and LSTP, a type of perimetry in which the stimulus is scaled, and the smallest sized stimulus is found at each test location. Our patients had significantly lower sensitivity and irregularities in the visual field that could mimic nerve fiber bundle defects. Our results suggest that, during perimetry, subjects who are distracted or anxious may produce visual field abnormalities that are indistinguishable from, for example, nerve fiber bundle defects due to disease.

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