Useful Field of View Performance in the Intact Visual Field of Hemianopia Patients

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Purpose. Postchiasmatic brain damage commonly results in an area of reduced visual sensitivity or blindness in the contralesional hemifield. Previous studies have shown that the ipsilesional visual field can be impaired too. Here, we examine whether assessing visual functioning of the "intact" ipsilesional visual field can be useful to understand difficulties experienced by patients with visual field defects.

Methods. We compared the performance of 14 patients on a customized version of the useful field of view test that presents stimuli in both hemifields but only assesses functioning of their intact visual half-field (iUFOV) with that of equivalent hemifield assessments in 17 age-matched healthy control participants. In addition, we mapped visual field sensitivity with the Humphrey Field Analyzer. Last, we used an adapted version of the National Eye Institute Visual Quality of Life-25 to measure their experienced visual quality of life.

Results. We found that patients performed worse on the second and third iUFOV subtests, but not on the first subtest. Furthermore, patients scored significantly worse on almost every subscale, except ocular pain. Summed iUFOV scores (assessing the intact hemifield only) and Humphrey field analyzer scores (assessing both hemifields combined) showed almost similar correlations with the subscale scores of the adapted National Eye Institute Visual Quality of Life-25.

Conclusions. The iUFOV test is sensitive to deficits in the visual field that are not picked up by traditional perimetry. We therefore believe this task is of interest for patients with postchiasmatic brain lesions and should be investigated further.

Keywords: useful field of view, postchiasmatic lesions, National Eye Institute Visual Quality of Life-25, Humphrey field analyzer, ipsilesional visual field, homonymous hemianopia

Homonymous visual field defects are a common result of postchiasmatic lesions. They reveal themselves as areas of reduced visual sensitivity or blindness, in the contralesional visual hemifield. These visual field defects can have severe debilitating consequences. Patients often experience problems in their daily life in perceptual and mental functions, such as reading and spatial orientation. Furthermore, many patients report problems avoiding obstacles while walking and many are forced to quit driving because they no longer meet the visual standards required for a driver's license.[1] In the Netherlands, the requirements for patients with visual field defects include a minimum visual field extension of at least 90° horizontally measured with traditional perimetry techniques, no decreases in other visual functions, approval by an ophthalmologist for driving, and passing a driver's examination.[2]

Traditional perimetry techniques measure sensitivity to a local light source at different locations in the visual field and provide characteristics of the visual field defect, that is, location, size and depth.[3] Areas outside the defect are called the "intact" visual field and are often assumed to be fully functional. Patients' difficulties are usually thought to directly or indirectly result from the location and extent of the defect itself. Rehabilitation thus mainly focuses on compensation with eye movements, displacement of the visual field (e.g., with monocular or binocular prisms), and on restoration of the visual field defect.[4] Previous research showed, however, that objective measures of the visual field defect cannot fully explain patients' daily life experiences.[5–7] In addition, the remaining intact visual field is often impaired as well (for a review see[8]). This defect includes tasks that measure contrast sensitivity,[9] gestalt recognition,[10] processing speed,[11] reaction time, and double-pulse resolution.[12] In addition, patients with hemianopia may not only suffer from pure sensory deficits, but also from other processing deficits, such as slow visual search[13] and decision making.[14] Here, we examine whether assessing visual functioning of the intact visual field can be useful to better understand the difficulties experienced by patients with postchiasmatic brain damage.

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The useful field of view (UFOV) has been defined as the area from which visual information can be extracted within one glance, without making any head or eye movements.[15] Rizzo and Robin[16] reported decreased sizes of the UFOV in two patients with hemianopia. This decrease was not merely caused by the visual field defect, as indicated by a traditional perimetry technique. Instead, many erroneous responses occurred for targets presented outside the visual field defect as well. Now, the UFOV test quantifies the useful field of view by measuring the minimal presentation durations in three subtests[17] (Visual Awareness Research Group, Punta Gorda, FL). These subtests include an identification task, a dual identification and localization task, and the same dual task with distractors. Previous research showed relationships between performance on the UFOV test and many perceptual and cognitive functions (for a review see[18]) as well as daily life activities.[19–21] For example, UFOV performance predicts driving ability as well as the speed at which everyday living tasks can be performed, such as counting spare change and reading ingredients on a food can. Although the observed relations differ between populations and activities,[20,22,23] these findings suggest that the UFOV may be able to explain difficulties experienced by patients with hemianopia that cannot be explained by perimetry outcomes alone.

In this study, we investigated UFOV performance of patients with hemianopia. To exclude obvious effects of vision loss in the contralesional visual field, we measured UFOV performance in the ipsilesional, intact hemifield only (iUFOV). That is, we presented stimuli throughout the visual field (as in the standard UFOV[24]), but only responses to stimuli presented in the ipsilesional half-field were included in the adaptive staircase scoring procedure. The same half-field assessment procedure was applied in controls. Patients were informed that the stimuli could also appear in their blind field, and were asked to respond to the best of their ability, guessing if necessary. This method forced participants to spread their attention throughout the visual field as they have to in daily life. In accordance with the findings from Rizzo and Robin,[16] we expected patients with hemianopia to perform worse on the second and third subtasks compared with a group of healthy control subjects. In addition, we explored patients' subjective visual functioning as assessed with an adapted version of the National Eye Institute – Visual Functioning Questionnaire-25 (NEI VFQ-25), a vision-related quality of life questionnaire.[25]

Methods

Subjects

We included 18 patients (15 males, 3 females) with visual field defects owing to postchiasmatic brain lesions. Their mean age was 57.3 years (SEM, ±4.5 years; range, 22–81 years). The visual field defects resulted from different causes, including ischemia and surgery, resulting in a variety of visual field defects (Table 1; for a full description see[26]). We also recruited an age-matched control sample of 18 subjects (8 males, 10 females) with normal or corrected-to-normal vision. Their mean age was 56 years (SEM,± 3.4 years; range, 28–81 years). Participants were excluded if they reported the presence of a neurologic, psychiatric, or ocular impairment that might influence attention or vision other than hemianopia, including neglect. Four patients and one control participant were unable to complete all three iUFOV subtasks owing to fatigue. They were therefore excluded from our statistical analyses. The study was part of a larger project, which was approved by the medical ethical committee Arnhem-Nijmegen (NL58053.091.16) and conducted in accordance with the declaration of Helsinki. All participants provided written informed consent before data collection.

Procedure

Before their visit, all subjects received a copy of the Dutch translation of an adapted version of the NEI VFQ-25 to fill out.[25,27] Upon their visit, patients' visual fields were assessed with the Central SITA-FAST 30-2 program of the Humphrey Field Analyzer (HFA) II (Carl Zeiss Meditec Group, Jena, Germany) by one of the authors (AG or KW). Supplementary Figure S1 shows the visual field defect measured for each patient. Then, patients performed the line bisection task to investigate visual neglect. Control subjects did not perform these two measures. Next, we measured distance visual acuity with the Freiburg visual acuity test[28,29] of all subjects at 4.5 m. Last, we performed two psychophysical measures, of which the order was reversed every other patient to counterbalance for the effects of fatigue, namely a scene perception task, which is described elsewhere,[26] and the iUFOV, which is the focus of the present paper. During the psychophysical tasks, we used calibrated eye tracking to verify online that the participants maintained a stable fixation at the center of the screen for the duration of each stimulus epoch.

Equipment

We used a Dell laptop running Windows 7 Professional 64-bit with an Intel Core i7-4712HQ CPU @ 2.30 Hz, 16 Gb of RAM and an Intel HD Graphics 4600 graphics adapter. The iUFOV task was done at a distance of 0.50 m with a 517 × 324 mm Dell U2412M monitor set at a resolution of 1920 × 1200 pixels and a refresh rate of 60 Hz. The stimulus presentation software was written in Matlab R2016a (Mathworks, Inc., Natick, MA) using the Psychtoolbox-3.[30–32] We used a head and chin rest to stabilize participants' heads. Gaze was monitored with an Eyelink 1000 remote (SR Research, Ontario, Canada) to ensure proper fixation at during the stimulus presentation. Calibration of the eye tracker took place before the psychophysical tests.

iUFOV Task

We assessed participants' performance on three subtests in a custom version of the UFOV test (Fig. 1). Before we recorded the actual performance, participants received instructions and four practice trials on each subtest to familiarize them with the different subtests. The tests all measure the threshold presentation duration required by the subject to reach a performance of 75% correct. Each trial started with a white (36.87 cd/m^2) fixation box of 2.8° × 2.8° presented in the center of the screen on a black background (0.133 cd/m^2; 276% Weber contrast). Participants were instructed to keep their gaze inside this fixation window during the stimulus presentation. We monitored the participant's fixation stability during the stimulus presentation live with calibrated eye tracking. After 1 second, one of three stimulus displays was presented, which was then replaced by a random dot pattern mask. The content of the stimulus and the participants' task depended on the subtest as described elsewhere in this arti-

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Table 1. Characteristics of Patients Diagnosed With Hemianopia and Control Participants*

Patient No.	Age (Years)	Lesion Age (Months)	Lesion Etiology	Affected Brain Hemisphere	Mean Deviation	Far Visual Acuity (Logmar)	Line Bisection Deviation Relative to VFD (mm)	Line Bisection Absolute Deviation (mm)	Included in Statistical Analyses
HP01	77	11	Hemorrhagic	R	−12.3	0.01	2.3	0.89	1
HP02	68	8	Ischemic	L	−13.2	−0.13	0.2	2.9	0
HP03	26	295	Hemorrhagic	R	−11.0	−0.20	0.9	2.2	1
HP04	52	51	Surgery (tumor)	R	−17.2	0.20	3.2	9.1	1
HP05	71	20	Ischemic	R	−16.3	0.08	−0.9	3.6	1
HP06	22	19	Surgery (tumor)	R	−21.1	−0.09	2.2	11	1
HP07	63	20	Ischemic	L	−12.5	0.19	3.4	3.9	1
HP08	25	39	Surgery (cavernoma)	L	−17.6	−0.18	4.6	5.6	1
HP09	70	30	Ischemic	R	−14.8	−0.10	3.9	4.2	0
HP10	75	31	Ischemic	R	−9.71	0.23	0.9	2.3	1
HP11	74	35	Ischemic	L	−6.28	0.23	0.1	1.8	1
HP12	64	32	Ischemic	L	−14.5	−0.16	2.9	3.7	1
HP13	60	30	Hypoxic–ischemic encephalopathy	R	−13.6	−0.12	7.5	7.5	1
HP14	36	84	Ischemic	R	−15.9	−0.13	−2.0	3.9	1
HP15	50	151	Ischemic	R	−12.8	−0.15	3.0	3.9	1
HP16	81	68	Ischemic	R	−17.2	0.44	−4.0	5.9	0
HP17	70	33	Hemorrhagic	R	−15.1	0.09	4.8	5.2	1
HP18	48	161	Surgery (tumor)	R	−17.0	−0.10	−0.5	6.3	0
Included patients , mean (SEM)	55 ± 5.3	61 ± 20	–	–	–14.0 ±1.0	0.00 ± 0.04	1.8 ± 0.65)	4.6 ± 0.77	N = 14
Control, mean (SEM)	56 ± 3.4	–	–	–		–0.10 ± 0.07		–	N = 17

*Line bisection scores represent the difference between the center of the line and the patient's response relative to their VFD (positive values represent errors towards the defect) or the absolute deviation from the midpoint.

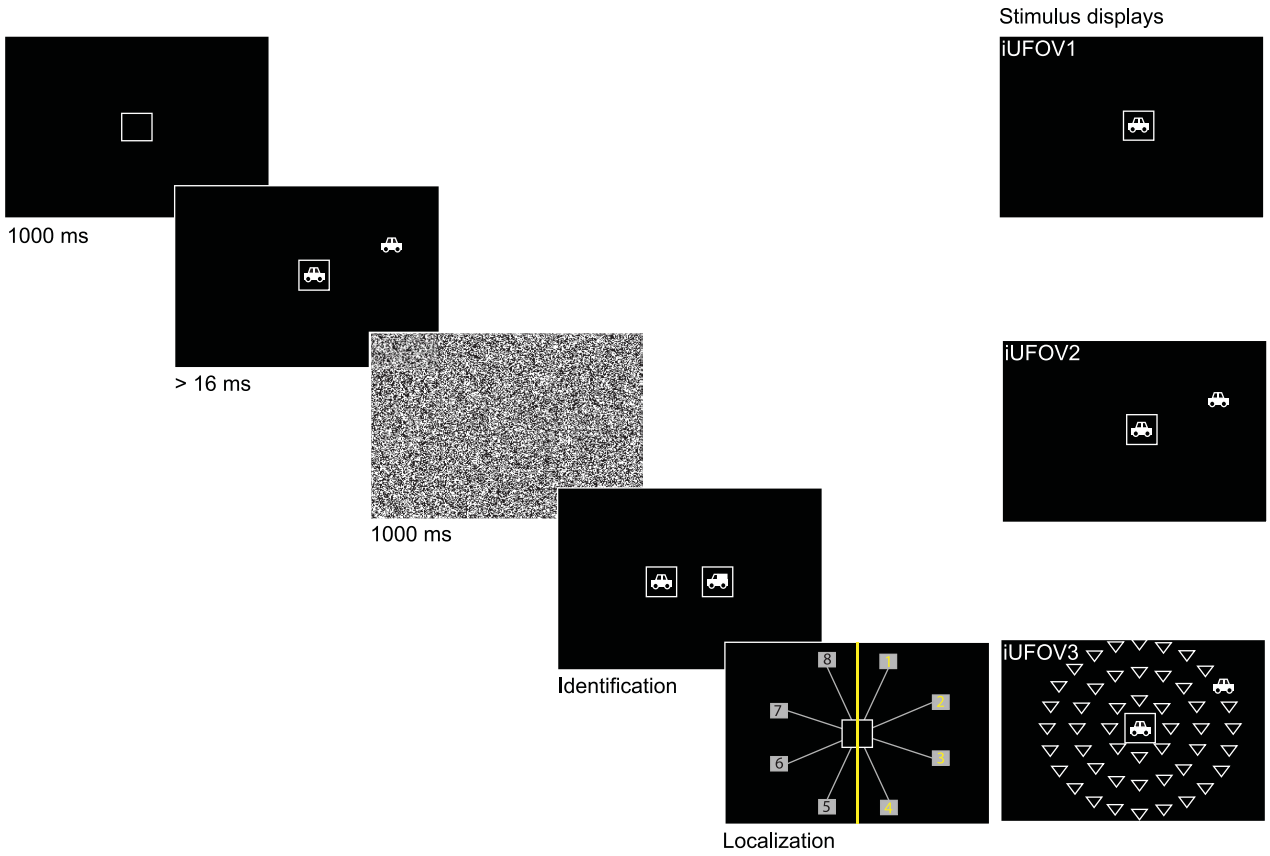

Figure 1. Visual representation of the iUFOV task. A fixation box was presented and after 1 second, one of three stimulus displays was presented. The presentation duration depended on performance of the participant to obtain a 75% correct performance. Then, the stimulus was replaced by a random dot mask. Subjects were instructed to fixate at the center of the screen until the mask appeared to ensure that stimuli presented on the left/right side of the screen appeared in the left/right hemifield. After 1 second, participants performed the identification task, where they indicated which of two stimuli was presented in the center of the screen. In iUFOV2 and iUFOV3, participants also performed the localization task. Only trials where the peripheral stimulus was presented in the intact hemifield (patients), or left or right hemifield (controls) were included in the score. This figure represents the task for a hemianopia patient with a left-sided visual hemifield defect, or a control patient who was assigned a right-sided visual half-field task. Only stimuli presented at the locations with yellow numbers, on the right-hand side of the yellow line, were included in the score.

cle. Participants were instructed to respond as accurately as possible and guess if necessary. They were allowed to shift their gaze while answering. The presentation duration of the stimulus depended on the subject's performance and was adapted online according to a QUEST psychometric procedure.[33] This procedure combines prior knowledge of the psychometric curve and performance on previous trials to estimate the most probable Bayesian estimate of the threshold. We calculated the mode of the posterior density function from 52 trials to determine the threshold. The subtests were always performed in the order listed elsewhere in this article.

iUFOV1. In this subtest, a full contrast stimulus (276% Weber), either a car or truck (1.7° × 1.2°) was presented while the subject maintained fixation within the fixation box (Fig. 1). The subject was instructed to indicate which of the two stimuli was presented. The front of the truck stimulus (left side) used in the commercially available UFOV test is equal to the front of the car stimulus. To make the two stimuli distinguishable for patients whose visual field defect occludes the right half of the stimuli, we adapted the truck (Fig. 1). That is, we shifted the front window further to the front and added a box at the right (back) side of the truck.

iUFOV2. In addition to the stimulus presented in iUFOV1, another stimulus of the same size and contrast as the central stimulus (276% Weber contrast; 1.7° × 1.2°) was presented at 12.9° eccentricity in one of eight equally spaced directions across the left and right hemifield. These directions were rotated 22.5° compared with the commercially available UFOV test to avoid the vertical midline of the visual field (Fig. 1). Depending on the anatomic location and extent of the patient's lesions, some of these stimuli could fall within the visual defect of the patient. We expected that presentation times would be longer and highly variable throughout the visual hemifield that contained the defect. For example, in a truly blind field, the presentation time would be infinite, because the stimulus can never be seen. Relative field defects may require more time than the intact visual field. Deriving one UFOV score throughout the visual field would be an aggregation of different scores that would be too low for defective areas of the field while it would be too high for the intact field areas. Another approach would be to split the visual field into a defective and intact visual field and derive two UFOV scores for each type of field independently. However, during a pilot test we observed that the presentation times for the two fields became so different that they became a clue as to the location of the stimulus. There-

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fore, we decided to measure performance in the intact hemifield alone. To that end, we excluded trials where the peripheral stimulus appeared in the contralesional visual hemifield from the QUEST procedure. This way, the stimulus duration threshold to reach a 75% correct performance level was based only on the 52 trials in which the peripheral stimulus appeared in the ipsilesional field, thus providing an assessment of the patient's intact field. For control participants, only responses to trials in which the peripheral stimulus appeared in either the left or the right visual field (randomized across participants) were included in the QUEST procedure. Participants were instructed to indicate both the identity of the central stimulus and the location of the peripheral stimulus. They were explicitly told that the peripheral stimulus was always a car and patients were informed that it could occur in their defective field as well. They were not told that these trials were excluded from their performance score. This method forced all participants to spread their attention across the visual field as in daily life, thus maintaining the ecological validity of the standard UFOV test.[19–21] Note that by presenting eight alternatives, the guessing correct probability for stimulus locations was still 1/8 (as in the standard UFOV) resulting in an overall guess rate of 1/16 for the identification and localization task combined for patients and control participants alike. To ensure that peripheral stimuli presented on the left or right side of the screen appeared in the subjects' left or right hemifield, participants had to fixate inside the fixation box until the stimulus display had disappeared. They were allowed to shift their gaze when responding to the different alternatives at the end of the trial.

iUFOV3. This subtest is similar to iUFOV2, except for the presence of forty-eight 2.5° × 2.5° distractors (276% Weber; Fig. 1). These were presented in three rings at a 4.0°, 8.6°, and 12.9° eccentricity throughout the entire visual field. The instructions were the same as for iUFOV2, that is, identify the central stimulus and localize the peripheral stimulus and fixate at the center during stimulus presentation. In addition, we instructed participants to ignore the distractors. The stimulus duration threshold was again based only on the 52 trials in which the peripheral stimulus was presented to the intact hemifield (patients) or either one of the two hemifields (controls). Once more, the participants were kept unaware of the fact that their ability to localize stimuli in the blind/opposite hemifield had no influence on the presentation durations.

Adapted NEI VFQ-25

We used an adapted Dutch version of the NEI VFQ-25 questionnaire[25,27] to quantify the perceived visual quality of life of both patients and healthy control participants. We slightly adapted and modernize the questionnaire to increase its' sensitivity. We analyzed three custom scales (Supplementary Table S1) traffic, digital tools, and visual speed and attention in addition to the standard scales, that is, general health, general vision, ocular pain, near activities, distance activities, social functioning, mental health, role difficulties, dependency, driving, color vision, peripheral vision, and the mean total score. We created the first subscale traffic because many patients did not receive a score on the driving subscale. The reason is that many patients had stopped driving of their own volition, but did not necessarily attribute this decision fully to their visual problems. In this case, the NEI VFQ-25 manual instructs to record the score as missing. Even though these patients are not driving anymore, moving through traffic on foot or by bike is still an important ability. We therefore included three additional questions regarding these types of mobility, based on the driving questions. Because patients may have attributed their decision to stop driving to other problems related to their brain damage, we attributed 0 points to everyone who stopped driving in this custom subscale. The second custom subscale, digital tools, was added because none of the NEI VFQ-25 questions are specifically dedicated to the use of digital tools such as computers and mobile phones even though modern society relies heavily on them. It only includes two questions that use television and cinema as examples. The last custom subscale, visual speed and attention, conceptually relates to the UFOV test. It was composed of scores for a subset of original NEI VFQ-25 questions and scores for questions that we added for the traffic and digital tools subscales (for details see Supplementary Table S1). The selected questions addressed activities that have been related to UFOV performance in the past.

HFA

We measured the severity of the visual field defect with automated perimetry: the HFA. This technique maps contrast sensitivity throughout the visual field by presenting a local light source. Upon detection of this light, the patient should press a button to indicate its presence. Patients are instructed to fixate on a central light, while the target lights are briefly presented (200 ms) at randomized locations. The HFA measures the contrast of the light source compared with background lighting that is necessary for the patient to detect it. Its results present a map of the sensitivity throughout the visual field. A number of standardized measures aggregate performance over the entire visual field in reference to an age-matched norm such as the mean deviation and visual field index. We did not use these standardized summary measures in our analyses because they tend to factor out the effect of age, and our adapted NEI VFQ-25 and iUFOV scores are not adjusted for age. Instead, we calculated the mean HFA score (in decibels) of the entire visual field measured with both eyes from the results given in the numerical display.

Statistical Analysis

We analyzed the data with Matlab R2016a (Mathworks, Inc.) using the statistics and machine learning toolbox. We used a mixed-design ANOVA to compare the patients' and control subjects' iUFOV1–3 performances. Mauchly's test of sphericity showed that the assumption of sphericity was violated, $\chi^2(2) = 8.07$, $P = 0.018$. We therefore report the Greenhouse-Geisser corrected results.

We used an arcsine-root transformation, that is, $\arcsin\left(\sqrt{x/100}\right)$, on the adapted NEI VFQ-25 subscale scores, because their values are by definition bounded between 0 and 100.[34] Then, we investigated differences between patients and control participants with separate *t*-tests to include all patients and controls who had a score on the subscale. We did not analyze differences between subscales. To correct for multiple comparisons, we used the false discovery rate (FDR) correction.

In addition to differences between patients and healthy controls, we were interested in the value of the iUFOV test compared with the HFA in explaining everyday life difficul-

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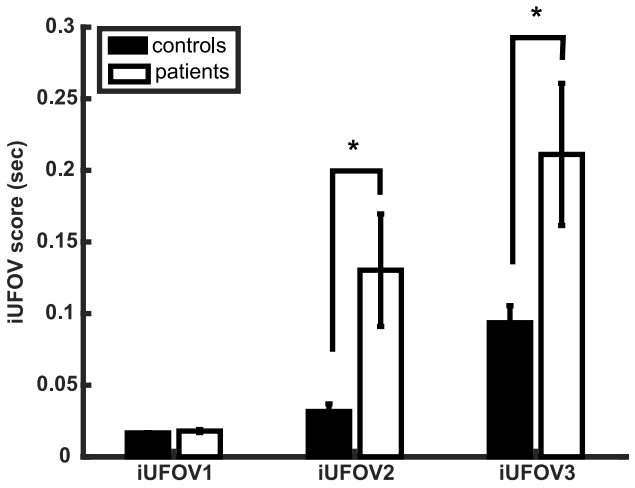

Figure 2. Mean (±1 SEM) iUFOV subtest scores for healthy control subjects (*black*) and patients with hemianopia (*white*). *Significant differences. Patients scored significantly higher, that is, worse, than control participants on iUFOV2 and iUFOV3, but not on iUFOV1.

ties of patients. Toward that end, we performed separate Pearson correlation analyses for each subscale, including the three custom subscales, and the composite scale with iUFOV scores and HFA scores. Then, we compared the strength of the correlations between the adapted NEI VFQ-25 and iUFOV scores with those between the adapted NEI VFQ-25 and the HFA scores. We did not apply correction for multiple comparisons to retain sensitivity of these exploratory analyses. Because iUFOV2 and iUFOV3 were strongly correlated ($r = 0.77$, $P < 0.05$) and iUFOV1 displayed hardly any variance across subjects, we summed the scores of all three subtests into one composite score. We repeated all analyses with age included as a covariate to ensure our results were not driven by age differences despite our efforts to match our control and patient groups on age.

Results

A two-sample *t*-test revealed no difference between the patients' and controls' ages, $t(29) = -0.028$, $P = 0.98$. Levene's test showed that their variances were also not different, $F(1,29) = 3.62$, $P = 0.07$.

Intact Hemifield UFOV

Figure 2 compares the performance of patients and control subjects on iUFOV1 (identification task), iUFOV2 (dual task), and iUFOV3 (dual task with distractors). Note that higher scores represent worse performance in the intact hemifield (patients) or the left or right hemifield for controls. The scores discard performance in the contralateral field even though peripheral stimuli did appear in that hemifield during iUFOV2 and iUFOV3 (Methods). A mixed design ANOVA showed a significant interaction effect between group and subtest, $F(2,58) = 5.32$, $P_{GG} = 0.013$. Contrasts showed a larger increase in presentation time from iUFOV1 to iUFOV2 in patients than for controls, $F(1,29) = 7.33$, $P = 0.01$. The difference between iUFOV2 and iUFOV3 was not different between patients and controls, $F(1,29) = 0.38$, $P = 0.54$. Post hoc tests showed that patients scored significantly worse than controls on iUFOV2 ($\text{mean}_{\text{difference}} = 0.099$ seconds, $P = 0.01$) and iUFOV3 ($\text{mean}_{\text{difference}} = 0.12$ seconds, $P = 0.018$), but not on iUFOV1 ($\text{mean}_{\text{difference}} = 0.0013$, $P = 0.17$). Thus, patients needed longer presentation times to perform the double tasks than controls, but not the single identification task. In addition, patients' scores were better for iUFOV1 than iUFOV2 ($\text{mean}_{\text{difference}} = 0.112$ seconds, $P < 0.001$), which in turn were better than iUFOV3 ($\text{mean}_{\text{difference}} = 0.081$, $P = 0.003$). For controls, however, we found no difference between iUFOV1 and iUFOV2 scores ($\text{mean}_{\text{difference}} = 0.015$ seconds, $P = 0.81$). iUFOV3 scores were significantly higher than iUFOV2 ($\text{mean}_{\text{difference}} = 0.062$ seconds, $P = 0.01$) and almost significantly higher than iUFOV1 ($\text{mean}_{\text{difference}} = 0.077$ seconds, $P = 0.05$) for controls. Although we found no significant differences between the two groups' mean and variance of age, we repeated the analysis with age as a covariate to ensure our results were not driven by age. This mixed design ANCOVA yielded similar results (Supplemental Information S1). Age did not show any significant main or interaction effects.

NEI VFQ-25

Table 2 compares the scores of patients and control participants on the arcsine-root transformed scores for each NEI VFQ-25 subscale as well as the total score. Separate *t*-tests were performed to avoid list-wise exclusion owing to missing scores on one subscale. Many participants missed scores on the driving subscale because they had stopped driving for other reasons besides or instead of their reduced vision. The *t*-tests showed that patients scored lower on every subscale ($\text{mean}_{\text{difference}} > 0.30$, $P_{FDR} \leq 0.01$; Table 2) except ocular pain, $\text{mean}_{\text{difference}} = 0.052$, $t(29) = 0.38$, $P_{FDR} = 0.70$. We repeated the analyses with age as covariate and found similar differences between patients and controls (Supplementary Table S3). Furthermore, age did not show any significant main or interaction effects.

Exploring the Predictive Value of iUFOV for Daily Life Visual Functioning

To test if the iUFOV test might be able to predict daily life visual functioning, we calculated correlations between the total iUFOV score and the (transformed) adapted NEI VFQ-25 subscale scores in our patients (Fig. 3, *black bars*). We found a significant relationship between the Peripheral Vision subscale and iUFOV total score ($r = -0.62$, $P < 0.05$; Supplementary Table S2). The other subscales were unrelated to the total iUFOV scores ($r > -0.53$, $P > 0.05$). Likewise, we calculated correlations between the HFA score and the adapted NEI VFQ-25 subscales (Fig. 3, *white bars*). Here, we only found a significant correlation between the color vision subscale and mean HFA scores ($r = 0.63$, $P < 0.05$). The other subscales were not correlated ($r < 0.50$, $P > 0.07$). Because the parametric assumptions may not have been met for all subscales, we also calculated Spearman's rank correlations (Supplementary Table S2). Again, without correction for multiple testing, we found that the subscale peripheral vision was significantly correlated to the iUFOV total score ($r_S = -0.54$, $P < 0.05$), whereas color vision was significantly correlated with HFA ($r_S = 0.70$, $P < 0.05$). In addition, we found a significant

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Table 2. Comparison of the Arcsine-Root-Transformed VFQ Scores Obtained From Patients With Hemianopia and Control Subjects

Subscale	Patients Mean (SEM)	No. of Patients	Controls Mean (SEM)	No. of Controls	Statistics
Total	1.0 (0.048)	14	1.3 (0.023)	17	$t(29) = -6.46$, $P_{FDR} < 0.001$
General health	0.85 (0.046)	14	1.1 (0.041)	17	$t(29) = -4.02$, $P_{FDR} < 0.001$
General vision	0.93 (0.045)	14	1.2 (0.033)	17	$t(29) = -4.43$, $P_{FDR} < 0.001$
Ocular pain	1.4 (0.073)	14	1.4 (0.066)	17	$t(29) = 0.368$, $P_{FDR} = 0.72$
Near activities	1.1 (0.064)	14	1.3 (0.054)	17	$t(29) = -3.30$, $P_{FDR} = 0.003$
Distance activities	1.1 (0.073)	14	1.5 (0.042)	17	$t(29) = -4.84$, $P_{FDR} < 0.001$
Social functioning	1.2 (0.084)	14	1.5 (0.024)	17	$t(29) = -4.37$, $P_{FDR} < 0.001$
Mental health	0.96 (0.055)	14	1.3 (0.047)	17	$t(29) = -5.42$, $P_{FDR} < 0.001$
Role difficulties	0.96 (0.081)	14	1.5 (0.041)	17	$t(29) = -6.06$, $P_{FDR} < 0.001$
Dependency	1.3 (0.092)	14	1.6 (0.015)	17	$t(29) = -2.95$, $P_{FDR} = 0.008$
Driving	0.71 (0.18)	9	1.3 (0.041)	16	$t(26) = -3.80$, $P_{FDR} = 0.001$
Color vision	1.3 (0.086)	14	1.6 (< 0.001)	16	$t(28) = -2.79$, $P_{FDR} = 0.01$
Peripheral vision	0.69 (0.035)	14	1.5 (0.031)	17	$t(29) = -18.3$, $P_{FDR} < 0.001$
Traffic	0.85 (0.075)	14	1.3 (0.041)	17	$t(29) = -5.85$, $P_{FDR} < 0.001$
Digital tools	1.1 (0.097)	14	1.4 (0.063)	17	$t(29) = -2.73$, $P_{FDR} = 0.01$
Visual speed and attention	0.96 (0.061)	14	1.3 (0.036)	17	$t(29) = -5.75$, $P_{FDR} < 0.001$

P-values are FDR corrected. $N_{controls}$, number of control participants with a score; $N_{patients}$, number of patients with a score; P_{FDR}, FDR-corrected *P* value.

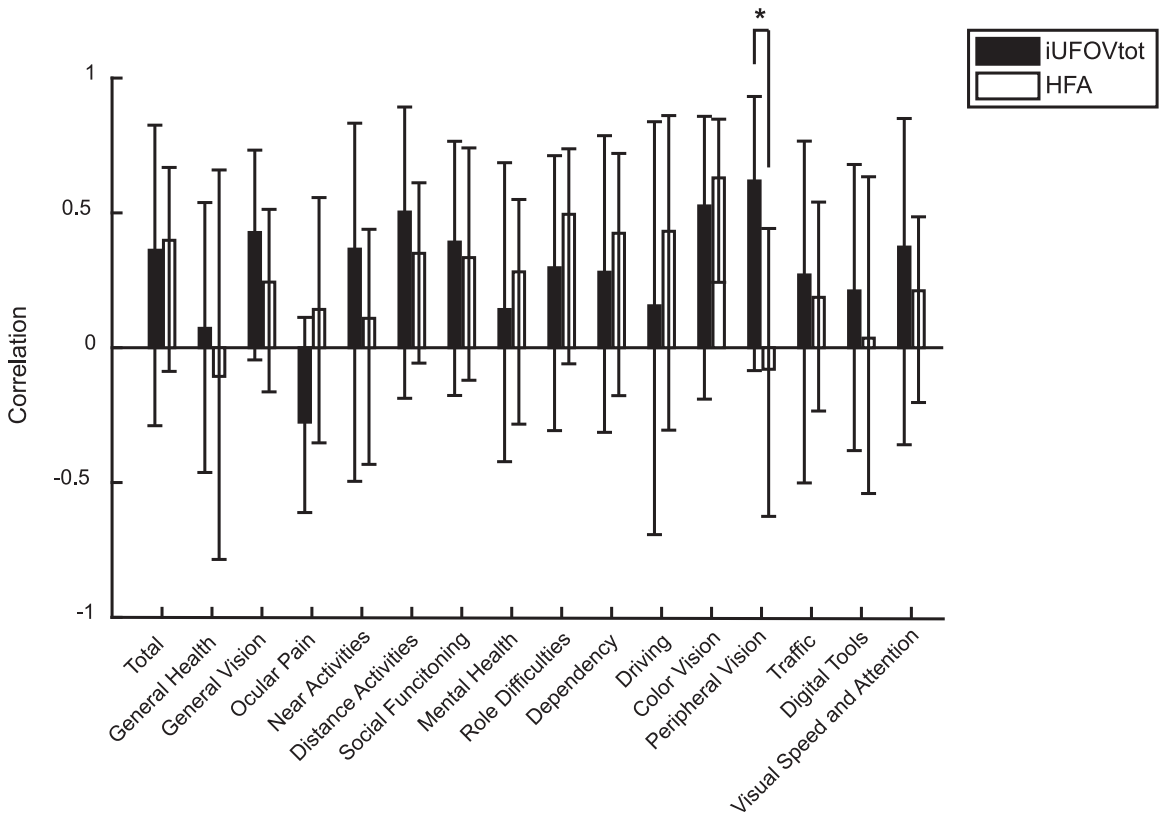

Figure 3. Correlations and 95% confidence intervals between adapted NEI VFQ-25 subscales and total iUFOV score (*black*) and between each NEI VFQ-25 subscale and HFA scores (*white*). Note that we multiplied correlations between iUFOV and NEI VFQ-25 with –1 to facilitate comparison with correlations between mean HFA scores and VFQ. *Significant difference between two correlations.

correlation between role difficulties and HFA ($r_S = 0.57$, $P < 0.05$).

Next, we compared the strength of the Pearson's correlations between iUFOV and adapted NEI VFQ-25 subscales scores with the strength of the correlations we found between mean HFA and adapted NEI VFQ-25 subscale scores. Because higher iUFOV scores represent a worse performance, whereas higher HFA scores represent better performance, the sign of their correlations with subscale scores should be reversed to reflect a similar meaning. We therefore multiplied the iUFOV correlations by −1 to facilitate comparison. That is, a positive correlation means that better iUFOV/HFA scores co-occur with higher adapted NEI VFQ-25 subscale scores. We found a significant difference for the peripheral vision subscale. This scale was more strongly correlated with the iUFOV total score than with the mean HFA score. However, it is important to note that this scale is composed of only one question. Moreover, patients' answers

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were divided among only two of four answer options (see Supplementary Fig. S2).

The visual speed and attention scale addresses daily life activities such as driving that have been linked to performance on the UFOV test[35] (Supplementary Table S1). We therefore expected this scale to be stronger correlated to total iUFOV scores than to mean HFA scores. However, we found no significant differences between correlations of this or the other custom scales.

Correlation HFA and iUFOV

Pearson's correlation showed no significant relationship between mean HFA scores and total iUFOV scores ($r = -0.52$, $P = 0.06$). However, the partial correlation between the two variables controlling for age was significant ($r = -0.60$, $P = 0.03$) as was the nonlinear Spearman correlation, whether or not age was included as a covariate ($r_{bivariate} = -0.59$, $P \leq 0.05$, $r_{partial} \leq 0.01$).

Excluded Patients

Four patients were not included in the analyses because they were unable to complete all three UFOV subtasks owing to fatigue. We found no differences between them and the included participants, except for performance on iUFOV1 and, for those who completed it, iUFOV2, which was significantly worse. We also found significantly higher scores for the peripheral vision subscale for this group, compared with included patients (Supplementary Table S4).

Discussion

In this study, we investigated whether the iUFOV task performed with the intact visual field can be useful in explaining difficulties experienced by patients' with visual field defects owing to postchiasmatic brain damage. As hypothesized, we found that patients had worse iUFOV2 and iUFOV3 scores than control participants, confirming that visual functioning of the intact visual field is in fact impaired. These results agree with previous research showing that the ipsilesional part of the visual field is affected in patients with hemianopia,[8–12] and extend the findings previously reported by Rizzo and Robin,[16] who measured UFOV size performed with the entire visual field.

Our finding that iUFOV1 scores were normal for patients suggests that foveal processing is in general unaffected in the intact half-field if the central stimuli can be distinguished, even if the stimulus is partly occluded by a visual defect. Another possibility is that iUFOV1 is not sensitive enough to pick up small impairments. Indeed, a floor effect has been reported for healthy participants in the past.[21,36,37] Yet, whereas healthy control participants in our study all reached the lowest, that is, best score, some patients did not. Furthermore, patients who were not included in the analyses because they were unable to finish all three iUFOV subtests did show reduced performance on this subtest. It is unclear why some patients could and others could not perform the iUFOV1 task with a single frame stimulus duration. The ones who needed longer stimulus presentations did not show consistent deviations from the rest of the group in terms of age, visual acuity, lesion type, location, or age, although two (HP06 and HP16) did reach the lowest, that is worst, HFA scores of the group.

As opposed to iUFOV1, patients' performance was clearly reduced for both iUFOV2 and iUFOV3, even though we did not include trials where the peripheral stimulus was presented in the contralesional hemifield in these scores. The random placement of the peripheral stimulus in the iUFOV task requires participants to spread their attention across the visual field as it keeps them unaware of the fact that only one hemifield is tested. This method is different from presenting stimuli in one hemifield alone. The latter would allow subjects to direct their attention toward the tested hemifield, giving them an advantage during testing that they do not have in everyday life. Our finding indicates that, although the ipsilesional field is unaffected according to traditional perimetry measurements, other aspects picked up by the iUFOV test, namely, simultaneously identifying central and localizing peripheral stimuli, reveal disturbances in this hemifield nonetheless. This finding agrees with previous reports of impairments in both lower level as well as complex task performance that relied on the ipsilesional field.[9,10,12,14]

Disrupted performance of patients could also be related to general attentional deficits, which is not an uncommon result of brain damage.[38,39] However, in HFA measurements the location of the stimulus is just as unpredictable, and thus should be equally affected by attentional deficits. Thus, the complexity of performing two tasks simultaneously instead of just one in iUFOV2 and iUFOV3 seems to disturb patients' ability more than a simple defocus of spatial attention. In addition, the increase in scores between iUFOV2 and iUFOV3 was similar for patients and healthy control participants, suggesting that patients are not abnormally disturbed by the presence of distractors. A greater influence of distractors would be expected if the patients suffered from general attentional deficits.

Alternatively, impaired performance may result from a reduced ability to perform the localization task itself. Perceptual distortions, for example, in size and orientation, have been reported for patients with hemianopia.[40–42] We cannot rule out the possibility that the task localizing the stimuli itself was more difficult for patients, because we did not test their performance on this task alone, in the absence of the central identification task. We found a negative nonlinear correlation between HFA scores and iUFOV performance as well as partial linear and nonlinear correlations with age as a covariate. This finding could imply that a lower sensitivity is related to lower speed in the ipsilesional field. However, it is important to note that the HFA score spans performance throughout the visual field, including the defect itself, which is likely the main source of variability in HFA scores, because our patients were highly variable in their visual field defects. The correlation between HFA and iUFOV scores could therefore also be a demonstration of the effects of the deficit extending into the ipsilesional field.

We found that patients scored lower on most subscales of the adapted NEI VFQ-25 compared with control participants, which agrees with previous reports.[6,7,43] Similar to the previous literature, we found that the greatest differences were in the peripheral vision subscale, whereas the smallest differences were found for the color vision and ocular pain subscales. In fact, we found no significant difference between patients and control participants on the ocular pain subscale. In addition to the traditional subscales, we composed three additional subscales, that is, traffic, digital tools, and visual speed and attention (Supplementary

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Table S1) on which patients also scored significantly lower than control participants.

Given the relations between the UFOV test and several measures of daily life activities that have been reported in the past, such as driving, reading, and finding items on a shelf,[19–21] we expected the total iUFOV score to be related to some of the adapted NEI VFQ-25 subscales. However, we found almost no significant correlations in our exploratory analyses. The only significant result we found without correction for multiple comparisons was between the iUFOV and the peripheral vision subscale. Note, however, that this subscale was composed of only one question ("Because of your eyesight, how much difficulty do you have noticing objects off to the side while you are walking along?") to which all patients' answers were divided among only two out of four answer categories (moderate difficulty and extreme difficulty). This result should therefore be considered with caution. We also found a significant correlation between color vision and HFA scores, which agrees with the findings of Gall et al.,[6] who investigated correlations between the size of absolute visual field loss and the NEI VFQ subscales. Unlike Gall et al.,[6] we found no correlations between any of the other subscales and HFA scores, although many were of a similar magnitude. With only 14 patients, however, we lacked power to reach levels of significance for these correlations.

We compared the correlations between the adapted NEI VFQ-25 subscales and iUFOV scores with the correlations between the subscale scores and visual field sensitivity measured by HFA. One might expect that the correlations with HFA are systematically higher than the ones with the iUFOV, because the mean HFA considers both hemifields, and hence captures vision loss in the affected hemifield as well, whereas the iUFOV only targets function loss of the intact hemifield. Yet this was not the case. The only difference we found was for the correlation that included peripheral vision, which was significantly stronger for iUFOV scores than for visual field sensitivity. Although we should interpret this result with caution for reasons mentioned elsewhere in this article, this finding suggests that HFA scores and iUFOV scores may be sensitive to different aspects of visual functioning. Both measures may complement each other to form a complete picture of patients' visual functioning. For this reason, their combined explanatory value might be better than either individual variable's performance. Unfortunately, in this exploratory study, our power was too low to gain reliable results for such model fits. Alternatively, incorporating the entire visual field into the summed iUFOV score might also enhance the relationship because the current iUFOV score does not measure the impairment resulting from the visual field defects in their affected hemifield.

Owing to the established age effects on perimetry,[44] clinicians often use age-corrected measures to examine perimetry results, such as mean deviation. However, we did not have age-corrected measures available for the iUFOV or adapted NEI VFQ-25, which are also affected by age.[36,37,45,46] We, therefore, calculated an uncorrected HFA score based on the raw visual sensitivity scores of the entire visual field for both eyes. To correct for age, we matched our patient and control groups. Statistical tests showed that there was indeed no significant difference between these groups in terms of mean and variance of age. In addition, we repeated all analyses with age included as a covariate. We were surprised to see that age hardly had an impact on our results despite the large range of ages (22–77 years) in both groups. Based on the previously reported relations between all three measures and age, we expected age to inflate or cause correlations between the adapted NEI VFQ-25 scores and HFA or iUFOV scores. Instead, we found almost no correlations and the ones we did find were still present when age was included in the analysis. We, therefore, believe that age was not a confounding factor in our results.

Although we did not find many significant or strong correlations between iUFOV scores for the intact visual field and the adapted NEI VFQ-25 subscales, we believe the iUFOV task is an interesting task to investigate further in this particular patient group. First, we found quite some variance in patients' performance. Four patients were unable to complete all three iUFOV subtests. These patients only differed from the others in their iUFOV1 and, for those who were able to complete it, iUFOV2 scores, which were significantly worse (Supplementary Table S4). They did not differ in age or HFA scores. In contrast, another subgroup of patients was able to perform just as well as our healthy control group. These findings agree with our observations that some patients seem to be much less affected by their visual deficit than others, although the defect is not necessarily smaller as indicated by perimetry results. The scores could also be augmented with errors in localization of the peripheral stimuli, because they might better capture the deficit incurred by the affected, contralesional hemifield. Second, previous literature has shown that UFOV performance can be enhanced with training.[47–49] Interestingly, a recent meta-analysis showed that UFOV training may improve instrumental activities of daily life, decrease adverse driving events, and increase well-being for community-dwelling older adults and clinical populations, including stroke patients.[49] Current rehabilitation methods for patients with visual field defects usually focus on (partial) restoration or displacement of the visual field defect or on compensation through eye movements.[4] UFOV training may offer a way to train functions that are neglected by other rehabilitation methods, such as speed of processing and attention. Previous studies have shown promising results in improving UFOV performance of stroke patients, although it is unclear to what extent the improvement generalized to other activities.[50,51]

Conclusions

Our results show that the iUFOV test is sensitive to declined visual functioning that is not picked up by traditional perimetry. In view of these results, and considering the correlations that have been reported in the literature between UFOV and daily life activities, we believe the UFOV task is of interest for evaluating visual functioning of patients with postchiasmatic lesions and should be investigated further.

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