Functional Field Score: The Effect of Using a Goldmann V-4e Isopter Instead of a Goldmann III-4e Isopter

Maaike Langelaan,¹,² Bill Wouters,³ Annette C. Moll,¹,² Michiel R. de Boer,¹,² and Ger H. M. B. van Rens¹,²,⁴

PURPOSE. To investigate the underestimation of field loss in functional field score (FFS) between the Goldmann isopters III-4e and V-4e in visually impaired patients, in order to develop a predictive model for the FFSIII-4e based on FFSV-4e that adjusts for possible confounders. Although the visual field is generally evaluated using Goldmann isopter III-4e, it has the disadvantage that not all low-vision patients are able to see the stimulus corresponding to this isopter.

METHODS. Goldmann visual fields were obtained from 58 patients with a variety of eye diseases. Eligibility criteria were age of 18 years or older and valid results of a Goldmann III-4e and V-4e visual field test in at least one eye. Linear regression was used to develop the model, setting FFSIII-4e as the dependent variable and FFSV-4e as the independent one.

RESULTS. The FFSV-4e was higher than the FFSIII-4e, the mean difference being 14.56 points (95% CI, 12.48–16.64). Multiple linear regression analysis showed that age, functional acuity score, primary eye disease, and central–peripheral visual field loss were not confounders for the prediction of FFSIII-4e. FFSIII-4e was estimated with the following equation: FFSIII-4e = −19.25 + 1.063 · FFSV-4e.

CONCLUSIONS. The relationship between FFSIII-4e and FFSV-4e is linear, and the FFSV-4e can be used to estimate the FFSIII-4e. In practice, just subtracting 19.25 points of the value of FFSV-4e will be sufficient to estimate the value of FFSIII-4e. This model should give confidence about using the bigger isopter for determining the visual impairment of a person by the FFS.

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Visual functioning depends on the visual impairment of a person and can be expressed in terms of the activities of daily life. Loss of visual field is the next major cause of visual impairment, and the visual capacity of a person is severely limited or who are neurologically disabled.2,3 In such cases, the size V stimulus seems to be preferable.4 The Goldmann V-4e stimulus consists of a target of 4 mm² with a luminance of 318 cd/m² (1000 apostilbs) projected onto a background luminance of 10 cd/m² (31.5 apostilbs).

Only a few studies have been performed to investigate the difference between the size of isopters III-4e and V-4e. Niederhauser and Mojon5 determined the normal position of isopters III-4e and V-4e in the peripheral visual field in healthy patients aged between 19 and 42 years. However, they plotted the average position, which resulted in an underestimation of the field loss when the larger isopter was used and therefore a possible overestimation of the patient’s functional vision.6 Although the area of the visual field depends primarily on the size and intensity of the stimulus, it is influenced by many factors, such as age,7 visual acuity,8 pupil size,9 the interference of eyelid and nose, cooperation,10 and interaction with the examiner and level of education of the patient.11 However, there seems to be no evidence of factors that could cause the difference between the visual field areas resulting from a change in the size of the stimulus. We hypothesize that age, primary eye disease, central or peripheral field loss and visual acuity may affect the difference between the visual field areas of the two isopters.

TABLE 1. Classification of the FVS¹¹

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
<th>Estimated Ability to Perform Activities of Daily Living</th>
<th>FVS (Points)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Range of normal vision</td>
<td>Has reserve capacity</td>
<td>&gt;90</td>
</tr>
<tr>
<td>2</td>
<td>Near-normal vision</td>
<td>Lost reserve capacity</td>
<td>71–90</td>
</tr>
<tr>
<td>3</td>
<td>Moderate low vision</td>
<td>Need for vision enhancement aids</td>
<td>51–70</td>
</tr>
<tr>
<td>4</td>
<td>Severe low vision</td>
<td>Slower than normal, even with aids</td>
<td>31–50</td>
</tr>
<tr>
<td>5</td>
<td>Prolonged low vision</td>
<td>Marginal visual performance, even with aids</td>
<td>11–30</td>
</tr>
<tr>
<td>6</td>
<td>(Near)-total blindness</td>
<td>Cannot perform visually; needs substitution aids</td>
<td>&lt;10</td>
</tr>
</tbody>
</table>


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FIGURE 1. (A) Goldmann isopters III-4c (solid line) and V-4c (dashed line) of the left eye. (B) Overlay grid for obtaining the VFSs.
Until recently, there was no uniform disability classification for visual impairments. To rectify this, the American Medical Association (AMA) published guidelines in the *Guides to the Evaluation of Permanent Impairment*. One part consists of guidelines for evaluating visual impairment based on the functional vision score (FVS). The FVS is built on the functional acuity score (FAS) and functional field score (FFS). To determine the FFS, the visual field score (VFS) for the right monocular field (VFSOD), left monocular field (VFSSD), and binocular field (VFSOU) are first scored separately. The FVS is the product of these two values:

\[
VFS = \frac{VFSOD + VFSSD + 3 \times VFSOU}{5}
\]

The plots made by Niederhauser and Mojon in their study resulted in a normal FFSIII-4e of 106 (95% CI, 99–118) points, whereas the normal FFSV-4e is 113 (95% CI, 103–124) points. However, they did not plot the position of the isopters in low-vision patients.

In the United States, the guidelines set down by the AMA are important in calculating compensation for workers who are injured on the job. Workers’ compensation is paid by the employer, who provides cash payments or medical care to the employee. Mandated by state law, these benefits include partial wage replacement and the costs of rehabilitation. In the Netherlands, the AMA guidelines are used for assessing the extent of damage after accidents and are used by insurance companies and lawyers in cases of malpractice.

The AMA guides recommend using the Goldmann isopter III-4e for calculating the FFS, and when this isopter III-4e is unavailable, they recommend the use of a larger isopter, Goldmann IV-4e or V-4e. As stated earlier, the use of a larger isopter leads to an overestimation of the FFS. As a consequence, benefits may be wrongly calculated. It is therefore important to be able to estimate the FFSIII-4e when only isopter V-4e is available.

In the present study, we investigated how large the overestimation of the FFS was, by analyzing the FVS in visually impaired patients, by using the Goldmann isopters III-4e and V-4e. Our purpose was to develop a prediction model for the FFSIII-4e based on FSSV-4e, while adjusting for possible confounders.

### Methods

#### Study Population

We used patient data from an ongoing cohort study on the quality of life of visually impaired adults. A retrospective chart review had been performed on low-vision patients visiting the national rehabilitation center.

### Table 3. Difference between the FFS of Goldmann Isopters III-4e and V-4e

<table>
<thead>
<tr>
<th>Mean SD 95% CI</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFSIII-4e</td>
<td>60.93 25.87 54.13–67.73</td>
</tr>
<tr>
<td>FFSV-4e</td>
<td>75.49 23.22 69.38–81.60</td>
</tr>
<tr>
<td>Difference</td>
<td>(FSSV-4e – FFSIII-4e) 14.56 7.90 12.48–16.64 &lt;0.001</td>
</tr>
</tbody>
</table>

Data are the result of paired-sample *t*-tests.

### Table 4. Linear Relationship between the FFS of Goldmann Isopters V-4e and III-4e

<table>
<thead>
<tr>
<th>( \beta )</th>
<th>95% CI</th>
<th>( \beta ) change*</th>
<th>( R^2 )†</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFSV-4e</td>
<td>1.063</td>
<td>0.973–1.152</td>
<td>0.910</td>
</tr>
<tr>
<td>FFSV-4e adjusted for age</td>
<td>1.062</td>
<td>0.973–1.151</td>
<td>−0.09</td>
</tr>
<tr>
<td>FFSV-4e adjusted for location of field loss</td>
<td>1.062</td>
<td>0.949–1.175</td>
<td>−0.09</td>
</tr>
<tr>
<td>FFSV-4e adjusted for FAS</td>
<td>1.060</td>
<td>0.971–1.149</td>
<td>−0.28</td>
</tr>
<tr>
<td>FFSV-4e adjusted for diagnosis</td>
<td>1.059</td>
<td>0.967–1.151</td>
<td>−0.38</td>
</tr>
<tr>
<td>FFSV-4e adjusted for all confounders</td>
<td>0.978</td>
<td>0.849–1.108</td>
<td>−8.00</td>
</tr>
</tbody>
</table>

\( \beta \) regression coefficients.

* Change in \( \beta \) of our present model compared with the \( \beta \) of the crude model. A negative sign means a decrease in \( \beta \).

† \( R^2 \) is the proportion of variance in the dependent variable (FFSIM-4e) that can be predicted from the independent variables.
center for blind and visually impaired people (Visio Het Loo Erf, Apeldoorn, the Netherlands) in 2002 and 2003. All patients entered an observational program for rehabilitation. We selected data for patients who were aged 18 years or more, with valid results from a Goldmann III-ie and V-ie visual field test for at least one eye. One eye could be blind.

We did not include patients for whom one of the monocular isopters was missing or not valid, due for example, to lack of fixation. Furthermore, persons with communication or cognitive problems that were too severe for understanding the procedures were also excluded from our study.

The study was performed according to the tenets of the Declaration of Helsinki, and the medical ethics committee of the VU University Medical Centre (Amsterdam, The Netherlands), approved the study protocol. Before testing began, we obtained written, informed consent from all participants.

**Study Procedures**

Goldmann visual field tests were routinely performed on each patient during the first week of their stay at the rehabilitation center. The ophthalmologist or a specially trained nurse of the center recorded isopters III-ie and V-ie for each patient using the Goldmann perimeter, printing both isopters on one sheet of paper (Fig. 1A).

To obtain the VFS, we used an overlay grid preprinted on a transparency, as has been described in the AMA guides\(^1\) (Fig. 1B). The grid is constructed so that the lower field receives 60% of the weight and the upper field, 40%. The central 10° field and the peripheral field both receive 50 points. With the grid overlay on the Goldmann visual field, we counted only the points that fell within the isopter, ignoring those on or outside it, or within scotomas. Binocular isopters were constructed by superimposing the isopters for the left and the right eye, if available. For persons blind in one eye, the VFS of that eye was recorded as 0, and the binocular VFS was taken as equal to the monocular VFS. To obtain the patient’s FFS, we inserted the VFS for each monocular field and the binocular field into equation 1. We then plotted the overlay grid (AutoCAD 2002; Autodesk Inc., San Rafael, CA).

In an earlier study, we tested the intrarater and interrater agreement and reliability of the FFS for isopters III-ie and V-ie,\(^1\) and concluded that both FFSs have a near-perfect reliability. Patients were scored three times: once by rater 1 and twice by rater 2. The mean of these three scores was taken as the best estimate of the FFS. Patients who joined the study at a later stage were scored once.

**Statistical Analysis**

The statistical analysis was performed in five steps: descriptive statistics, regression analyses, goodness-of-fit assessment for the linear model, internal validation of the regression model by bootstrapping, and an assessment of the predicted power of the regression model. We used a paired-sample t-test to assess the difference between the FFSs of isopters III-ie and V-ie.

We used linear regression to develop the model, setting $FFS_{\text{III-ie}}$ as the dependent variable and $FFS_{\text{V-ie}}$ as the independent one. We took the variation between subjects into account by calculating a 95% prediction interval (i.e., a range of possible values for $FFS_{\text{III-ie}}$ given a certain value of $FFS_{\text{V-ie}}$). This interval is not constant, being at its narrowest near the middle of the range and becoming wider toward the extremes.\(^10\)

One by one, we included possible confounders—age, FAS, central loss, peripheral loss, and primary eye disease—in the model. The variable was indicated as a confounder if the regression coefficient of $FFS_{\text{V-ie}}$ was changed by more than 10% after adding one of the possible confounders.

We evaluated the goodness-of-fit of the linear model by testing the following three assumptions: (1) homoscedasticity and linearity of residuals, (2) independence between dependent variables and predictor variables, and (3) normal distribution of the dependent variables. Scatterplots and correlation coefficients between unstandardized residuals and predictor variables were used to test for homoscedasticity and linearity of residuals. We ensured independence of dependent variables by appropriate model selection and used correlation coefficients to test the independence of predictor variables. We looked for evidence of normality for the distribution of both dependent variables by drawing raw score histograms with fitted normal distribution curves and normal probability plots of error terms.

A model often performs less well with data from new patients, than with the developmental data set. The extent of optimism can be estimated for similar patient populations by using internal validation techniques such as bootstrapping.\(^17\)–\(^20\) Bootstrapping replicates the process of sample generation from an underlying population of the same size as the original data set, by drawing samples with replacement from the original data set.

![Figure 2. Regression between the FFSs of isopters V-ie and III-ie and the 95% prediction interval for all patients.](http://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/932937/)

### Table 5. Relation between the FFS for Isopter III-ie (Dependent Variable) and that for Isopter V-ie (Independent Variable)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Original (Main) Regression</th>
<th>Bootstrap Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\beta$ (95% CI)</td>
<td>$\beta$ (95% CI)</td>
</tr>
<tr>
<td>Intercept</td>
<td>$-19.90$ ($-26.36$ to $-12.24$)</td>
<td>$-19.25$ ($-25.58$ to $-12.37$)</td>
</tr>
<tr>
<td>Slope</td>
<td>$1.063$ (0.97 to 1.15)</td>
<td>$1.063$ (0.98 to 1.14)</td>
</tr>
</tbody>
</table>

$\beta$, regression coefficients.
As optimism is a well-known problem of models derived from multiple regression, we next performed a bootstrap analysis. We drew a total of 2000 new samples with replacements from the sample population. We stopped at 2000, when we found that more samples only marginally improved the estimate. The multiple regression was calculated for each of the samples, yielding bootstrap distributions for the regression coefficients and intercepts.

Finally, to assess the predictive power of the model, we calculated a linear regression between the predicted and the observed values of the FFS\textsubscript{III-4e}. In this way, we tested the hypothesis that the corresponding slope and intercept are equal to 1 and 0, respectively.

Bootstrapping was performed on computer (ReSample software and analysis tool pack of Excel XP [http://www.resample.com]); Microsoft, Redmond, WA) as were all other statistical analyses (SPSS 11.5 software; SPSS Inc., Chicago, IL).

**RESULTS**

**Baseline Characteristics**

Reliable Goldmann III-4e and V-4e isopters were obtained from 58 patients, whose characteristics are given in Table 2. Of these patients, 31 also took part in the study of the intra- and interrater agreement and reliability\cite{15}, whereas 27 patients joined at a later stage. For 15 patients, the binocular VFSS for...
isopters III-4e and V-4e were taken to be equal to the monocular VFSs each patient was blind in one eye.

The Prediction Model

The mean difference between the FFS for isopters V-4e and III-4e for the whole group was 14.56 (95% CI, 12.48–16.64). These data are presented in Table 3.

A first multiple linear regression analysis showed that age, FAS (see equation 2), primary eye disease, and central or peripheral visual field loss were not confounders for FFSIII-4e (Table 4), the variance being almost completely explained by FFSV-4e as the independent variable ($R^2 = 0.91$). Therefore, the bootstrap analysis was repeated with only the FFSV-4e as the independent variable. The estimates of the regression coefficients and their standard errors are given in Table 5.

The following equation was used to calculate the FFSIII-4e from FFSV-4e.

$$FFS_{III-4e} = -19.25 + 1.063 \times FFS_{V-4e}$$

Figure 2 shows the relationship between FFSV-4e and FFSIII-4e, and Figure 3 shows how this relationship varied according the category of disease.

A linear regression model appears to provide an adequate fit for this particular population of visually impaired adults. No departures from the usual assumptions were observed. Scatterplots between unstandardized residuals and the predictor variable FFSV-4e suggest constancy and linearity of the error terms (results not given). As the neutral value of 0 was absent from the 95% CI, for the regression coefficient of FFSIII-4e we can assume that the relationship between FFSV-4e and FFSIII-4e is linear. We could assume that the variables were independent, because each case represented one patient. An approximately normal distribution for the dependent variable FFSIII-4e is suggested by the appearance of the raw score histograms fitted with normal distribution curves, as well as that of the Q-Q plots of variable distribution quantiles against quantiles for the normal distribution.

$$FFS_{III-4e,observed} = -3.5e^{-14} + 1.00 \times FFS_{III-4e,predicted}$$

The intercept and slope in equation 5 do not differ significantly from 0 and 1, (95% CI, −5.53–5.53 and 95% CI, 0.92–1.08, respectively). The correlation coefficient between the observed and predicted values for FFSIII-4e is equal to 0.95 ($P < 0.001$). Table 6 gives the percentage error encountered when comparing the FFSIII-4e and the predicted FFSIII-4e with the observed values for FFSIII-4e. Of the predicted values for FFSIII-4e, 81.0% are within the range of ±10 points of the observed values, 94.8% are within 15 points, and 98.3% are within 20 points. For the values of FFSIII-4e this was 37.9%, 58.6%, and 77.6%, respectively.

**Discussion**

Our purpose was to derive a linear model for the prediction of the FFS for the Goldmann isopter III-4e from the FFS of isopter V-4e. This model could then be used to improve the quality of the evidence in terms of the FFS if the visual impairment of a person has been determined using the larger isopter, as described in the fifth edition of the AMA guides.14 In the comparison of the predicted and the observed functional field scores, the CI of the slope of the regression line contains the value of 1. Therefore, the slope does not differ significantly from 1, indicating a linear relationship between the FFS of the two isopters. In practice, simply subtracting 19.25 points of the value of FFSV-4e is sufficient for an estimate of the value of FFSIII-4e.

As mentioned, the variables age, primary eye disease, central or peripheral field loss, and FAS influence the size of a specific isopter. However, results from the linear regression analyses suggest that the difference between the two isopters does not seem to be affected by these factors. Although as confounders they are related to both the independent and the dependent variable, they do not contribute significantly to the variance of the model. The variance is almost completely explained by FFSV-4e.

Age was found not to be a confounder for the relationship between FFSIII-4e and FFSV-4e. There seems to be no evidence (for example, difference in concentration or understanding of procedure) to explain the difference in FFS between young and elderly adults.

The patients on whose data our regression model is based, had a wide range of ophthalmic and/or neurologic diagnoses, which means a large variability in visual field loss, its amount and location depending on the nature of the disease.

Adjusting the model for diagnosis showed it not to be a confounder in the relationship between FFSV-4e and FFSIII-4e.

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**Table 6. Percentage Error Encountered When Comparing FFS of Isopter V-4e and the Predicted Value of FFSIII-4e with the Observed Value of FFSIII-4e**

<table>
<thead>
<tr>
<th>Range Compared with Observed FFSIII-4e (%)</th>
<th>Error FFSV-4e (%)</th>
<th>Error Predicted FFSIII-4e (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>±10 Points</td>
<td>62.07</td>
<td>18.97</td>
</tr>
<tr>
<td>±15 Points</td>
<td>41.38</td>
<td>5.17</td>
</tr>
<tr>
<td>±20 Points</td>
<td>22.41</td>
<td>1.72</td>
</tr>
</tbody>
</table>

**Figure 4. Regression between predicted and observed FFSs of isopter III-4e and the 95% prediction interval.**
We noted that the intercepts of the disease categories macular degeneration and diabetic retinopathy were smaller than those of the other disease categories (Fig. 3), but the sample sizes for each category were too small for meaningful conclusions about the relationship of diagnosis with FFS. There was no difference in the perception of the two stimuli between people with high or low visual acuity, showing that the FAS was also not a confounder for the relationship between FFSIII-4e and FFSV-4e.

If the predicted values of FFSIII-4e are compared with the observed values, 81.0% of the points are within a range of 10 points of the observed values, which shows a considerably higher agreement than those of a comparison between the observed values of FFSIII-4e and FFSV-4e. Within a range of 20 points, the agreement between observed and predicted comes close to 100%.

In the AMA guides, vision is classified also according to FVS (Table 1). From our results and equation 3, it can be seen that an overestimation of the FFS by 19.30 points by using a larger isopter and also presuming FAS to be a constant variable, leads to a higher FVS score. The CI for the intercept ranges from −26 to −12 points. This may lead to someone’s being classified incorrectly with a difference of up to two classes. Estimation of the FFSIII-4e leads to a more accurate FVS and the patient’s receiving a fairer and appropriate benefit from, for example, his medical insurance.

Our study has some limitations. First, the lower limit of the FFSV-4e is 24. There were no patients with a lower score on isopter V-4e and for whom isopter III-4e could be produced. The use of regression as a prediction can only work over the limits of data collected. Therefore, the equation for calculating the FFSIII-4e cannot be applied in the case of patients with a very low FFSV-4e. Second, the age range of the subjects was 20 to 66 years, and thus the model is valid only for this age category. Whether the model can be extended to children or elderly people remains to be investigated. Third, the number of participants in the analyses was relatively small, the CI for the estimation of the intercept ranging between −26 and −12 points. Although it is clear from our study that there is a marked difference between FFSV-4e and FFSIII-4e of at least 12 and maximally 26 points, studies with large sample sizes are needed for more precise estimates. We used bootstrap analysis to evaluate the model’s performance for the same patients returning for further treatment. However, this was an internal procedure. As the goal of this study was to develop a general model, the model should be evaluated on new data from a population of patients who in age, number, and visual impairment differ from the original.

In conclusion, we found the relationship between the FFS of isopter III-4e and isopter V-4e to be linear. The FFS of isopter V-4e can be used to estimate the FFS of isopter III-4e by subtracting 19.25 points from the FFS of isopter V-4e. This estimation should only be used if it is not possible to plot isopter III-4e.

References