

Repeatability Evaluation of a Contrast Sensitivity System for Transfer to the Eye Clinic

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Abstract: The Contrast Sensitivity Function (CSF) is a valuable tool which can be used to characterize functional vision and also for the diagnosis and management of patients with different eye diseases. In spite of its usefulness, the CSF is currently hardly ever used in clinical practice. The aim of this study was to validate the use of the system called FVC-100 (Tecnovinc-UNT-CONICET, Argentina), which calculates the CSF, in order to transfer this important tool to ophthalmological clinics. The validation was carried out through the design of a repeatability test and the subsequent analysis of the results. Furthermore, we evaluated the impact of different factors influencing the repeatability of the measurements such as age and previous training. The tests were based on the discrimination of sinusoidal gratings for different spatial frequencies (1, 4 and 12 c/°) in both eyes of 12 people, aged between 20 and 70. The results show that the calculated values of SC of each subject have a high repeatability and are not dependent on age or training. These results allow us to conclude positively regarding the effectiveness of the FVC-100, and to validate its use in clinics for the calculation of the FSC as a standard measure of functional vision quality.

1. Introduction

The concept of functional vision is associated with the capability of people to perform everyday tasks [1]. It is known that functional vision is not only related to visual acuity (VA), i.e. a measurement of the minimum detail within high contrast that a person can see, but also to contrast sensitivity (SC), that is the reverse of the minimum contrast that a person needs to distinguish a background stimulus, at different sizes and luminance levels. Measuring is carried out by using sine gratings of different spatial frequencies that covers the human range of vision, obtaining the Contrast Sensitivity Function (CSF). Bibliography has established that this function offers a valuable tool for the diagnosis and tracing of patients who have different diseases such as cataracts, amblyopia and glaucoma, among others [2 – 4]. However, and considering that nowadays there are commercial measurement systems, its use is reduced in clinics. In the past few years, interest regarding CSF has been renewed [5, 6], and there have been different tests evaluated for clinics [7, 8].

In several scientific and technological investigative works in carried out by our institution, DLLyV – ILAV (Department of Lighting, Light and Vision – Institute of Investigation in Light, Environment and Vision, FACET – UNT), that have led to several master's thesis, final engineering projects and several scientific papers [5, 6, 9 – 12] the specifications that a system needs to be implemented successfully in Ophthalmological Clinics were analyzed and determined. As a result of this, a computerized system was developed, which we call FVC-100, to determine the CSF. This system has proved to be a valuable tool to clinical environment [11], and is continuously being improved on [13].

In this work, an experiment with the FVC-100 was designed, with the purpose of evaluating the repeatability degree in order to use it in a successful way in the clinic. In addition, this evaluation includes the effects of age and training on the repeatability degree. The hypothesis of this work is that a single measure would be accurate enough and carried out in an adequate time, parameters which are



important, not only for patients but also for doctors and optometrists, were set in order to implement CSF as a clinic standard.

2. Materials and Methods

2.1. The Generator of Visual Stimulus

The system to be controlled is a computerized apparatus which ~~to~~ determines the contrast sensitivity function (FVC-100, Tecnovinc – UNT – CONICET, Argentina) It was developed entirely by the faculty where the present work was carried out. This system permits the generation of the visual stimulus and shows them on the screen of a CRT monitor LG brand, model FLATRON EZ T730SH with a widescreen of 17". Using a video adapter/attenuator and, providing a luminance resolution of 0.01 cd/m², approximately 14 bits of resolution are obtained, which in turn permits reaching 3500 gray levels, needed to generate stimulus that can be presented with Michelson contrasts between 0.002 and 1, within errors of between 1.5% and 10% [5].

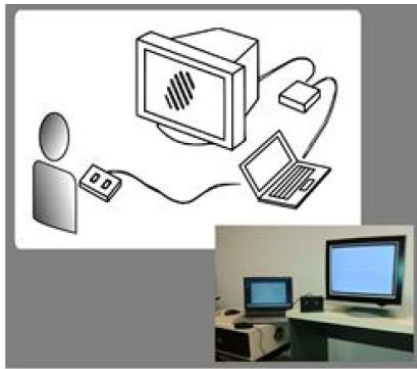


Figure 1. Sistema FVC-100 – Scheme and picture. Extracted image from C. Paz Filgueira and J. Santillán, 2014.

The viewing distance is 1.5 m from the monitor to minimize the demand for accommodation / convergence. The visual stimulus consists of sine gratings that are presented in a circle subtending 6.7 degrees which is located in the center of the CRT. The grating spatial frequency is modified by specific software and it lasts 500 ms. Furthermore, such gratings were randomly inclined 7 degrees to the left or to the right.

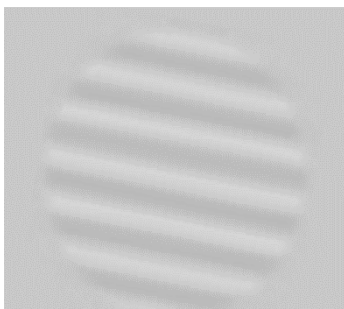


Figure 2. Typical sine grating shown in CRT monitor. Extracted image from C. Paz Filgueira and J. Santillán, 2014.

Since the task of the observer/patient is to discriminate the orientation of the grating, the system has a joystick control with two buttons, so that if the grating is visualized with a tilt to the left, the left button is pressed, otherwise, the right button will be pressed.

At a specific spatial frequency, each stimulus is generated by software that use an algorithm called QUEST (Quick Estimation by Sequential Testing) [12], which is an adaptive psychometric method. As the answer method is an alternative forced choice (2AFC), the observer has a 50% chance of guessing correctly and a 50% chance of guessing incorrectly. With each correct answer, the algorithm calculates and shows a lower contrast stimulus on the screen and when there is an incorrect response, the stimulus that is shown has a higher contrast than the preceding one. As mentioned before, this

method is adaptive because each grating presented on the CRT is defined according to the answers given by the previous stimuli, so that the next stimulus is based on the current and all previous ones.

The measurement of the contrast threshold for each spatial frequency was performed with a total of 25 repetitions or stimuli presentation (see Figure 3), except in the case where the observer answers the first 17 reps correctly, then the test was increased to 42 repetitions (see Figure 4). The inverse of the final value obtained is the contrast sensitivity value for the spatial frequency that was measured. It should be clarified that each repetition involves the calculation of a new contrast value from the response of the observer/patient, and the generation of a new stimulus by the apparatus.

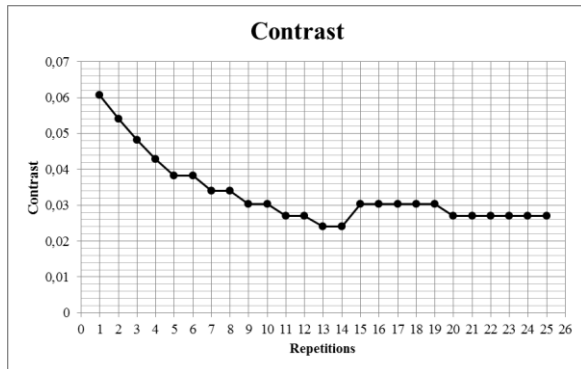


Figure 3. Contrast variation according to responses throughout a measurement for a given spatial frequency, with 25 steps.

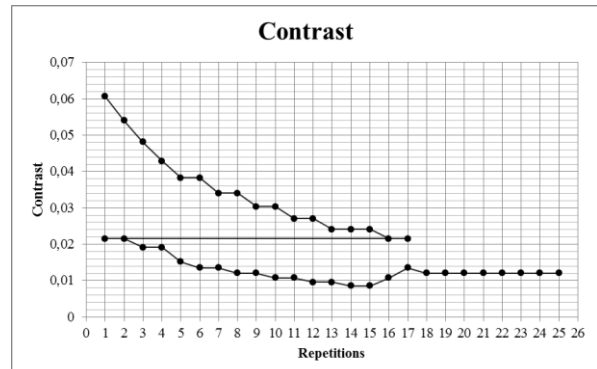


Figure 4. Contrast vs Repetitions when the orientation of the first 17 networks presented have been answered correctly.

2.2. Participant Selection Criteria

Measurements were taken from 12 people aged between 20 and 70, for which we distinguish two wide age classes: from 20 to 49 and from 50 to 70 years old, considering the results from different studies describing the influence of the age of the subjects in determining contrast sensitivity [6, 13-15].

Within the inclusion criteria, it was considered that participants in these tests should be emmetropes or could have any refractive pathology such as myopia, hyperopia and/or astigmatism, but that they must be properly corrected at the time of the measurement. In this way, it was considered that they should have a Visual acuity (AV) greater than or equal to 0.8 per eye and, in order to control this requirement, all participants were measured with a Snellen chart from 3B Optic Instruments (see Figure 5, left). Furthermore, a OQAS System from Visiometrics, Terrassa, Spain (see Figure 5, right), was used, based on the double step technique to evaluate the retinal image quality. As a result of this measuring, the Object Scatter Index (OSI), was obtained and it was considered that participants should have an OSI lower than or equal to 1.5 [16].



Figure 5. On the left, Snellen chart for VA measure. On the right OQAS System to measure the OSI (Object Scatter Index).

2.3. Experimental design to evaluate the repeatability, the age and training effects in contrast sensitivity measurements using FVC-100

The test was done in a room without ambient lighting. The illuminance between the subject's eyes (2.15 lux) and the average luminance of the stimulus and its immediate surroundings on the monitor (70 cd/m²) were measured performing the experiment under photopic adaptation [9]. The measurement of the illuminance was done with luxometer Minolta T1M brand and a luminance meter LMT 1009 was used for the luminance. CS Measurements were performed monocularly, occluding the fellow eye during the test. As the objective of this work was to evaluate FVC-100's repeatability, five measurements per eye were considered. Even though FVC-100 allows for a selection of up to six spatial frequencies (1, 2, 4, 8, 12 and 24 c/°), it was decided to perform the test with only three: 1c/°, 4c/° and 12c/°, that is, a low, a medium and a high spatial frequency. The experimental design consisted of each participant performing measurements with an only one frequency per day, and the order with which the measurements were performed was random. This approach was taken because it was necessary to ensure that, during successive measurements under the same stimuli pattern, the amount of time taken would be as short as possible for the subject, in order to avoid his/her fatigue and/or distraction during the measuring.

To assess whether there is any influence in terms of the results that denote if the measurements of participants with prior training are better or more repetitive than measurements of subjects that had never done this test before, participants were divided into two groups: those who had knowledge of the test and those who did not. Therefore, we established four groups of participants with an equal number of people in each group:

- a) 20-49 years old with training
- b) 20-49 years old without training
- c) 50-70 years old with training
- d) 50-70 years old without training

2.4. Computer Tools for Statistical Analysis

Firstly, the statistical tools provided by the Microsoft Office software package, particularly Microsoft Excel, were used to carry out the basic descriptive data analysis and graphics. To perform ANOVAs (Analysis of Variance) and the verification of the assumptions of the proposed model, we worked with free software, called R [17], which allowed us to obtain the results and reach the conclusions to be displayed below.

3. Results

Measurements were carried out on twelve subjects (24 eyes) of both age ranges, and it was observed, as the bibliography indicates, that there are meaningful differences between CS measurements for the two age groups and for considered spatial frequencies [6, 13 – 15].

In the following pictures (6, 7 and 8) we can observe the obtained results of CS per frequency (1, 4 and 12 c/°) and per eye for both groups of age, versus the repetitions. The two first rows correspond to young subjects (aged 20-49) and the last two rows are for older groups (aged 50-70). Furthermore, the groups of trained and untrained subjects can be seen separately in each row.

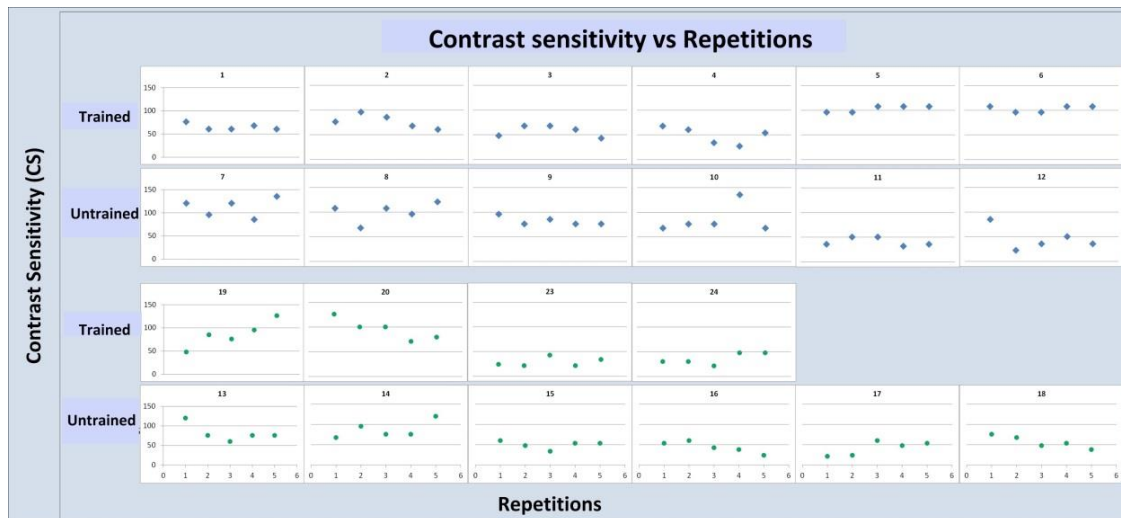


Figure 6. CS Results for $1c/0$

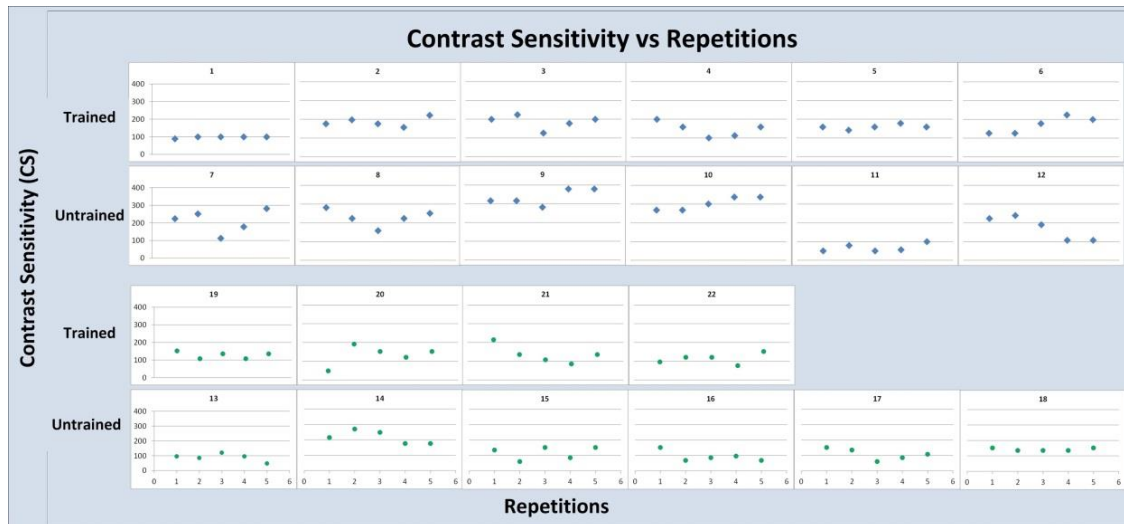


Figure 7. CS Results for $4c/0$

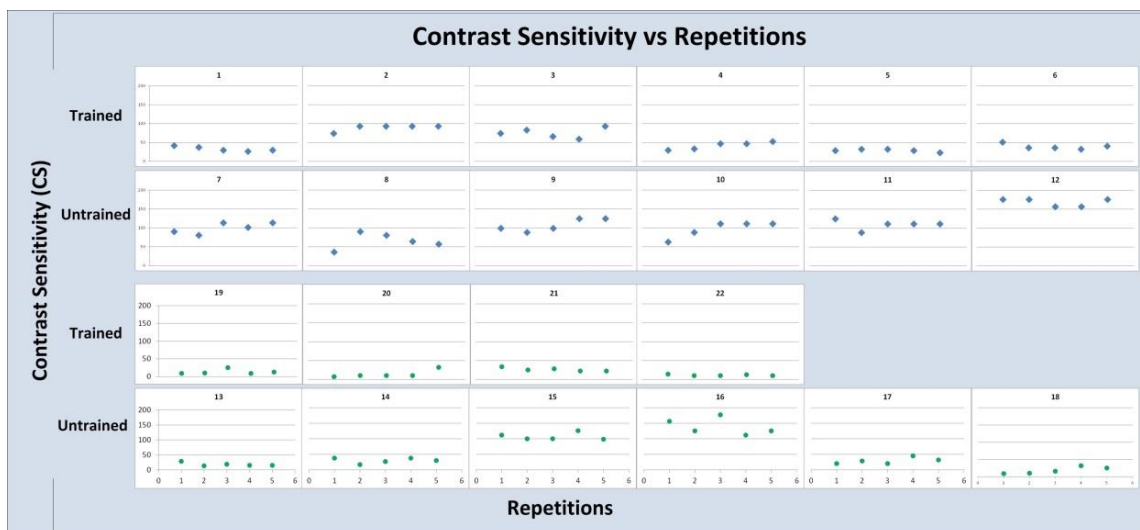


Figure 8. CS Results for $12c/0$

From these graphics and a descriptive analysis, we can observe that measurements are approximately constants for 1c/o and 12c/o frequencies and that there is a higher variability of the measurements for 4c/o in both age groups, training independently.

After this an ANOVA was performed on each spatial frequency to assess the influence of Age, Training and Eye of each subject considering the average of the observations, with the result that age is significant for the three frequencies, which is a well known result. However, as the main objective of this work was to assess the repeatability of measurements, a second ANOVA was carried out that considers each observation (not the average). Considering then observations that are not independent because they come from the same subject, a mixed random effects model with a random intercept was adjusted, where a time/repetition factor captures said situation. After that, the model assumptions were verified.

Model specifications:

$$Y_{it} = \beta_{0i} + \beta_{1i}t_i + \beta_{2i}o_i + \beta_{3i}e_i + \beta_{4i}a_i + \varepsilon_{it} \quad (1)$$

Where:

Y_{it} is the observation

β_{0i} is the random intercept: basic case of a Young subject, untrained and the task done through his left eye.

β_{1i} is the fixed coefficient of the variable time/repetition.

t_i is the time variable, which takes values from 1 to 5.

β_{2i} is the fixed coefficient of the variable “eye”.

o_i is the “eye” variable, which takes values of 1 and 0 depending on whether the treatment is applied to the right or the left eye.

β_{3i} is the fixed coefficient for the variable training.

e_i is “training” variable, which takes values of 1 and 0 depending on whether the subject is trained or untrained.

β_{4i} is the fixed coefficient of “age” variable.

a_i is “age” variable, which takes values of 0 and 1 depending on whether the subject is Young or adult.

And finally ε_{it} is the error term.

The results obtained were as follows:

- For 1c/o:

Under this new model, only the effects of the age on the contrast sensitivity ($p < 0.01$) are still meaningful. The “time” factor (number of repetitions) is not significant ($p = 0.947$). The estimated confidence intervals for the coefficients referred to time, includes zero, so the goal of repeatability is reached.

The graphics corresponding to the validity of the model are shown below:

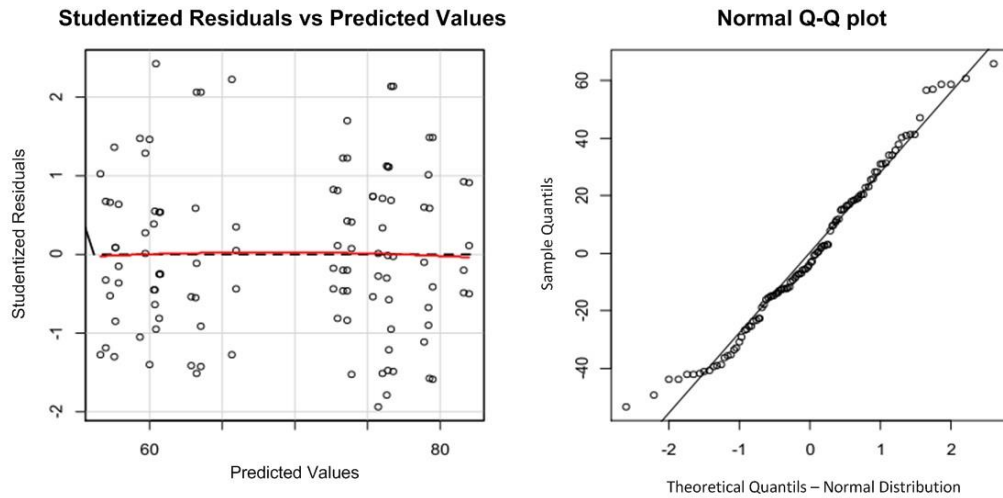


Figure 9. Model verification results for $1c^\circ$.

Observing the chart on the left of Figure 9, it is evident that the model residuals have zero mean and constant variance. In the figure on the right of the same graph, the model residuals behavior is compared with the expected values under normality, as they concentrate around the oblique line representing the normal case. This assumption can also be accepted.

Conducting formal tests to validate the assumptions give as a result that they are acceptable, both in terms of normality of residuals (the Shapiro-Wilk test results in a p-value=0.068 and the tests to prove that the distribution is not symmetrical and mesokurtic are rejected) and its homoscedasticity, which implies that the stochastic variance of regression errors is the same for each observation.

- For $4c^\circ$:

The ANOVA of repeated measures is significant again for the “age” factor on contrast sensitivity ($p < 0.01$), but not for the time factor ($p = 0.64244$). The estimated confidence intervals for coefficients referring to time include zero for the first four measurements, but not for the fifth although the effect is not meaningful. On this basis, we can affirm that the objective about the repeatability is reached.

In the graphical verification of the assumptions, those relative to homoscedasticity and normality are doubtful, as seen below:

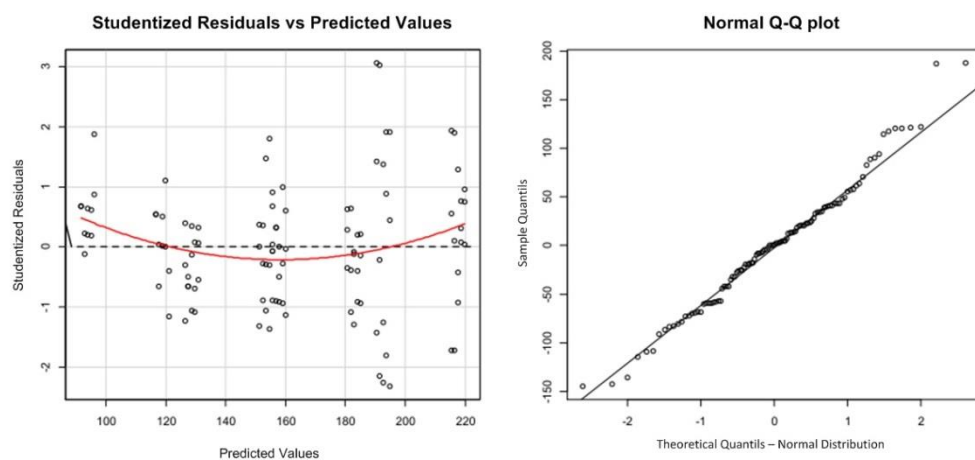


Figure 10. Model verification results for $4c^\circ$.

In the graphic on the left of Figure 10, a “funnel” shape can be seen, with larger dispersion for higher values of observation. On the right thereof, the presence of values that deviate from normal is observed at the beginning and at the end. The formal tests suggest normality can be accepted (The Shapiro-Wilk test results with a p-value=0.2029) but not homoscedasticity (the p value from ncv.test is lower than 0.001). This aspect is improved by carrying out a data transformation by the logarithm, (having at the end a p-value=0.3364 with the ncv.test) and the conclusions arrived at regarding the relativity of the effects of time are the same.

- For 12c/°:

The ANOVA of repeated measures is significant again for age and training ($p < 0.001$) and it is still not relevant for the observations of the effect of repetitions/time ($p = 0.9627$). As the estimated intervals (at 90% of confidence) include zero, we cannot reject the hypothesis about the average effect of repetitions on the measurement being null. In this case repeatability is also supported by the functioning of FVC-100.

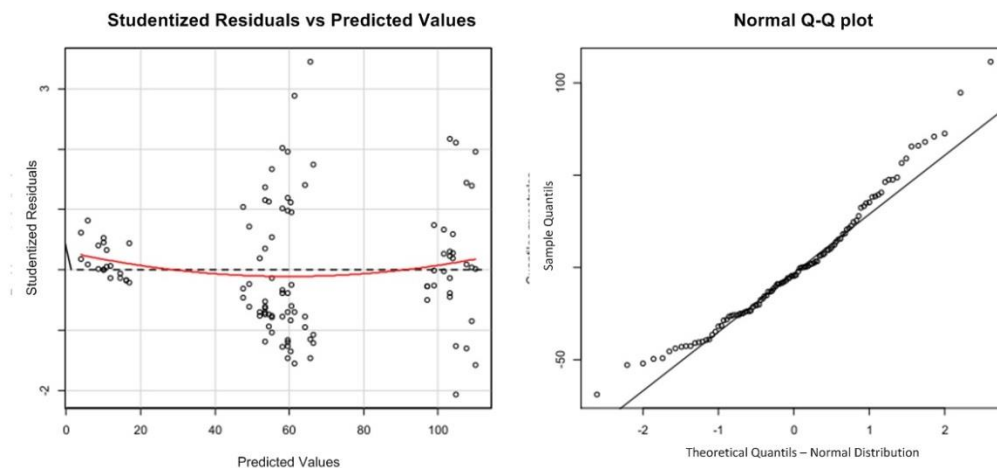


Figure 11. Model verification results for 12c/°.

Upon verification of the model assumptions and observing Figure 11, we can assume the validity of homoscedasticity and zero mean assumptions for residuals, but not that of the normal distribution (the p-value from the Shapiro-Wilk test is 0.005586). We can analyze that this absence of normality is due to the asymmetry observed in the data, reflected on points that are far enough away from the bisector on both ends. After a data logarithmic transformation, the situation improves (W de Shapiro-Wilk with a p-value=0.03416) without losing the validity of other assumptions nor the conclusions about the significance of the factors.

4. Discussions and Conclusions

The results obtained from this work show that for the three groups of spatial frequencies studied, the measurements are repeatable with time or repetition coefficients that are not statistically meaningful, and this condition does not depend on training or on the age of the participants/patients. This means that the changes on the observed value are not relevant between one measurement and another, making the FVC-100 a useful tool for the clinic, because one measurement alone would be enough to characterize a person's vision. However, as there is a slightly higher variability for the medium spatial frequency, since at 4c/° most people present their highest contrast sensitivity value and the contrast values are minimum, we recommend making another measurement at this frequency range to obtain a better estimation.

To conclude, we can say that the overall results are highly promising in terms of the objective of this study, as is the evidence of the robustness of measuring contrast sensitivity to be transferred to the eye clinic.

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