Designing a new test for contrast sensitivity function measurement with iPad

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PURPOSE: To introduce a new application (*ClinicCSF*) to measure Contrast Sensitivity Function (CSF) with tablet devices, and to compare it against the *Functional Acuity Contrast Test (FACT)*.

METHODS: A total of 42 subjects were arranged in two groups of 21 individuals. Different versions of the *ClinicCSF (.v1 and .v2)* were used to measure the CSF of each group with the same iPad and the obtained results were compared with those measured with the *FACT.* The agreements between *ClinicCSF* and *FACT* for spatial frequencies of 3, 6, 12 and 18 cycles per degree (cpd) were represented by Bland-Altman plots.

RESULTS: Statistical significant differences in CSF of both groups were found due to the change of the *ClinicCSF* design ($p<0.05$) while no differences were manifested with the use of the same *FACT* test. The best agreement with the *FACT* was found with the *ClinicCSF.v2* with no significant differences in all the evaluated spatial frequencies. However, the 95% confidence interval for mean differences between *ClinicCSF* and *FACT* were lower for the version which incorporated a staircase psychophysical method (*ClinicCSF.v1*), mainly for spatial frequencies of 6, 12 and 18 cycles per degrees.

CONCLUSIONS: The new *ClinicCSF* application for iPad retina showed no significant differences with *FACT* when the same contrast sensitivity steps were used. In addition, it is shown that the accurateness of a vision screening could be improved with the use of an appropriate psychophysical method.

Key Words: contrast sensitivity function, visual performance, tablet devices, iPad, FACT

INTRODUCTION

The Contrast Sensitivity Function (CSF) has been generally accepted as a better predictor of visual performance than high contrast Visual Acuity (VA). In fact, VA is usually considered as a measure of the clarity of vision, and it basically depends on the finest detail that an eye can resolve. On the other hand, the CSF is a more complete metric since it is a measure of the threshold contrast needed to see spatially varying stimuli.[1] Indeed, the CSF is nowadays considered a routine clinical tool in optical quality assessment of the eye [2,3] and in eye disease detection (e.g., cataracts,[4] optic nerve pathologies,[5,6] retinitis pigmentosa,[7,8] glaucoma,[9,10] etc.).

When CSF testing was initially introduced in clinical practice and clinical research, tests usually consisted of computer-generated visual images. However, those devices were typically costly, they needed a calibration and normative data were not readily available. Consequently, chart-based methods for assessing CSF were developed in the early 1980s.[11]

In clinical practice, Contrast Sensitivity (CS) is generally measured by means of optotypes of different contrast, such as Pelli-Robson chart[12] or by means of sinusoidal gratings of different spatial frequency.[13] The main difference between them is that an optotype contains a wide range of spatial frequencies whose relative weights depend on the letter and its size, while a sinusoidal grating evaluates the response of the visual system to a single spatial frequency.[14]

Today, the most popular commercial tests for measuring CSF by means of sinusoidal gratings are: Functional Acuity Contrast Test (FACT),[15] and the Vector

Vision CSV-1000 (VectorVision, Greenville, OH).[16] These tests commonly use 9 patches for each spatial frequency but they differ in: the specific spatial frequencies evaluated, in the step contrast sizes and ranges, and in the psychophysical method to achieve the threshold.[17]

Since tablets appeared, new applications (apps) have been proposed in the ophthalmology and optometry practice.[19,20] The great advantages of these devices are that they offer the possibility to standardize vision screenings, and since there are many common models which share characteristics such as screen chromaticity and resolution, the chromatic properties of such devices might be assumed to be nearly the same. The aim of this study is to introduce a new App, called *ClinicCSF*,[21] to measure CSF with tablet devices and to compare it with other commercial device: the *Optec Visual Function Analyzer (Stereooptical, Chicago),* [22] that contains the *FACT*.

METHODS

Subjects and instruments

Forty-two subjects divided in two groups participated in this study. Subjects from the Group I (mean age, 33 ± 12 years) were examined by a trained optometrist with the *ClinicCSF.v1* in an optometry center. Subjects from the Group II, members of the staff and students from the University of Valencia (mean age, 37 ± 11 years), were measured by with the *ClinicCSF.v2* by a different practitioner. The iPad retina display (2048-by-1536-pixel resolution at 264 ppi) and the *FACT* used in both screenings were the same. Monocular VA was measured in both groups with the ETDRS procedure included in the Optec, previously to monocular measurement

with *ClinicCSF* and *FACT*. Exclusion criteria were strabismus and any cause of monocular reduced visual acuity with habitual correction (worse than 0.3 logMAR). Informed consent was obtained for each subject and the research was conducted in accordance with the principles laid down in the Declaration of Helsinki.

App description

ClinicsCSF is an app developed by pure mobile ActionScript 3.0 code that can be compiled for iPad or Android devices. The app loads 9 patches of sinusoidal gratings for spatial frequencies of 3,6,12 and 18 cpd created with MATLAB software (The MathWorks, Natick, MA) and the COLORLAB[23] library. This library was used to calibrate the iPad screen by computing the function that links the digital values with the XYZ-CIE tristimulus values and to compute the sinusoidal gratings as follows: First, for each RGB channel of the iPad (primary colors) and for an equal combination of the three (grey scale), ten equally spaced colors were generated and measured with a Spyder4Elite colorimeter obtaining the calibration function. Second, the calibration data were loaded and the digital values of the gratings were computed from the tristimulus values with the COLORLAB library. Finally, the true color patches were exported to JPG format to be compiled into the *ClinicCSF* app. To minimize edge effects, stimuli were generated with blurred edges by means of a half-Gaussian ramp that fades the stimuli with an achromatic background of 86 cd/m^2 mean luminance (CIE xy coordinates: 0.33, 0.33).

Figure 1. Appearance of the *ClinicCSF* App during the testing process. A single sinusoidal grating is displayed with a blurred circular edge that smooth the grating into an achromatic background.

The app was designed to be presented at a distance of 2 meters for which a stimulus of 4 cm subtended 1 degree (see Figure 1). Two different versions, called "*ClinicCSF.v1" and "ClinicCSF.v2*" were developed. In both versions, the stimuli were presented randomly in different orientations: vertical, tilted 15˚ to the right or tilted 15º to the left. The main differences between *ClinicCSF.v1* and *.v2* were the psychophysical method used to achieve the CSF threshold and the step sizes between each one of the CS levels. The *ClinicCSF.v1* was programmed with the same contrast sensitivity values that the *CSV1000* and the *ClinicCSF.v2* with the *FACT* values in order to allow a better comparison with previously reported results (see Figure 2).

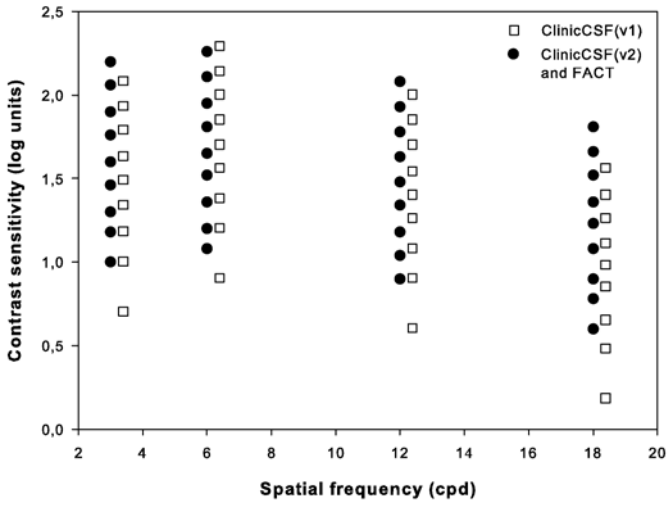

Figure 2. CS values in log units for each one of the patches in both versions of the *ClinicCSF*. The contrast sensitivity step sizes for the *ClinicCSF.v2* and the *FACT* were the same (black dots).

With the *ClinicCSF.v1*, a simple-up down staircase[25] psychophysical method was used starting in the fifth patch level for each spatial frequency. In this method, CS goes one level up (e.g. from level 5 to 6) after each right answer until the observer fails. Then, CS goes down until the observer gets right again. The CS threshold was determined by averaging the sensitivities at the *turnaround points* (i.e. the CS at the levels where direction changed) in the adaptive track for a total of five reversals.

The psychophysical method adopted for *ClinicCSF.v2* consisted of three steps: (1) starting at the first level, it goes one level up after each right answer until the observer fails; (2) the same procedure than previous step but starting two levels below the level on which the answer was wrong in step 1; (3) the exam ends after

two successive wrong responses as the *FACT* procedure being the CS threshold the corresponding to the latest correct answer.

Experimental Procedures

The same procedure was followed for both groups of subjects who wore their habitual correction. Subjects from Group 1 and Group 2 were evaluated with the *ClinicCSF.v1* and *.v2* respectively, and with the *FACT*. The ambient lighting conditions were around 15 lux during all measurements with *ClinicCSF* and *FACT* in both groups. Pupil size and accommodation were not controlled artificially because this study attempted to gain an understanding of the nature of CSF in the natural state of the eyes. The *FACT* offers four possible configurations in the measurement of the CSF, so the “day condition without glare” was chosen in this experiment. Both, the *ClinicCSF* and the *FACT* were performed in the same session. The time involved in the CSF measurement with each test was approximately two minutes.

Statistical Analysis

Both eyes were considered in the statistical analysis due to the low correlation that was obtained between their CS values using the kappa statistic ($k<0.20$).[26] Differences in age, VA, and CS between groups were evaluated using the Mann-Whitney test, and comparison between tests in the same group was computed with Wilcoxon test. This analysis was based on a non-normal distribution of the data. On the other hand, as the difference of scores between tests were normally

distributed, Bland–Altman procedure[27] was used to assess the agreement between each one of the *ClinicCSF* versions and the *FACT*. The data were managed using SPSS software version 20 (SPSS Inc, Chicago, Illinois, USA), and *P<0.05* was considered to indicate significance.

RESULTS

No statistical differences were found in age between both groups of subjects (P=0.064) and median monocular visual acuities were 0 logMAR (range, -0.2 to 0.3) in the Group 1 and 0 logMAR (range:-0.2 to 0.2) in the Group II (P=0.570).

Median CS and range scores obtained at each spatial frequency are summarized for both groups in Table 1 and graphically represented by mean box plot whiskers in Fig. 3. The CSF median values were generally higher for the *ClinicCSF.v1* than for the *FACT* test in Group 1 (Fig. 3A); the differences were statistically significant (P<0.001) for all frequencies except for 3 cpd. However, the *ClinicCSF.v2* gave similar scores than the FACT for all the evaluated spatial frequencies in subjects from group 2 (P >0.05) (Fig. 3B).

Table 1. Comparisons of medians (ranges) between *ClinicCSF.v1* vs *FACT* from Group 1 and *ClinicCSF.v2* and *FACT* from Group 2.

Spatial frequency (cpd)	Subjects Group 1			Subjects Group 2		
	ClinicCSF.v1 Median (range)	FACT Median (range)	Wilcoxon test	ClinicCSF.v2 Median (range)	FACT Median (range)	Wilcoxon test
3	2.03 (1.47-2.08)	2.06 (1.46-2.20)	*p*=0.193	2.06 (1.18-2.06)	2.06 (1.60-2.20)	*p*=0.108
6	1.99 (1.39-2.29)	1.81 (1.20-2.26)	*p*<0.001	1.95 (1.20-2.11)	1.88 (1.08-2.11)	*p*=0.636
12	1.65 (1.18-1.94)	1.48 (0.90-2.08)	*p*<0.001	1.48 (0.90-2.08)	1.55 (0.90-1.93)	*p*=0.207
18	1.20 (0.81-1.56)	1.08 (0.60-1.66)	*p*<0.001	1.08 (0.60-1.66)	1.08 (0.60-1.52)	*p*=0.959

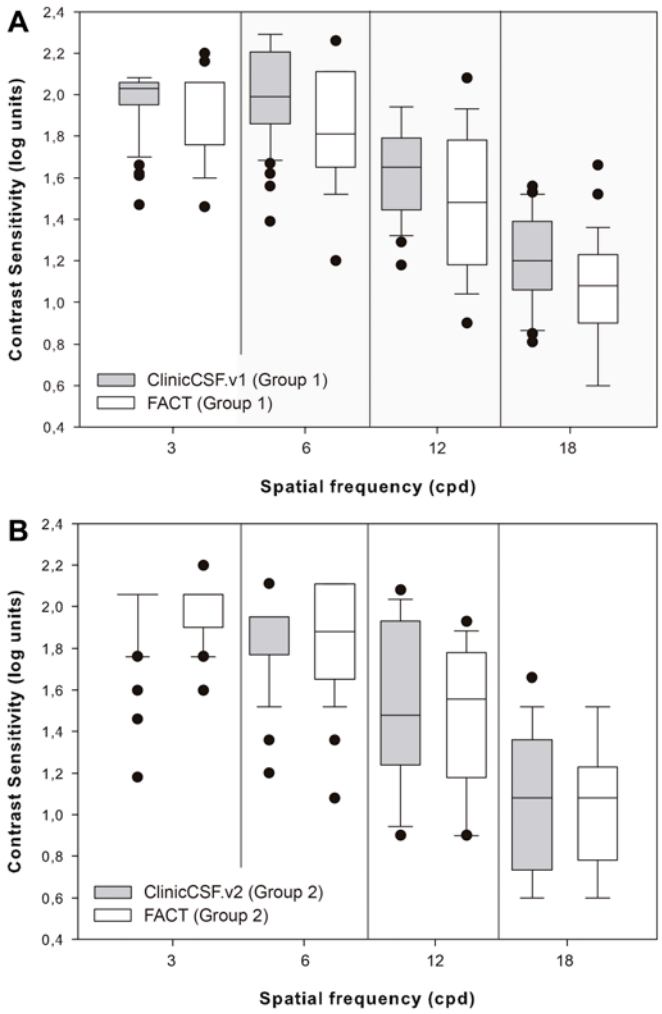

Figure 3. Bland Altman plots. CS difference between methods versus mean of CS scores measured with *FACT* and *ClinicCSF.v1* for spatial frequencies of 3cpd (top-left), 6cpd (top-right), 12 cpd (bottom-left), and 18 cpd (bottom-right). The solid lines represent the mean difference between the two instruments and dashed lines correspond to the 95% confidence interval (mean ± 1.96SD).

As can be seen in Table 2, both groups gave similar contrast sensitivities when the same *FACT* test was used to perform the exam (*P>0.05*). Even though both groups reported similar CSs with the *FACT* test (Fig. 4A), there existed significant differences between groups when they were measured with different versions of the *ClinicCSF* for spatial frequencies of 6 and 18 cpd (*P< 0.05*) (Fig. 4B).

Table 2. Comparisons of medians (ranges) between groups using the same *FACT* test and two different versions of the *ClinicCSF* application.

Spatial frequency (cpd)	FACT			ClinicCSF		
	Group 1 Median (range)	Group 2 Median (range)	Mann-Whitney	Group 1 (v1) Median (range)	Group 2 (v2) Median (range)	Mann-Whitney
3	2.06 (1.46-2.20)	2.06 (1.60-2.20)	*p*=0.789	2.03 (1.47-2.08)	2.06 (1.18-2.06)	*p*=0.051
6	1.81 (1.20-2.26)	1.88 (1.08-2.11)	*p*=0.930	1.99 (1.39-2.29)	1.95 (1.20-2.11)	*p*=0.009
12	1.48 (0.90-2.08)	1.55 (0.90-1.93)	*p*=0.881	1.65 (1.18-1.94)	1.48 (0.90-2.08)	*p*=0.090
18	1.08 (0.60-1.66)	1.08 (0.60-1.52)	*p*=0.614	1.20 (0.81-1.56)	1.08 (0.60-1.66)	*p*=0.021

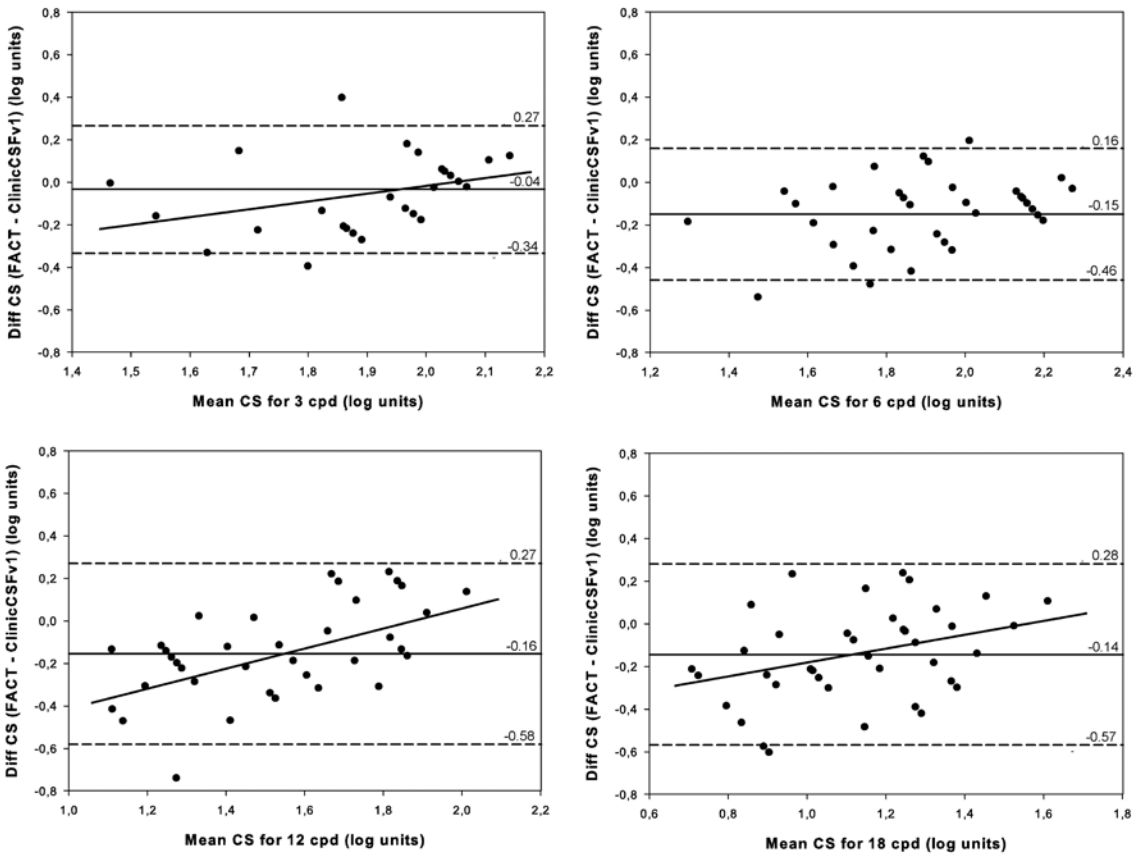

Figure 4. Bland Altman plots. CS difference between methods versus mean of CS scores measured with *FACT* and *ClinicCSF.v2* for spatial frequencies of 3cpd (top-left), 6cpd (top-right), 12 cpd (bottom-left), and 18 cpd (bottom-right). The solid lines represent the mean difference between the two instruments and dashed lines correspond to the 95% confidence interval (mean ± 1.96SD).

In Fig. 5, Bland-Altman plots are represented by means of the difference between the two methods [*ClinicCSF.v1* – *FACT*] against the mean [(*ClinicCSF.v1*+*FACT*)/2]. The same representation was also done for the *ClinicCSF.v2* and the *FACT* in the Fig. 6 by a direct comparison of each one of the spatial frequencies. It can be seen that the *ClinicCSF.v1* overestimated the CS with

respect to the *FACT*, and this overestimation was not found with the *ClinicCSF.v2* (continuous lines in Figs. 5 and 6). It should also be noted that although we found less differences between the *ClinicCSF.v2* vs. *FACT* than between the *ClinicCSF.v1* vs. *FACT*, narrower agreement limits were obtained with the staircase psychophysical method of the *ClinicCSF.v1*; mainly for spatial frequencies of 6, 12, and 18 cpd (dashed lines in Figs. 5 and 6).

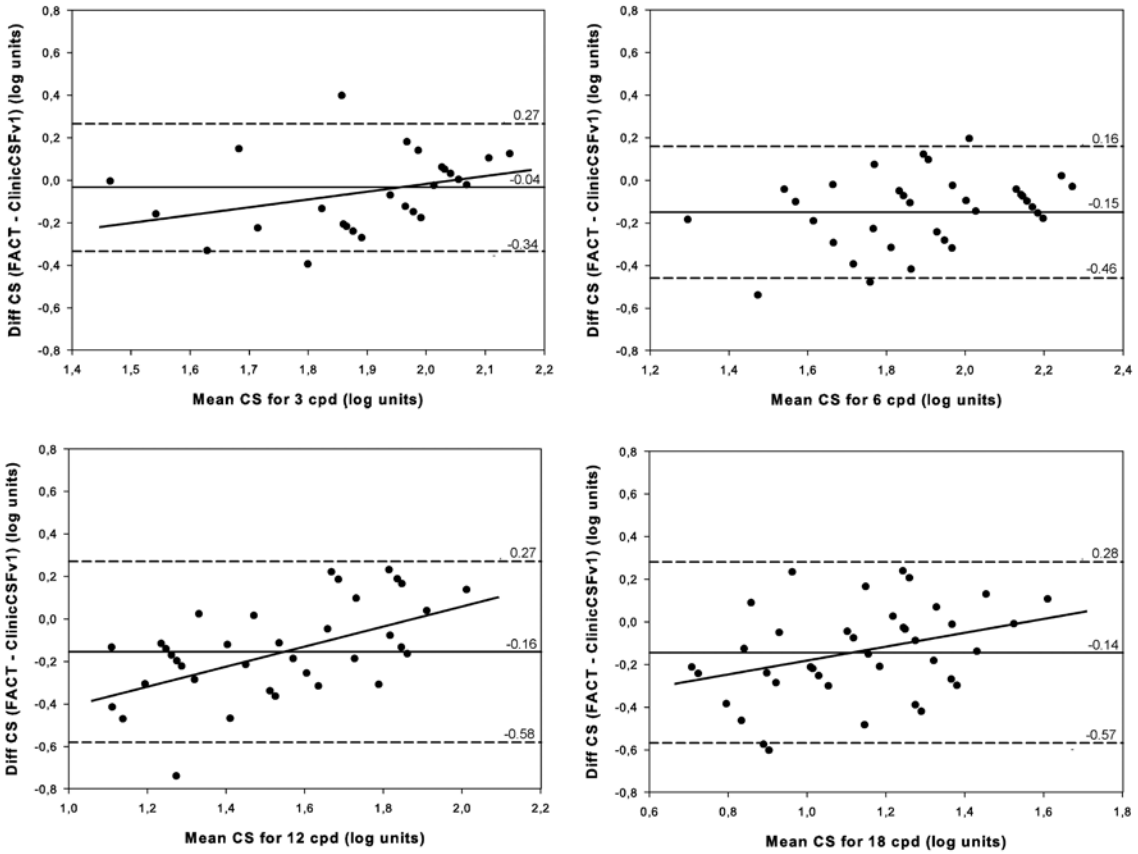

Figure 5. Bland–Altman plots. CS difference between methods versus mean of CS scores measured with FACT and ClinicCSF.v1 for spatial frequencies of 3cpd (top-left), 6cpd (top-right), 12cpd (bottom-left), and 18cpd (bottom-right). The solid lines represent the mean difference between the two instruments and the dashed lines

correspond to the 95% confidence interval (mean±1.96SD). A linear fit was done for statistically significant correlations ($p<0.05$) and the Pearson coefficients (r) are reported for 3cpd (r=0.37), 12cpd (r=0.56), and 18cpd (r=0.34).

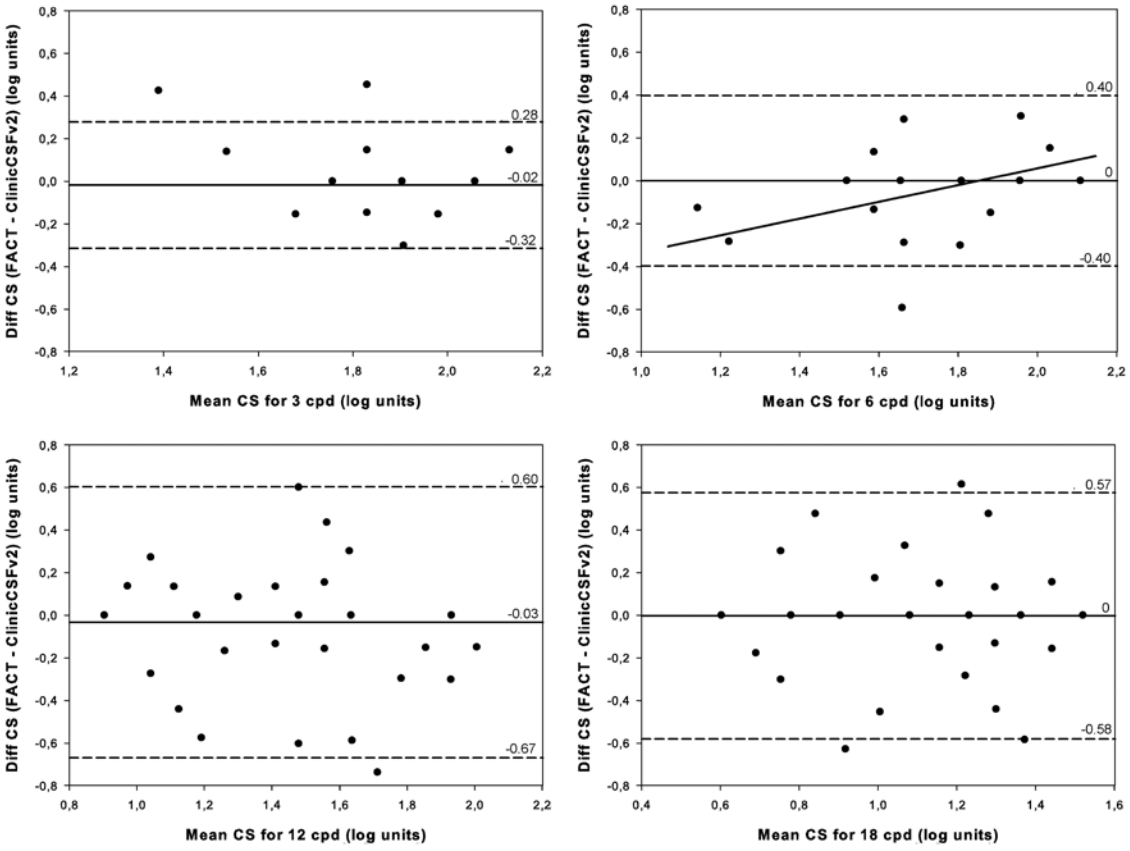

Figure 6. Bland–Altman plots. CS difference between methods versus mean of CS scores measured with FACT and ClinicCSF.v2 for spatial frequencies of 3cpd (top-left), 6cpd (top-right), 12cpd (bottom-left), and 18cpd (bottom-right). The solid lines represent the mean difference between the two instruments and the dashed lines correspond to the 95% confidence interval (mean±1.96SD). A linear fit was done

for statistically significant correlations ($p<0.05$) and the Pearson coefficients (r) are reported for 6cpd ($r=0.44$).

Correlations between differences versus mean scores obtained with tests were analyzed by the Pearson coefficient (*r*) and represented in the Bland-Altman plots by linear least squares fitting in case of being statistically significant ($p<0.05$). Therefore as can be seen in Fig. 3 for the comparison between *ClinicCSF.v1* and *FACT*, the regression line show positive correlations with the increment of mean CS for 3, 12 and 18 cpd (r = 0.37, 0.56 and 0.34, respectively). On the other hand, the correlation was significant only for 6 cpd (r = 0.44) in the comparison between *ClinicCSF.v2* and *FACT*.

DISCUSSION

The aim of this study was to present a new iPad App to measure CSF. Two versions *(ClinicCSF.v1 and .v2)* have been proposed and tested in comparison with other commercial test *(FACT).* Although two different groups of subjects were used in the evaluation of each one of the *ClinicCSF* versions, no statistical differences in visual acuity and age were found between both groups. Special attention was paid on age of participants considering that contrast sensitivity function could be influenced by this variable.[28] In fact, some commercially available tests, such as the *CSV1000*, have different normative ranks depending on subject age.[29]

We found significant differences between *ClinicCSF.v1* and *FACT* for all spatial frequencies except for 3 cpd (Table I). This lack of agreement can be attributed firstly to the fact that each test measures different CS levels and secondly to the different psychophysical method employed in each version. Other comparative studies also found discrepancies due to the similar reasons. Franco et al.[13] compared the *VCTS-6500* and the *CSV-1000* and found mean differences of 0.30, 0.20, 0.08 and 0.18 for spatial frequencies of 3, 6, 12 and 18 cpd respectively, being the differences statistically significant for all spatial frequencies. Such differences are even higher than those obtained in the present study except for 12 cpd. (Fig. 2). As expected, the differences between the *ClinicCSF.v2* and the *FACT* were very much lower due to that both versions have the same CS levels and use the same thresholding technique, unlike the *ClinicCSF.v1* (Table I).

Other researchers have sounded a note of caution with regard to the comparison of the same test with different configurations. For instance, *FACT* differs from the previous *Vistech* version in several characteristics: using smaller step sizes, a 3 alternative forced choice, “blurred” grating patch edges with the gratings smoothed, and a larger patch size to increase number of cycles at low spatial frequencies. Pesudovs et al.[18] attributed dissimilar results between *Vistech* and *FACT* to the fact that this new version uses smaller step sizes with the same number of steps, and thus ranges of measurement are also smaller. As a consequence, they reported a ceiling effect in post-LASIK patients and a floor effect in cataract patients. Furthermore, Hitchcock et al.[30] showed that not only step sizes could have

influence on the CS since they found that although contrast levels were the same, results could be different depending on the way tests were presented.

The biggest differences in the CSFs between groups were found when we changed some properties of the test design (Table II). This demonstrates just how important is to use the same test in the comparison between groups of subjects. Consequently, clinical results in studies which implement different CS tests might also differ due to the configuration of tests used. In fact, the discrepancies in the comparison of several CS tests have been widely studied, mainly in order to obtain normative data for contrast sensitivity functions.[31]

We also found that mean differences confidence intervals were highly influenced by the psychophysical method used to achieve the CS threshold. Confidence intervals of the Bland-Altman plots for differences between *ClinicCSF.v1* and *FACT* were narrowed by using a staircase method. This fact underlines the importance of including a psychophysical method in iPad based screening tests instead of using it simply as an illuminated screen.[32,33] In our opinion these results emphasize the validity of the *ClinicCSF* application in the measurement of contrast sensitivity function considering that a high agreement with the *FACT* could be obtained if we use the same contrast sensitivity levels in both instruments and if we incorporate a psychophysical method to reduce the confidence interval.

One limitation of this study is that two different groups of subjects were used to compare each one of the *ClinicCSF* versions with the *FACT*. The reason is that

ClinicCSF.v1 was first designed and evaluated clinically with one group of subjects. Lately *ClinicCSF.v2* was developed as an improved version of *ClinicCSF.v1* and it was no possible to measure the same group of subjects. A better statistical analysis of variance could have been done if we had measured the CSF with the three tests in the same group of subjects.

We have provided further evidence that test comparison is highly influenced by differences in CS levels between tests and psychophysical methods to achieve CS threshold could help to increase test precision. One potential limitation of our current proposal is related to the maximum brightness configuration of the iPad that might produce a glare effect in some patients, and a possible post-image after each answer. This issue should be considered in future versions of the App.

Our work led us to conclude that *ClinicCSF* app, designed for a given tablet device, can give similar results than *FACT* in CSF measurement in a normal population. Further experiments using the *ClinicCSF* app in other tablet devices are required in order to extrapolate our results. It is expected that no substantial technical differences exist among different tablet units of the same model, therefore a calibration of each device will not be needed.

We think that our new test could be useful to popularize the CSF measurement in centers that do not usually perform it, due to the high cost of current commercial equipment. Further experimental investigations are also needed to estimate normative ranges and ROC curves.

DISCLOSURE

Rodríguez-Vallejo, M. has designed and programmed the ClinicCSF App which he currently distributes by the Apple Store with his own developer account. The other authors report no conflicts of interest and have no proprietary interest in any of the materials mentioned in this article.

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