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Original Article

Visual impairment in children with spastic cerebral palsy measured by psychophysical and electrophysiological grating acuity tests

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Abstract

**Objective**: We measured grating visual acuity in 173 children between 6 and 48 months of age who had different types of spastic cerebral palsy (CP). **Methods**: Behavioral acuity was measured with the Teller Acuity Cards (TAC) using a staircase psychophysical procedure. Electrophysiological visual acuity was estimated using the sweep VEP (sVEP). **Results**: The percentage of children outside the superior tolerance limits was 44 of 63 (69%) and 50 of 55 (91%) of tetraplegic, 36 of 56 (64%) and 42 of 53 (79%) of diplegic, 10 of 48 (21%) and 12 of 40 (30%) of hemiplegic for sVEP and TAC, respectively. For the sVEP, the greater visual acuity deficit found in the tetraplegic group was significantly different from that of the hemiplegic group (p< .001; One-way ANOVA). In the TAC procedure the mean visual acuity deficits of the tetraplegic and diplegic groups were significantly different from that of hemiplegic group (p< .001). The differences between sVEP and TAC means of visual acuity difference were statistically significant for tetraplegic (p< .001), diplegic (p< .001), and hemiplegic group (p= .004). **Conclusions**: Electrophysiologically measured visual acuity is better than behavioral visual acuity in children with CP. Better visual acuities were obtained in both procedures for hemiplegic children compared to diplegic or tetraplegic. Tetraplegic and diplegic children showed greater discrepancies between the TAC and sVEP results. Inter-ocular acuity difference was more frequent in sVEP measurements.

Key words: cerebral palsy, visual development, spatial vision, psychophysics, sweep VEP.
Introduction

Cerebral palsy (CP) describes a group of disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, cognition, communication, perception, and/or behavior, and/or by a seizure disorder\(^1\). These defects are permanent, but they may exhibit some plasticity and their incidence is constant at about 2 per 1000 live births over approximately the last decade\(^2;\,\,3\). The most frequent and severe motor impairment in such children is spastic CP\(^4\).

Frequently CP is associated with ocular disturbances such as strabismus, nystagmus, and a high prevalence of refractive error\(^5;\,\,6;\,\,7;\,\,8\), visual function impairments such as low visual acuity and inter-ocular acuity difference have been often observed\(^9;\,\,10;\,\,11;\,\,12;\,\,13;\,\,14\).

Low visual acuity was reported in 75% of the CP children by Odding et al.\(^3\) and other studies showed different proportions of reduction in visual acuity compared to controls\(^15;\,\,16;\,\,9;\,\,10;\,\,17;\,\,18;\,\,19;\,\,11;\,\,20\). Cerebral visual impairment, caused by defective function of the retrochiasmatic visual pathway, is also found in children with spastic CP\(^12;\,\,21\). Hertz & Rosenberg\(^9,\,10\) evaluated the reliability of the forced-choice preferential look (FPL) in spastic CP children and found large test-retest variability in this population.

We have used the sweep visual evoked potential (sVEP) to study visual acuity in spastic CP children\(^22;\,\,23;\,\,13\) and in premature infants\(^24,\,25\). We showed that there is a positive correlation between the visual acuity measured with the sVEP and the motor impairment measured by the Gross Motor Function Classification System (GMFCS)\(^26\) - a scale of motor classification designed to rate the degree of impairment in spastic CP children\(^16\).
Other studies evaluated visually impaired children with moderate to severe visual impairment, including children with CP\textsuperscript{15; 16; 9; 10; 17; 18; 19; 11; 20}. However, these studies used pattern visual evoked potential (pattern VEP) which is difficult to perform in special populations due to the long time it requires. Bane & Birch\textsuperscript{27} reported greater success obtaining acuity estimates with FPL than with the pattern VEP. The mean acuities were better for the behavioral test, and the discrepancy between behavioral and VEP tests was also lesser in CP children relative to controls.

Westall et al.\textsuperscript{28} also specifically compared TAC and VEP visual grating acuity measures in a group of children with a wide range of vision-threatening disorders, including developmental delay and CP. There was a significant difference between VEP and FPL for children with developmental delay, seizure disorders and CP. However, the study concluded that only the developmental delay condition was associated with relatively poorer visual acuity in the TAC procedure than in the VEP procedure. The authors also found that the discrepancy between the FPL and the VEP tests increased with the severity of the developmental delay.

A different result was reported by Mackie et al.\textsuperscript{29} who found different ranges of visual acuity impairment in both FPL and pattern-reversal VEP measurements. These authors also observed that FPL results were significantly correlated with VEP results, but the measured visual acuities obtained with the VEP were better in children with poor vision\textsuperscript{29}. In short, authors who compared VEP and TAC procedures, showed conflicting results - VEP data displayed greater variability than TAC\textsuperscript{27} and discrepancy between VEP and TAC results was reported\textsuperscript{28}, while others found significant correlation between the two measures\textsuperscript{29}. 
Visually evoked potentials have been used as a clinical tool for the quantitative evaluation of visual acuity in children with neurological or visual impairment and the sVEP shows advantages compared to the pattern VEP. The sVEP evaluates visual acuity and contrast sensitivity in a shorter recording time. It is a pattern VEP that vary (by sweeping) the spatial frequency from low to high in about 10 s, estimating the visual acuity by determining the highest spatial frequency to which the visual system responds. Tyler et al. concluded that the extrapolated sVEP acuity is comparable to the psychophysical acuity when a fine resolution and high luminance display is used. The sVEP is a relatively fast and powerful technique and has been successfully used in non-verbal children with a wide array of vision-threatening disorders.

Psychophysically measured grating acuity is undoubtedly the most frequent measurement performed in clinical practice. Nevertheless, it is necessary to have in addition, an objective method for acuity measurement in these difficult-to-test populations. The pattern VEP has yielded conflicting results when compared to the TAC. Given these results and the advantages of the sVEP method, the aim of our study was to compare the visual acuity measured with TAC and sVEP in children with spastic CP.

**Methods**

**Subjects**

Subjects were 173 infants and children with spastic CP aged 6–48 months (mean = 28 ± 13 months) referred by the Department of Ophthalmology and Orthoptics of the Association for Assistance of Handicapped Children (AACD) of Sao Paulo, Brasil. All participants received an ophthalmologic examination, cyclopegic evaluation of the refractive error and had normal fundi. In addition, the status of oculomotor function was
evaluated before the FPL procedure by an orthoptical exam. All children who had any ocular disease that was not corrected by the use of refractive lenses were not referred for the study. Children who needed correction for refractive errors were wearing glasses for at least 2 months and had been examined not more than 6 months before testing. The whole study comprised a period of 20 months, between 2003 and 2005.

Based on the motor impairment the children were classified by a physiotherapy professional as having tetraplegia (n= 68) - a paralysis affecting the four limbs, diplegia (n= 58), which affects two limbs, more often the inferior limbs, or hemiplegia (n= 47) in which the paralysis affects half the body. Since the GMFCS needs some sessions to be concluded it was applied only in a subgroup of the sample (27 children). The broad clinical descriptions of etiology for these groups were ‘prenatal’, ‘perinatal’, ‘postnatal’ or ‘unclear’, and the proportions of these were similar for the three groups, although perinatal etiology was the most common. The age distribution was similar for all motor impairments. The main characteristics of the spastic CP children and the oculomotor status are shown in Table 1.

The results for the VEP and TAC visual acuity thresholds were expressed as the log of the minimum angle of resolution (logMAR). However, for statistical analysis we considered the visual acuity as the difference between the score obtained in the CP children and the mean threshold expected for the corresponding age based on population norms.
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(Salomao & Ventura\textsuperscript{34} for TAC; Salomao et al.\textsuperscript{35} for sVEP). Significant inter-ocular
difference was defined as a visual acuity difference better than 1.0 octave (0.301 Log(10)
units).

\textit{Teller Acuity Card (TAC) Procedure}

Psychophysical grating acuity was assessed with the Vistech Teller Acuity Cards
(TAC). The TAC test was performed monocularly for left eye and right eye, with the eye
tested being randomly selected. Infants and children were occluded with an opaque patch
(Oftam AMP, Brasil). Cards were presented to the child for viewing at a distance of 55 cm
from the child’s face.

A set of 16 cards (Vistech, Dayton, OH) with half-octave steps of spatial
frequencies ranging from 2.11 to -0.10 LogMAR of visual angle was arranged face down
on a table behind the screen. Low spatial frequencies were at the top of the stack and
progressively higher spatial frequencies were below. The examiner received the cards from
an assistant, was not informed about the start card spatial frequency, and was masked to the
left-right position of the grating on all trials.

The examiner’s task was a 2-alternative forced-choice: on each trial, the examiner
had to judge, based on the subject’s eye or head movements (or any other behavior), on
which side of the card the grating, left or right, had been displayed. For each spatial
frequency, the card was presented to the examiner as many times as he found necessary to
make a judgment, with the grating’s L-R position being randomized each time.

A variation of the standard TAC procedure was used in which acuity threshold is
estimated using a forced-choice, staircase procedure \textsuperscript{34}. This method makes the acuity
estimates potentially more reliable and objective.
Staircase Procedure

Cards were presented from lower to higher spatial frequencies in 1-octave steps up to the first incorrect judgment, and then at 0.5-octave steps to determine the threshold. After each incorrect response, a lower spatial frequency was presented until a correct response was obtained. After each correct response, a higher spatial frequency was presented until the examiner made an incorrect response. Each change of spatial frequency of the cards (from low to high, or high to low spatial frequency) constituted a reversal. The procedure continued until four consecutive reversals occurred (excluding the first incorrect response). Grating acuity threshold was defined as the arithmetic mean of the spatial frequencies of the cards presented during the 4 reversals. Further information about the staircase method and the behavioral population norms used in this study can be found in Salomao & Ventura\textsuperscript{34}.

The TAC measures were performed at the Association for Assistance of Handicapped Children in Sao Paulo, Brasil, and then the patients were referred to the Institute of Psychology of the University of São Paulo for the sVEP measurements.

Sweep Visual Evoked Potential Procedure

Stimuli and Apparatus

Electrophysiological measures of grating acuity were made using the NuDiva version of the original sVEP system\textsuperscript{30}. The stimuli were vertical square-wave gratings displayed on a high-resolution video monitor (Dotronix Model EM2400-D788, Dotronix Technology, Inc., USA), with a mean luminance of 159.5 cd/m\textsuperscript{2} and constant achromatic contrast of 80%. The full screen on the monitor was 33.6 × 25 degrees at a test distance of
50 cm. In each 10-second trial, a sequence of gratings was presented from low to high spatial frequencies, at the rate of one spatial frequency per second, with 12 pattern reversals at each frequency, since the reversal rate was 6 Hz. Any range of spatial frequencies could be selected within the interval of 2.07 and 0.00 LogMAR.

VEP recordings were obtained using Grass Gold Disc EEG electrodes (FS-E6GH-60, Grass Technologies, Astromed Inc, West Warwick, USA) placed on the scalp with electrode cream and cotton pads (Webril II, Kendal Healthcare Prod, USA) in a bipolar montage 2–3 cm to the left (O1) and right (O2) of a common reference electrode (Oz) placed 1 cm above the inion on the midline. A ground electrode was placed 2–3 cm above Oz. The EEG was amplified by a Neurodata Acquisition System 12C-4-23 (Grass Technologies, Astromed Inc, West Warwick, USA) (gain = 10,000; −3 db cutoff at 1 and 100 Hz).

The EEG was digitized in real time (digital sampling rate = 397 Hz). A Discrete Fourier Transform was performed, yielding a measure of amplitude and phase of the second harmonic (F2, i.e. 12 Hz) of the stimuli frequency. The Discrete Fourier Transform was calculated on the basis of each 10 sec data record by multiplying the EEG point-by-point by sine and cosine waveforms of the appropriate frequency. The mean amplitude at a pair of adjacent nonharmonic frequencies was used as a noise estimate for each response frequency. These frequencies were located ± 2 Hz from the response frequency (6 Hz).

Procedure

The test was performed in a darkened room. For each trial, when the child was alert and looking attentively at the video monitor, the experimenter activated the 10-sec grating stimulus sequence. Throughout each trial, the child’s attention and fixation was drawn to
the center of the monitor by dangling and moving small toys in front of the video monitor. Trials were interrupted whenever fixation or attention was lost, and were restarted (within the same trial) when fixation to the monitor center was regained. When a trial was interrupted, the NuDiva system automatically backed up the sweep by 0.5 sec.

sVEP Analysis

The range of spatial frequencies was selected according to that expected for the age for normal subjects. If the threshold was not detected the range was changed to lower spatial frequencies. Sweep-VEP correlates of visual acuity were estimated using an automated algorithm. This algorithm performs a linear fit of the data relating the sVEP second harmonic amplitude to linear spatial frequency. The threshold spatial frequency is considered to be the value of the extrapolation of this function to zero amplitude. A signal-to-noise ratio of 2:1 at peak amplitude for individual trials and 3:1 for the average was required. A threshold was obtained for each channel and the channel with the best signal-to-noise ratio and constant phase was chosen for the visual acuity analysis. Three to 12 repetitions of the sVEP were obtained and at least three with the highest spatial frequency peak meeting the signal-to-noise ratio and with a constant phase were chosen for averaging. Final visual acuity estimates, expressed in octaves, were calculated as the logarithm of the minimum angle of resolution (log MAR)\textsuperscript{27, 36}. Visual acuity estimates were compared with Salomao et al.,\textsuperscript{35} normative data. Visual acuity results are shown in octaves as a difference from the mean visual acuity expected at the corresponding age in normal children.

We considered significant interocular acuity differences higher than 0.5 octaves for the sVEP and 1 octave for the TAC procedures. One octave means doubling or halving of the visual acuity measured in logMAR. These values were based on Salmoao et al.\textsuperscript{35} for
sVEP and Salomão and Ventura\textsuperscript{34} for TAC since both normative studies were performed in Brazilian children.

**Data Analysis and Statistics**

We calculated the Bland-Altman comparison, in which the “limits of agreement” are estimated by two standard deviations around the mean of the differences between the two measurements Bland and Altman\textsuperscript{37}. The limits of agreement are a measure of how much two methods are likely to disagree. In other words, the disagreement between the tests is the range of the 95\% limits of agreement calculated. As would be expected, the smaller the difference, the stronger will be the agreement between methods.

Statistical analysis was performed with the software Statistica (StatSoft v6.0, Inc., Tulsa, OK, USA,). Adherence to the normal distribution was checked with the Kolmogorov-Smirnov test. Assessments of statistical differences among groups were performed with the Repeated Measures ANOVA test. Tukey Test for Unequal N was used as a Post Hoc test. One-Way ANOVA and Student T test was used to calculate statistical differences between dependent variables. Yates corrected Chi-Square was used to compare the percentages of successful testing between sVEP and TAC methods. Tolerance limits were calculated based on mean (± 2SD) for sVEP\textsuperscript{35} and according to values obtained by Salomao and Ventura\textsuperscript{34} for TAC.

**Results**

Electrophysiological visual acuity measurements with the sVEP method were successfully obtained in 167 of 173 (97\%) children with spastic cerebral palsy, whereas behavioral visual acuities measured with the TAC in the same group of children were
successfully performed in 148 of 173 (85%) children. This difference in the rate of testing success was statistically significant (Yates corrected Chi-square = 11.48; p = 0.0007).

The sVEP tests with unreliable results were considered unsuccessful. This occurred in 4 children with tetraplegia and in 2 with diplegia, whose data were excluded from the sample. Inconclusive results, due to poor cooperation occurred in the TAC procedure in 15 children with tetraplegia and in 10 with diplegia.

Visual acuity of CP children measured by the sVEP and TAC was poorer than that of normal children of the same age, for all subjects. There was a discrete but non-significant improvement in VA with age only with the sVEP measurements. VA losses exceeded 0.5 octave below the lowest normal tolerance limit for 63 of 167 (38%) in the sVEP and in TAC measurements, the losses exceeded 1 octave below the lowest normal tolerance limit occurred in 115 of 148 (77%).

Individual visual acuity thresholds (log MAR) of the best eye obtained in the sVEP and TAC procedures are shown in Figure 1 as a function of age for each CP subgroup. The lines in the figures present the tolerance limits for the sVEP and for the TAC. The VEP tolerance limits considered the age range and are expressed in LogMAR: 0.65 to 0.15 for 6-11 mos; 0.48 to 0.12 for 12-17 mos; 0.35 to 0.05 for 18-24 mos; 0.24 to 0.00 for 25-29 mos; 0.20 to 0.02 for 30 to 36 mos; 0.18 to -0.03 for 37-48 mos. Figure 1 shows that for all groups tolerance limits are at lower spatial frequencies, that is, poorer, than normal logMAR values for sVEP compared to behavioral acuity.

The visual acuity thresholds were, in general, poorer than the tolerance limits for a progressively lower number of children from the tetraplegic, to diplegic and to hemiplegic groups. For sVEP acuities the proportions below normal were similar for tetraplegia and diplegia groups (44 of 63-69%; 36 of 56-64%, respectively) and lower for hemiplegia.
group (10 of 48-21%). For TAC acuities, the proportions below normal were even larger than for sVEPs, tetraplegia (50 of 55-91%) and diplegia (42 of 53-79%), with the hemiplegia group (12 of 40-30%) again showing the lowest proportion below normal limits. For the tetraplegic children that difference was significantly or the TAC compared with the sVEP proportion below the normals ($X^2 = 6.08; p= .009$). In no group was there a single case in which visual acuity was better than the lower tolerance limit. All differences from age norms were in the direction of a poorer visual acuity.

The visual acuity deficit relative to the normal mean acuity as a function of age is shown in Figure 2 A for all subjects using both sVEP and behavioral grating acuity methods. Deficits were greatest for the children with tetraplegia and progressively less for children with diplegia and hemiplegia. For the sVEP, the largest visual acuity deficit found in the tetraplegic group was significantly poorer than that of the diplegic and both acuities were poorer than the hemiplegic group ($F= 10.68, p< .001$; Repeated Measures ANOVA). In the TAC procedure the mean visual acuity deficits of the tetraplegic and diplegic groups were significantly different from that of hemiplegic group ($F= 12.09, p< .001$; Repeated Measures ANOVA).
The comparison between threshold differences in the two methods showed the TAC was associated with better visual acuity losses for the three CP groups. The differences between sVEP and TAC means of visual acuity difference were statistically significant for tetraplegic (0.57 octaves; F= -4.63, p< .001; Repeated Measures ANOVA), diplegic (0.64 octaves; F= 7.46, p< .001; Repeated Measures ANOVA), and hemiplegic group (0.33 octaves; F= 3.11, p= .004; Repeated Measures ANOVA) (Figure 2 B).

Although the sVEP and TAC produce different visual acuity estimates, very large differences in results might indicate problems during testing or lack of applicability of the method. The latter could be the situation of the children with CP. Due to their severe motor impairment the TAC might not be suitable for use in that population. To check this, the data were examined to check the existence of very wide discrepancies between the results of the two visual tests. We classified results as “inconsistent” if the difference between the sVEP and TAC visual acuities were higher than 1 octave according to the criteria proposed by Westall et al.\textsuperscript{28}. Inconsistent results were found in 16/67 (24%) for the tetraplegic, 25/59 (42%) for the diplegic and 11/47 (23%) for the hemiplegic groups. For most children, visual acuity was better when measured by the sVEP than by the TAC procedure. However, a few children had a better TAC than sVEP result. This was observed in 4/67 (6%) children with tetraplegia, 4/59 (7%) with diplegia and 11/47 (23%) with hemiplegia.

Additional analysis, however, is recommended by Bland and Altman\textsuperscript{37,38}. The results of Bland-Altman analyses for each CP group are shown in Figure. 3. Each panel consists of a plot of the difference between measurements against their mean, showing the
mean difference ($\mu_D$ dashed line) and the limits of agreement ($\mu_D \pm 2\sigma$ pointed lines) for each comparison.

For the tetraplegic group, the mean difference ($\mu_D$) between TAC and sVEP was 0.28 and the limits of agreement were -0.22 to 0.78 LogMAR (which means a range of 3.30 octaves); for the acuity measured for the diplegic group, the mean difference ($\mu_D$) was 0.21 LogMAR and the limits of agreement were -0.19 to 0.60 LogMAR (a range of 2.62 octaves); for the acuity measured for the hemiplegic group, the mean difference ($\mu_D$) was 0.10 LogMAR and the limits of agreement were -0.16 to 0.36 LogMAR (a range of 1.72 octaves).

There were more individuals with significant interocular differences measured by sVEP than measured by TAC. Greater inter-ocular difference was found in 32/63 (51%) children with tetraplegia, 30/56 (53%) with diplegia and 9/47 (19%) with hemiplegia measured by the sVEP. The prevalence of inter-ocular measured by the TAC was 9/59 (15%) tetraplegic, 6/49 (12%) diplegic and 3/40 (8%) hemiplegic groups. The prevalence of inter-ocular differences found by sVEP and TAC tests was statistically significant for the tetraplegic (T= 6.24, p< .001), diplegic (T= 6.56, p< .001) and hemiplegic groups (T= 3.46, p< .001) (Student T test for depended Samples, with Bonferroni correction of the p value).

Ocular motility disorder (heterotropia, intermittent heterotropia or nystagmus) was
identified in 84% (53/63) of the children with tetraplegia, 57% (32/56) children with
diplegia and in 50% (24/47) children with hemiplegia. Excluding children with significant
inter-ocular differences who also had ocular motility disorder, the prevalence of inter-
ocular differences is 5/63 (10%) for children with tetraplegia, 15/56 (27%) children with
diplegia and 3/47 (6%) children with hemiplegic.

In order to check if the significant IAD could be related to other variables such as poor fixation, we compared the IADs of the amblyopic subjects, considering the presence or not of an alternating fixation. For the sVEP results, we found in the tetraplegic group that the children with alternating fixation had a higher visual acuity than the children with non-alternating fixation (T= 2.22; p= 0.032).

No correlation was found between the age or the gestational age and the visual acuity between test methods for the tetraplegic, diplegic and hemiplegic groups (p> .05). No difference was found between the visual acuity of male and female children for TAC and sVEP (p> .05) and comparing preterm with term children (p> .05) in both methods.

Discussion

The higher rate of testing success with the sVEP compared to TAC was statistically significant, suggesting that the TAC is more affected than the sVEP by the poor cooperation from most of the CP children tested. Nevertheless, for both methods there was a significant reduction in the visual acuity of the three different motor impairment groups of spastic cerebral palsy children: tetraplegics, diplegics and hemiplegics for both psychophysical and electrophysiological methods. The reduction in the visual acuity was worse from hemiplegic to diplegic and to tetraplegic children. Since in both methods we found a similar profile of visual acuity impairment, we argue that reduction could be related
to the visual damage rather than to difficulty in the test situation and that both tests are able
to measure the visual acuity and detect their impairments, although they differ in success
rate.

Comparing to other studies using the TAC measurements of visual acuity in
children with CP\textsuperscript{9,11,16,18,45}, or in studies that included CP children\textsuperscript{10,28,32,40}, our rate for
successful monocular testing using that method is similar.

Visual acuities falling outside the TAC tolerance limits were significantly more
frequent than those falling outside the sVEP tolerance limits. However, it is important to
stress here that for the most severe groups (tetraplegic and diplegic) both tests were able to
detect a high percentage of children outside the tolerance limits.

Studies have reported that visual acuity tests can provide important prognostic
information since abnormal acuity measurements were always associated with abnormal
motor outcome in infants with perinatal hypoxic-ischaemic insults\textsuperscript{39,40}. Despite the
significant difference in the success rate found between the two methods, our study is in
line with those studies since the children in the tetraplegic and diplegic groups had a greater
percentage of lower visual acuity compared to the less severe motor impairment group, the
hemiplegic. Additional agreement was given by the demonstration that the motor
impairment score was highly correlated with the impairment in the grating acuity measured
by the sVEP\textsuperscript{13}.

The results showing that fewer children with tetraplegia and diplegia were
successfully tested than children with hemiplegia by TAC, along with the poorer TAC
acuities and higher variability in TAC acuities in children with tetraplegia, suggests effect
of severe developmental difficulties. It could means that concomitant with the brain injury
cauing motor impairment, the cognitive and social-emotional functions could also be
impaired. Indeed, damage in these functions can cause a decrease or even an impediment to a behavioral response of visual acuity.

The present result show higher discrepancies in comparing the visual acuity values measured by the sVEP and by TAC than Westall et al.\textsuperscript{28}. This could be due to some factors. First, we evaluated spastic CP children with homogeneous characteristics (age, aetiology, etc) in a larger sample of children than in the study by Westall et al.\textsuperscript{28}. Second, the sVEP gives the experimenter online information about the signal-to-noise ratio, and plots online the entire amplitude and phase versus spatial frequency function obtained in each measurement, allowing repetition when specified criteria are not met. This contributes to a more precise measurement of thresholds than it is possible to obtain using the pattern VEP paradigm. The duration of the test could be the third factor. The sVEP is a faster test than traditional VEP procedures, and requires a shorter time of cooperation from the child during the exam sessions which might lead to better visual acuities. These shorter periods of cooperation could directly contribute to achieve better visual acuity results\textsuperscript{44}.

Experimental evidence comes from the paper of Glickman et al., (1991)\textsuperscript{44} in which they compared the visual acuity measured in Rhesus monkey, using both the steady-state VEP and the sweepVEP. The authors concluded that the sweep VEP and the steady-state VEP give similar results. So, considering the shorter time to conclude the evaluation and the repeated measurements we infer that the methodological difference could be a source of variation in favor of the visual acuity measured by the sVEP. Fourth, the staircase psychophysical procedure used in our work\textsuperscript{34} reduced variability in visual acuity\textsuperscript{9; 10} by averaging the results of multiple measurements.

Another important found in the present study is that our children had normal fundi which suggest that visual losses in these children should be due, most likely, to a more
central impairment in the visual pathway than the retina. This hypothesis is supported by the fact that perinatal anoxia was the most frequent etiology in our children, and both the visual cortex and the retina are vulnerable to hypoxia\textsuperscript{41, 42, 43}.

No detailed prevalence of visual impairment according to the motor impairment group was found for the spastic cerebral palsy. A relationship between visual function and type of motor impairment had been poorly described in the literature. Low visual acuity is reported in 75\% of the CP children\textsuperscript{3} and other studies showed different proportion of the reduction in visual acuity compared to controls\textsuperscript{15; 16; 9; 10; 17; 18; 19; 11; 20}. We found that the visual impairment prevalence depends on the degree and type of motor impairment. For tetraplegics, the TAC acuity was reduced in 91\% of the children and for the hemiplegic 30\% was outside the tolerance limits.

The sVEP is a modified steady-state pattern reversal VEP, in which the spatial frequencies change dynamically within a short time (10s) and an algorithm measures the amplitude and the phase of the signal, computes the SNR and a respective T-circle statistics for each data epoch. The faster procedure of the sweepVEP compared to the traditional pattern VEP certainly offers a better possibility of visual function measurements since to the test requires short times of cooperate on. According to Tyler et al.\textsuperscript{31}, since the grating acuity extrapolation in sVEP is to 0µV, the extrapolated acuity is comparable to the psychophysical acuity.

There are some important limitations to be addressed. A test-retest reliability of sVEP and TAC acuities was not measured so repeatability of acuities that is an important indicator of accuracy is not known. However, since in the sVEP we performed an averaging of at least 3 measurements, and the visual acuity was resulted of this procedure, considering statistical confirmation of the data, we assume that the values of visual acuity by this
methodology are contemplating certain reliability. For the TAC, we used a different procedure that includes a staircase paradigm at it consist in presenting gratings of higher spatial frequency as the child responds correctly, and if the response is incorrect, we present grids of lower spatial frequency until a new correct answer. Since this procedure was repeated for four times and the visual acuity calculate is also a mean value of hit and miss in each of the four reversals, we also assume that there is certain reliability in the TAC acuity.

Another relevant possible limitation of our study that should be pointed is regarding to the testing order. Since the children were referred to the sVEP after their ophthalmologic evaluation, including the TAC acuity measurement, the sVEP was always performed in a second section. The non-randomness of the procedures can lead to some response bias for sVEP results. However, only after the visual acuity results measured by sVEP is that the TAC visual acuity was known.

In conclusion this work shows a close association between motor and visual impairment which supports the interpretation of the cortical origin of the visual losses. It also shows the discrepancies between the psychophysical and electrophysiological acuities measured. For the more severe motor impairment children the sVEP offers a way of obtaining relevant information about the processing of visual acuity stimuli at the level of the visual cortex. On the other hand, the psychophysical measurement shows the functional limits of visual acuity. Both methods are complementary and provide important information about physiological and functional aspects of the spatial vision in these children. The inter-ocular differences of visual acuity were present in both methods and should alert the physicians to consider an ophthalmological evaluation for CP children.
Acknowledgements: We would like to thank Keli Roberta Mariano for the great help in TAC measurements and to Prof. Russell David Hamer for his invaluable discussions and suggestions in the whole paper. Thanks are also due to the ophthalmology staff from Association for Assistance of Handicapped Children for the ophthalmological exams. This research was supported by grants to DFV from FAPESP Projeto Temático 02/12733-8, CNPq #523303/95-5, USP-PROPESP and CAPES/PROCAD #0019/01-1. MFC and DFV are CNPq research fellows.
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Figure Legends:

Figure 1. Individual visual acuity thresholds (in LogMAR) obtained in the sweep VEP and TAC procedures for tetraplegic (upper panels), diplegic (middle panels) and hemiplegic (lower panels) children. The black lines indicate the visual acuity range expected for each age; they are the upper and lower tolerance limits determined for the TAC (Salomão and Ventura, 1995) and for the sVEP (Salomao et al., 2008).

Figure 2. Visual acuity deficits of CP children relative to the age-matched norms expressed in LogMAR units (left y-axis) and octaves (right y-axis). Central squares indicates the mean and the vertical bars denotes the two standard deviations. (A) For the sVEP, acuity from the tetraplegic children are worse than of the diplegic children and both differed from that of the hemiplegic children; for the TAC tetraplegic children differ form hemiplegic children. (B) for all the three CP groups the impairment related to the normal were significantly greater in TAC than in the sVEP.

Figure 3. Limits of agreement obtained with the Bland-Altman’s analysis. The dashed line is the mean agreement between the sVEP and TAC visual acuity results. The dotted lines are the 95% limits of agreement calculated for the respective group. For tetraplegic and diplegic children there was a larger limit of agreement range compared to hemiplegic children indicating a higher agreement between the results of sVEP and TAC for this group.
Table 1. Main characteristics of the cerebral palsy children according to their group of motor impairment

<table>
<thead>
<tr>
<th></th>
<th>Tetraplegia</th>
<th>Diplegia</th>
<th>Hemiplegia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male / Female</td>
<td>N= 40/ N= 27</td>
<td>N= 37/ N= 22</td>
<td>N= 27/ N= 20</td>
</tr>
<tr>
<td>Prematurity (&lt;37 weeks)</td>
<td>N= 21</td>
<td>N= 30</td>
<td>N= 21</td>
</tr>
<tr>
<td>Gestational age</td>
<td>39.8 (37.5 - 40.9)</td>
<td>39.8 (37.5 - 41.1)</td>
<td>39.8 (37.5 - 41.8)</td>
</tr>
<tr>
<td>No</td>
<td>N= 46</td>
<td>N= 29</td>
<td>N= 20</td>
</tr>
<tr>
<td>Gestational age</td>
<td>33.3 (26.8 - 36.9)</td>
<td>30.2 (22.7 - 36.2)</td>
<td>32.9 (21.8 - 35.3)</td>
</tr>
<tr>
<td>Aetiology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prenatal</td>
<td>11 (16%)</td>
<td>5 (8%)</td>
<td>2 (4%)</td>
</tr>
<tr>
<td>Perinatal</td>
<td>38 (57%)</td>
<td>39 (66%)</td>
<td>26 (55%)</td>
</tr>
<tr>
<td>Postnatal</td>
<td>10 (15%)</td>
<td>9 (16%)</td>
<td>14 (30%)</td>
</tr>
<tr>
<td>Unclear</td>
<td>8 (12%)</td>
<td>6 (10%)</td>
<td>5 (11%)</td>
</tr>
<tr>
<td>Oculomotor alterations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strabismus</td>
<td>49 (73%)</td>
<td>30 (51%)</td>
<td>20 (43%)</td>
</tr>
<tr>
<td>Nystagmus</td>
<td>2 (3%)</td>
<td>1 (2%)</td>
<td>3 (6%)</td>
</tr>
<tr>
<td>Others</td>
<td>2 (3%)</td>
<td>1 (2%)</td>
<td>1 (2%)</td>
</tr>
<tr>
<td>Refractive error</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absence</td>
<td>54 (80%)</td>
<td>41 (70%)</td>
<td>34 (72%)</td>
</tr>
<tr>
<td>Myopia</td>
<td>4 (6%)</td>
<td>4 (7%)</td>
<td>2 (4%)</td>
</tr>
<tr>
<td>Range</td>
<td>-1.00 to -0.00</td>
<td>-0.50 to -2.50</td>
<td>-0.50 to -1.75</td>
</tr>
<tr>
<td>Hyperopia</td>
<td>16 (24%)</td>
<td>20 (34%)</td>
<td>12 (26%)</td>
</tr>
<tr>
<td>Range</td>
<td>+0.75 to +4.00</td>
<td>+1.00 to +3.50</td>
<td>+0.75 to +3.75</td>
</tr>
</tbody>
</table>

# median (minimum and maximum values)

203x208mm (300 x 300 DPI)
Figure 1

For Peer Review Only

183x179mm (300 x 300 DPI)