Original Article

Test and retest of auditory processing: reliability of the evaluation

Processamento auditivo em teste e reteste: confiabilidade da avaliação

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ABSTRACT

Purpose: To verify the reliability of a few Central Auditory Processing (CAP) tests through a test-retest study. **Methods:** Forty Portuguese speaking volunteer subjects were randomly selected and evaluated on CAP abilities in the situations of test and retest, with interval periods that varied from one week to one month. The following tests were applied: localization, verbal and non-verbal sequential memory, two monotic and two dichotic tests. These last ones were selected according to each subject's age and response conditions. **Results:** There was no difference between the tested ears, nor between the test and retest situations for the entire group. When the performances of subjects indicating an auditory processing disorder were compared to those whose results were within normal limits there was a variation in the majority of the tests, in both situations. **Conclusion:** The CAP tests used in this study indicated their reliability through the test-retest.

Keywords: Hearing; Hearing disorders; Auditory perception; Auditory perceptual disorders; Hearing tests

INTRODUCTION

Although recent in Brazil, the behavioral assessment of Central Auditory Processing (CAP) is a fairly common clinical practice due to its great contribution to audiological diagnosis.

The CAP was defined as "a set of mechanisms and processes of the auditory nervous system responsible for the phenomena of localization, discrimination, recognition, and temporal aspects of hearing including: temporal resolution, temporal masking, temporal ordering, auditory performance with competing message and distorted acoustic signals"[1].

CAP disorders have been clearly defined as an alteration on specific auditory processing, which may be associated with difficulties in language development, learning, and hearing or comprehending speech[1].

The first tests for the assessment of the central auditory nervous system appeared in the 1950s, with the primary purpose of analyzing the integrity of the auditory pathway[2]. However, the application of behavioral tests on the evaluation of auditory function in individuals with normal hearing thresholds was first reported in the 1970s, when the theory of CAP was first introduced. Since then, several tests have been developed to specifically assess CAP.

In Brazil, CAP behavioral tests emerged first as a translation of tests developed for the English-speaking population and so far have been widely studied and applied in several clinical populations in order to verify their validity and efficiency.

The aim of this study was to verify the reliability of behavioral tests developed to evaluate the CAP of Brazilian Portuguese-speaking individuals. This investigation will be done through a test-retest analysis in children diagnosed with CAP disorders.

METHODS

This study was developed at the Auditory Processing Investigation Laboratory from the Speech-Language Pathology and Hearing Sciences Course of the Department of Physiotherapy, Speech, Language and Hearing Sciences, and Occupational Therapy of the Medical School, Universidade de São Paulo (*FMUSP*). The study was approved by the Ethics Committee

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Received: 21/5/2010; **Accepted:** 19/7/2010

for Research Project Analysis (CAPPesq) of the Clinical Board of Hospital das Clinicas, FMUSP, under protocol number 731/04.

Participants

Forty individuals (26 men, 65%; and 14 women, 35%) aged between seven and 23 years participated in the study. All participants had normal hearing thresholds and no obvious neurological or mental disorders.

The following materials were used in the data collection of the current study: Heine otoscope®; sound attenuating booth from Siemens® (ANSI S3.1, 1991); middle ear analyzer from Grason-Stadler®, GSI-33 (ANSI, 1989); Audiometer Grason-Stadler's®, GSI-61 (ANSI S3.6, 1989); supra aural headphone model TDH-50 (ISO 7566, 1987); list of words for speech tests[3]; Compact Disc Player by Sony® with direct input to the audiometer; Laser Compact Disc (CD) with tests of auditory processing[4]; bell, agogo (a percussion metal musical instrument), coconut and rattle - musical instruments used on the simplified assessment[4]; protocols for medical history, records of audiometric assessment, and records of the CAP tests.

Procedures

This study was conducted in two phases. The first phase consisted on the collection of medical history information, basic audiological evaluation (otoscopy, tympanometry, pure tone and speech audiometry) and behavioral assessment of CAP. This phase was considered the "test" condition. Pure tone audiometry with thresholds up to 20 dBHL in the frequencies from 500 Hz to 8 kHz (ANSI 69) was considered normal. Subjects with hearing thresholds above these levels were excluded from the study.

In the second phase of the study ("retest"), participants of the study underwent the same CAP behavioral tests. The retest condition was conducted within a period of one week to one month after the test condition.

The CAP tests selected were applied with each individual according to age and condition of speech response – i.e. tests that did not involve verbal responses were selected in the presence of articulatory disorders.

All CAP tests used in the current study were part of the Manual of Auditory Processing Evaluation[4]. The following tests of auditory processing were selected:

Tests of the simplified assessment: sound source localization and sequential memory for verbal and non-verbal sounds.

Monotic tests: Pediatric Speech Intelligibitily Test (PSI) with ipsilateral competing message (ICM); Synthetic Sentence Identification (SSI) with ipsilateral competing message; Speech in Noise (FR) or Figure Identification in Noise (also named PSI with words and white noise)[4]. In these tests, the signal was presented at 40 dBSL in relation to the Speech Recognition Threshold (SRT).

Dichotic tests: Staggered spondaic Word Test (SSW); dichotic digits test (DD); and Non-Verbal Dichotic with Targeted Listening (DNV). In these tests, the signal was presented at 50 dBSL above the SRT of each ear.

A summary of the characteristics and standards adopted for each measure is described below:

- Test of sound localization in five directions (LOC): Assesses the ability to locate the sound source. This test may be carried out with a rattle and the individual is instructed to point to the direction of where he/she thinks the sound comes from. The individual is expected to locate at least four of the five tested positions[5].
- Memory of sequential non-verbal sounds with four instruments (MSNV): Assesses the ability of sequential memory for nonverbal sounds. First the sounds of each instrument are separately presented so that the individual can acknowledge each instrument. Next, four sequences of sounds with variations in the order the instruments are played. The individual should not see the sequence played, but must turn and point to and/or name the sequence heard. The correct identification of at least two sequences is considered a good performance[5].
- Sequential memory of verbal sounds (MSV): The syllables /pa/, /ta/ and /ka/ are presented in three different sequences. The individual has to repeat the syllables in the order they were presented. The objective of this test is to evaluate the sequential memory of verbal sounds. According to Pereira, the correct identification of at least two sequences is expected[5].
- PSI: ipsilateral monotic test at a signal to noise ratio of 0 dB and -15 dB. Only the last relation was considered in this study. This test evaluates the auditory background ability and the association of auditory-visual stimuli preferentially in young children or older individuals with reading difficulties. Normality: 60% accuracy for both ears as MCI in the signal to noise ratio of -15 dB[6].
- SSI: applied in the monotic form with signal to noise ratios of 0 dB and -15 dB. This test evaluates the auditory background ability and association of auditory-visual stimuli preferentially in young individuals or adults without reading difficulties. Normality: 60% accuracy for both ears as MCI in the signal to noise ratio of -15 dB[7].
- FR: applied in the monotic form with a signal to noise ratio of +20 dB - considering the audiometer used and the calibration type White Noise (WN) effective. It assesses the ability of auditory closure. This test was not applied in individuals with articulatory disorder that would compromise the comprehension of the response provided by the subject. Normality: percentages of correct responses greater than or equal to 68% in the first tested ear and 70% in the second ear[4].
- Identification of figures with ipsilateral noise or PSI with words and white noise: applied at the signal to noise ratio of +20 dB. The message consists of monosyllables and white background noise. It assesses the ability of auditory closure in cases of articulatory disorders that compromise the comprehension of the response provided by the subject or when testing very young children. Normality: percentages of correct responses greater than or equal to 90% in both ears[6].
- SSW: dichotic test that evaluates the background ability to linguistic sounds. It was used in literate children with no

articulatory disorders that would compromise the analysis of responses. It presents a variety of quantitative and qualitative aspects for analysis - only the former aspects were considered in the statistical analysis of the current study. Normality considered for this test was proposed by Bennett[8] and is displayed in Chart 1.

Chart 1. Pattern of responses expected in the adaptation of the American version of the SSW test to Brazilian Portuguese[9]

Age (years)	Right - competitive	Left - competitive
7	77.5%	60.0%
8	82.5%	75.0%
9	85.0%	80.0%
10	87.5%	82.5%
11	92.5%	85.0%
12 or more	95.0%	90.0%

- DD: dichotic test. It evaluates the background ability to linguistic sounds. It was used in young children and/or children with articulatory disorders that would compromise the analysis of responses. Normality expected for young adults is 90% in both ears[9].
- DNV: dichotic test. It evaluates the background ability to non-linguistic sounds in the stages of free attention, and directed attention to the right and left ears. For this analysis, only the stages of directed attention were considered. It is noteworthy that only 12 stimuli were presented. Normality: 11 correct responses for each ear, i.e. 91.6%[10].

At the retest condition, participants were once again submitted to visual inspection of the external auditory canal (EAC), followed by screening tympanometry and ipsilateral acoustic reflex research at the frequency of 1 kHz. Thus, individuals with conductive hearing loss were excluded from the study. Next, the LRF was confirmed and, subsequently, the application of the same CAP tests used in the first assessment (test) was conducted.

It is noteworthy that the data obtained in a CAP evaluation are quantitative and qualitative. However, in the current study, only quantitative data were considered for the analysis.

Initially, accuracy and errors on each test of the battery for CAP assessment were computed and the percentage of correct responses calculated for each test. Descriptive statistical measures (median and standard deviation) and inferential measures (ANOVA, i.e., analysis of variance) were calculated. The latter was used with the aim to analyze possible significant differences between the groups established for the analysis. The significance level adopted was of 0.05 (5%).

RESULTS

The results obtained when comparing the performance on behavioral CAP tests of the 40 participants of the study in conditions of test and retest (performed within one month of the test condition) are presented below.

As no differences were observed on accuracy of right and left ears for each CAP test in test (T) and retest (R) conditions, data were analyzed considering the results obtained in each ear, thus increasing the sample size.

The comparisons of mean accuracy in the test and retest conditions in all CAP behavioral tests are displayed in Table 1.

Table 2 describes the mean accuracy comparative analysis between test-retest conditions of participants with results within normal limits on the CAP behavioral assessment.

Mean accuracy comparative analysis between test-retest conditions of participants with CAP disorders is displayed in Table 3.

No differences between test and retest results were found

Table 1. Description of comparative analysis of CAP behavioral tests in test and retest conditions

Test	Condition	Mean	Median	SD	n	p-value
LOC	T	88.7	100	14.4	40	0.084
	R	93.5	100	9.5	39	
MSNV	T	63.2	66.7	35.7	40	0.113
	R	69.2	66.7	30.6	39	
MSV	T	81.2	100	23.9	40	1.000
	R	78.3	100	28.8	39	
PSI/SSI	T	73.9	80.0	17.8	80	0.095
	R	78.3	80.0	15.1	80	
FR/IF	T	75.7	75.0	11.0	80	0.557
	R	74.7	76.0	11.0	80	
DNV	T	82.8	91.7	21.0	78	0.451
	R	85.3	91.7	19.7	78	
DÍG	T	72.3	75.0	22.1	14	0.108
	R	81.9	85.0	11.7	14	
SSW	T	73.6	72.5	17.5	64	0.258
	R	77.0	78.8	16.4	64	

ANOVA ($p \leq 0.05$)

Legend: LOC = sound localization; MSNV = sequential memory for nonverbal sounds; MSV = sequential memory for verbal sounds; FR = speech in noise; IF = speech in noise identification; DNV = nonverbal dichotic; DIG = dichotic digits; T = test condition; R = retest condition; SD = standard deviation

for participants with CAP within normal limits. Similarly, no differences were observed between test and retest results for participants with CAP disorders.

Table 4 describes the comparative analysis between participants with CAP within normal limits and participants with CAP disorders in the test condition.

The comparative analysis between participants with CAP results within normal limits and participants with CAP disorders in the retest condition is presented in Table 5.

Differences were found for LS, MSNV, DNV and SSW tests in the comparison between participants with normal and altered CAP results in the test condition.

DISCUSSION

The reliability in the CAP behavioral assessment is based on the evidence of stability of results of the applied tests, which is verified by the analysis between conditions of testing and retesting.

According to the results described in Table 1, there was

Table 2. Description of comparative analysis of CAP behavioral tests in test and retest conditions in participants with results within normal limits

Test	Condition	Mean	Median	SD	n	p-value
LOC	T	100.0	100.0	0.0	7	NA
	R	100.0	100.0	0.0	7	
MSNV	T	90.5	100.0	16.3	7	0.611
	R	85.7	100.0	17.8	7	
MSV	T	90.5	100.0	16.3	7	1.000
	R	90.5	100.0	25.2	7	
PSI/SSI	T	87.1	90.	12.7	14	0.879
	R	87.9	90.	11.9	14	
FR/IF	T	80.6	80.0	7.5	14	0.919
	R	80.9	80.0	7.2	14	
DNV	T	98.2	100.0	3.6	14	0.297
	R	99.4	100.0	2.2	14	
SSW	T	95.2	97.5	5.5	14	0.401
	R	91.1	95.0	17.1	14	

ANOVA ($p \leq 0.05$)

Legend: LOC = sound localization; MSNV = sequential memory for nonverbal sounds; MSV = sequential memory for verbal sounds; FR = speech in noise; IF = speech in noise identification; DNV = nonverbal dichotic; DIG = dichotic digits; T = test condition; R = retest condition; SD = standard deviation

Table 3. Description of comparative analysis of CAP behavioral tests in test and retest conditions in participants with altered results

Test	Condition	Mean	Median	SD	n	p-value
LOC	T	86.3	80	14.8	33	0.064
	R	92.1	100	9.9	32	
MSNV	T	57.3	66.7	36.2	33	0.325
	R	65.7	66.7	31.7	32	
MSV	T	79.2	100	25.0	33	0.616
	R	75.8	66.7	29.2	32	
PSI/SSI	T	71.1	70.0	17.5	66	0.071
	R	76.2	80.0	15.0	66	
FR/IF	T	74.6	72.0	11.4	66	0.510
	R	73.3	72.0	11.3	66	
DNV	T	79.4	91.7	21.7	64	0.464
	R	82.2	91.7	20.5	64	
DÍG	T	72.3	75.0	22.1	14	0.160
	R	81.9	85.0	11.7	14	
SSW	T	67.6	70.0	14.7	50	0.058
	R	73.1	75.0	14.0	50	

ANOVA ($p \leq 0.05$)

Legend: LOC = sound localization; MSNV = sequential memory for nonverbal sounds; MSV = sequential memory for verbal sounds; FR = speech in noise; IF = speech in noise identification; DNV = nonverbal dichotic; DIG = dichotic digits; T = test condition; R = retest condition; SD = standard deviation

Table 4. Description of mean accuracy comparative analysis between participants with CAP behavioral tests within normal limits and participants with CAP disorders in the test condition

Test	Condition	Mean	Median	SD	n	p-value
LOC	N	100.0	100.0	NA	7	0.020*
	A	86.0	80.0	15.0	32	
MSNV	N	90.5	100.0	16.3	7	0.024*
	A	57.3	67.0	36.2	32	
MSV	N	90.5	100.0	16.3	7	0.263
	A	79.2	100.	25.0	32	
PSI/SSI	N	87.1	90.0	12.7	14	0.002*
	A	71.1	70.0	17.5	66	
FR/IF	N	80.6	80.0	7.5	14	0.066
	A	74.6	72.0	11.4	66	
DNV	N	98.2	100.0	3.6	14	0.002*
	A	79.4	91.7	21.7	64	
SSW	N	95.2	97.5	5.5	14	<0.001*
	A	67.6	70.0	14.7	50	

* Significant values (p≤0.05) - ANOVA

Legend: LOC = sound localization; MSNV = sequential memory for nonverbal sounds; MSV = sequential memory for verbal sounds; FR = speech in noise; IF = speech in noise identification; DNV = nonverbal dichotic; DIG = dichotic digits; N = CAP results within normal limits; A = altered CAP results; SD = standard deviation

Table 5. Description of mean accuracy comparative analysis between participants with CAP behavioral tests within normal limits and participants with CAP disorders in the retest condition

Test	Condition	Mean	Median	SD	n	p-value
LOC	N	100.0	100	0	7	0.044*
	A	92.1	100	10.0	33	
MSNV	N	86.0	100	17.8	7	0.116
	A	65.7	66.7	32.0	33	
MSV	N	90.5	100	25.0	7	0.224
	A	75.8	66.7	29.2	33	
PSI/SSI	N	87.9	90.0	11.9	14	0.008*
	A	76.2	80.0	15.0	66	
FR/IF	N	80.9	80.0	7.2	14	0.020*
	A	73.3	92.0	11.3	66	
DNV	N	99.4	100	2.2	14	0.003*
	A	82.2	91.7	20.5	64	
SSW	N	91.1	95.0	17.1	14	<0.001*
	A	73.1	75.0	14.0	50	

* Significant values (p≤0.05) - ANOVA

Legend: LOC = sound localization; MSNV = sequential memory for nonverbal sounds; MSV = sequential memory for verbal sounds; FR = speech in noise; IF = speech in noise identification; DNV = nonverbal dichotic; DIG = dichotic digits; N = CAP results within normal limits; A = altered CAP results; SD = standard deviation

improved performance in CAP behavioral tests in the retest condition for all tests except for the MSV and the FR/Figure Identification in Noise. However, no differences were found for any test in comparison with its respective retest.

An improved performance on the second assessment has been reported by several authors who justified this finding by the familiarity effect with the testing situation or by learning effects[11,12].

Despite the improved performance observed for some tests in the current study, these differences were not significant. Thus, in general, these findings were in agreement with several authors who have reported a stability coefficient of 0.82 for the PSI test[13], and 0.77 for the dichotic listening test[14]. However, some authors have reported not finding a good test-retest correlation in the SCAN battery of CAP tests. They attributed this finding to the large interval time between the two conditions – which was of approximately six months[15]. Similarly, authors who conducted the test-retest analysis of Filtered Speech have found significant improvement in response both in children and adults[16,17].

Regarding the analysis performed with data from participants with CAP results within normal limits, as described in

Table 2, a homogeneous performance was observed in this group when analyzing the values of mean, median and standard deviation. Likewise, there were no statistically significant differences between test and retest situations. Furthermore, of the seven tests analyzed, four had the same average responses in the retest condition. This may indicate that, in clinical practice, the CAP test results within normal limits have good reliability.

As for participants with altered results for the CAP assessment, the responses were more variable, with higher standard deviations being observed. There was an improvement in performance on the retest condition of six tests. However, these differences were not statistically significant (Table 3).

In comparing the two groups (normal and altered CAP results) in the test situation (Table 4), there were statistically significant differences in all tests except for the Speech in Noise test, for which only a trend to significance was observed - p-value of 0.066.

With respect to the retest condition, when comparing the two groups (Table 5) differences were also observed for most tests - except for Sequential Memory for verbal and nonverbal sounds. However, the group with CAP disorders presented better performance on the retest condition, differing from the group without CAP alterations. These data were not consistent with previous studies. Other authors have reported no differences in performance between children with and without CAP disorders in the retest condition[12,16].

In the present study, no differences were found between the test and retest conditions such for the group of participants without CAP alterations as for the group with CAP disorders.

The improvement in performance in the retest condition was observed in both groups. However the between condition difference was higher for the group with CAP disorders possibly reflecting a familiarity or learning effect.

It is believed that besides the difficulty in performing the tests themselves, individuals with CAP disorders are more susceptible to the influence of other factors such as motivation, insecurity, unknowing of tests, attention, memory, learning, among others, resulting in greater variation in results in situations of test and retest.

However, it should be highlighted that even when these variations are observed, the overall normal and altered CAP assessments were constant between the two conditions for the two groups studied. This consistency reinforces the reliability of the clinical application of the CAP tests analyzed in this study.

CONCLUSION

This study analyzed the reliability of results of behavioral CAP tests verified by test-retest condition analysis.

In the present study, the results of the analyzed behavioral tests were considered reliable as no differences were found in the comparison between the test and retest conditions.

Regarding the analysis of groups of participants with normal and altered CAP results, no differences were found between test and retest conditions. However, there was greater variability of responses in the retest condition for the group of participants with CAP disorders.

RESUMO

Objetivos: Verificar a confiabilidade de alguns dos testes que avaliam o Processamento Auditivo Central (PAC), por meio de um estudo do tipo teste-reteste. **Métodos:** Quarenta indivíduos voluntários, falantes do Português, foram sorteados ao acaso e avaliados quanto ao PAC nas situações de teste e reteste, com intervalos que variaram entre uma semana a um mês. Foram aplicados os testes de localização, memória sequencial verbal e não verbal, dois testes monóticos e dois dicóticos. Estes últimos, escolhidos de acordo com a faixa etária e condições de resposta de cada sujeito. **Resultados:** Não houve diferença entre as orelhas testadas, nem entre as situações de teste e reteste, de todo o grupo. Quando comparados os desempenhos dos indivíduos, cujos resultados apontaram para um transtorno do PAC, com aqueles cujos resultados estiveram dentro da normalidade, em ambas as situações houve variação na maior parte dos testes aplicados. **Conclusão:** Os testes do PAC utilizados neste estudo demonstraram sua confiabilidade por meio do teste-reteste.

Descritores: Audição; Transtornos da audição; Percepção auditiva; Transtornos da percepção auditiva; Testes auditivos

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