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Original Article

Artigo Original

The memory systems of children with (central) auditory disorder

Os sistemas de memória de crianças portadoras do distúrbio do processamento auditivo (central)

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Keywords

Auditory Perception
Memory
Child

ABSTRACT

This study aims to investigate working, declarative, and procedural memory in children with (central) auditory processing disorder who showed poor phonological awareness. Thirty 9- and 10-year-old children participated in the study and were distributed into two groups: a control group consisting of 15 children with typical development, and an experimental group consisting of 15 children with (central) auditory processing disorder who were classified according to three behavioral tests and who showed poor phonological awareness in the CONFIAS test battery. The memory systems were assessed through the adapted tests in the program E-PRIME 2.0. The working memory was assessed by the Working Memory Test Battery for Children (WMTB-C), whereas the declarative memory was assessed by a picture-naming test and the procedural memory was assessed by means of a morphosyntactic processing test. The results showed that, when compared to the control group, children with poor phonological awareness scored lower in the working, declarative, and procedural memory tasks. The results of this study suggest that in children with (central) auditory processing disorder, phonological awareness is associated with the analyzed memory systems.

Descritores

Percepção Auditiva
Memória
Criança

RESUMO

O objetivo do presente estudo foi investigar os sistemas de memória de trabalho, memória declarativa e memória procedural em crianças portadoras de distúrbio do processamento auditivo (central) que apresentam baixo desempenho na avaliação da consciência fonológica. A amostra foi constituída de 30 crianças, na faixa etária entre 9 e 10 anos, que foram distribuídas em 2 grupos: um grupo controle, constituído de 15 crianças com desenvolvimento normal e um grupo experimental, constituído de 15 crianças com distúrbio do processamento auditivo (central), que foram classificadas de acordo com 3 testes comportamentais e com baixo desempenho na avaliação da consciência fonológica por intermédio da bateria de testes CONFIAS. Os sistemas de memória foram avaliados por meio de testes adaptados no programa E-Prime 2.0. A memória de trabalho foi avaliada com base na *Working Memory Test Battery for Children* (WMTB-C), enquanto a memória declarativa foi avaliada por meio de um teste de nomeação de figuras, e a memória procedural, por meio de um teste de processamento morfossintático. Os resultados revelaram que, quando comparadas ao grupo controle, as crianças do grupo experimental apresentaram desempenho inferior na avaliação dos sistemas de memória de trabalho, declarativa e procedural. O presente estudo sugere que, em crianças com distúrbio do processamento auditivo (central), o processamento fonológico está relacionado com os sistemas de memória em estudo.

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INTRODUCTION

(Central) auditory processing disorder, or (C) APD, is defined as the inability of the central auditory pathways to focus, discriminate, recognize, or understand information presented through hearing. This disorder, although related to a deficit in the processing of sound information, does not generate hearing loss, or intellectual difficulties, being characterized as an auditory disorder[1]. First, (C) APD may manifest only in the auditory system; however, due to the same division of neural substrates and of the parallel and sequential processing of some brain regions, this disorder may be linked to losses related to language and cognitive aspects such as attention span and memory[2].

Some studies[3,4] have shown the relationship between the (central) auditory processing and phonological awareness, which is defined as the ability to manipulate the sound structure of words from the substitution of a particular sound and to segment this sound into smaller units[5]. Phonological awareness involves cognitive aspects that depend on working memory, such as the retention of verbal information required during testing involving the ability to reflect on the structure of language[6]. From this observation, some studies[7,8] have shown that children with difficulties in phonological awareness must also have low performance ratings for the working memory system. This memory system, of limited capacity, allows the temporary storage and manipulation of information necessary for the performance of complex tasks such as language comprehension, learning, and reasoning[9]. As an attempt to explain the mental representation of the working memory system, a model that involves a major component called central executive was proposed[9]. This component controls attention, being able to simultaneously manage the storage and processing of information, as well as to oversee three subcomponents: the phonological loop, responsible for the storage of verbal information; the visuospatial sketchpad, responsible for the retention of visual and spatial information[9]; and the episodic buffer, the subcomponent that manages the retrieval of information from long-term memory[10]. It is worth asking, however, if the relationship between phonological awareness and memory extends to long-term memory systems. When addressing the long-term memory, this study adopts a specific model, the declarative/procedural model. This model assumes that language depends on two distinct mental abilities: a stored mental lexicon and a mental grammar that operates through computational rules[11]. The declarative/procedural model's premise is the distinction of dual-mode processing, wherein the declarative memory system underlies the mental lexicon, while the procedural memory system underlies aspects of mental grammar[11].

Based on the theoretical assumptions presented, this study aimed to investigate the working memory, declarative memory, and procedural memory systems in children with (C) APD with low performance in the assessment of phonological awareness.

METHOD

This study was approved by the Ethics Committee of Universidade Federal de Santa Catarina (UFSC), Florianópolis, Santa Catarina, under the protocol number 02077612.4.0000.0121. All of the legal guardians of the participating children signed an Informed Consent.

The sample consisted of 30 children between the ages of 9 and 10, who were divided into two groups: the control group, with 15 children with normal development, 8 females and 7 males; and the experimental group, with 15 children with (C) APD who had a low performance in the assessment of phonological awareness, 9 females and 6 males. Children in both groups were students in the 4th grade of elementary education in a public school located in Florianópolis, Santa Catarina.

For the control group, the following criteria were used: children should be literate, not present evidence of neurological and psychiatric disorders, attention difficulties, speech, and learning disorders. In addition, children with hearing loss or complaints related to school education were not included in this group. The children in the control group had a normal performance (up 68 points) in the CONFIAS[12] test battery, which assesses phonological awareness.

For the experimental group, the same criteria for inclusion in the control group were followed. The difference was that the children in this group had complaints about difficulties in school learning, orthographic exchanges, and difficulties in reading and text comprehension. This group consisted of children with (C) APD, according to the results of the specific tests that diagnose this disorder, performed in this study. It is important to note that children in the experimental group were not undergoing any speech-language therapy process, and presented less than 50 points in the CONFIAS[12] test battery.

To meet the objectives proposed in this study, the following procedures were conducted: hearing and behavioral assessment of (central) auditory processing, assessment of phonological awareness, reading and writing, and working, declarative, and procedural memory systems.

The audiological evaluation consisted of otoscopy, pure tone audiometry, speech audiometry, and impedance testing. In otoscopy, Welch Allyn otoscope, model 22840, was used. In audiological and behavioral assessment of the auditory processing, a two-channel Interacoustics audiometer, model AC40, with TDH-39 headphones, was used; and in the impedance testing, Interacoustics system model AT235 was used.

Depending on the number of tests that children should perform on the assessment day, only three behavioral tests were selected to evaluate the (central) auditory processing: the Pediatric Speech Intelligibility (PSI) test, with sentences in monotic hearing[13], which evaluates the auditory ability of figure-background with analysis of the signal/noise ratio of -10; the dichotic digits test (DDT)[14], which evaluates the auditory ability of figure-background for verbal sounds in dichotic hearing; and the binaural integration stage was used in this test. To analyze the temporal aspects, the gaps-in-noise (GIN) test[15] was applied, which evaluates the auditory ability of temporal resolution with analysis of temporal acuity threshold. The criteria below normal rates in one or more tests proposed in this study classified children with (C) APD for inclusion in the experimental group.

The assessment of phonological awareness was performed using the sequential evaluation instrument CONFIAS[12], consisting of 16 tasks with difficulty scales, with 9 distributed at the syllable level and 7 at the phoneme level. To ensure that children were literate, reading fluency and writing tests were used in tests of reception and production of oral language[16].

Behavioral tests of working, declarative, and procedural memories were prepared in the Laboratory of Language and Cognitive Processes, linked to the Graduate Program in Linguistics at UFSC. All tests were developed in E-Prime 2.0 software[17], which consists of a computer program used for the preparation of behavioral cognitive testing. The tests that are described below were applied using a Samsung notebook, model 305E4A-BD1, with Philips speakers, model SPA5210, and were composed of two phases: the first phase related to learning and practice for familiarization with the test, and the second phase related to testing to meet the proposed objectives.

The evaluation of the working memory system was performed through tests adapted to Brazilian Portuguese, according to the Working Memory Test Battery for Children[18]. The tests that have been adapted for this study are described below.

Remembered phrases

This test aimed to evaluate the storage and processing of linguistic information simultaneously. The child's task was to identify whether the sentences heard were true or false, according to the context of world reality, and then store and verbalize the last word in the sentence. The sentences were organized in groups of two to six sentences. The scoring criterion established was according to the number of correct words stored properly.

Word List Recovery

This test aims to assess the storage of phonological information from real words. The child's task was to repeat the words correctly in the order they were presented. The scoring criterion established was according to the number of correct words verbalized in the sequence presented.

Nonexistent Words

This test aims to assess the storage of phonological information from unreal words. The test was composed of a group of pseudowords aimed at the assessment of the phonological working memory by drawing a parallel with the phonological loop. The child's task was to repeat the pseudowords the way they heard it. The scoring criterion established was according to the number of correct words verbalized.

Declarative memory

The goal of the declarative memory test was to evaluate the access to mental lexicon by the task of naming 100 figures, which were presented individually on the computer screen. Children verbalized the answer into a TSI microphone, model 58B.

The declarative memory test had two scoring parameters: accuracy of response and reaction time (RT). The accuracy of response is related to the number of figures named correctly by the participating child, and the reaction time is related to the time, expressed in milliseconds (ms), the child took to name the figure. This analysis was performed automatically by a feature available in the E-Prime 2.0 software[17].

Procedural memory

The purpose of the procedural memory test was to evaluate the processing of the rules of morphosyntax of regular verbs of the Portuguese language, conjugated in the past tense. This test consisted of regular verbs and pseudoverbs, based on the phonological structure of Brazilian Portuguese. The child's task was to conjugate verbs and pseudoverbs that appeared on the computer screen concurrently with a sentence, according to the provision, in our language, as to person and tense. The established scoring criterion was the number of correct responses expected for both verbs and pseudoverbs provided by the participating children.

In this study, the significance level adopted for statistical analyses was 0.05 (5%). Since the goal of the study was to compare the control group and the experimental group for all variables, the ANOVA statistical test was used.

RESULTS

To reveal the difference between the groups in terms of (central) auditory processing and the assessment of phonological awareness, Tables 1 and 2 are presented.

Table 1 shows the performance between the experimental group and the control group for the evaluation of the (central) auditory processing. In examining Table 1, it was found that the

Table 1. Comparison between groups in (central) auditory processing tests

(Central) auditory processing tests	DDT		Temporal acuity threshold GIN (ms)		PSI (ratio -10)	
	Control	Experimental	Control	Experimental	Control	Experimental
Mean (right ear)	98.3%	82.4%	4	6	100%	70%
Mean (left ear)	92.3%	74.4%	4	6	90%	70%
Standard deviation (right ear)	0.56	0.75	0.62	0.77	0.68	0.61
Standard deviation (left ear)	0.53	0.71	0.63	0.74	0.58	0.60
p-value	<0.001*		<0.001*		<0.001*	

*Significant values (p≤0.05) – ANOVA test

Caption: DDT = dichotic digits test; GIN = gaps in noise; PSI = pediatric speech intelligibility; ms = milliseconds performance between the groups was different for the (central) auditory processing. The data presented in Table 1 indicate that there was significant difference in DDT, GIN, and PSI with sentences in both ears between control and experimental groups, categorizing the experimental group as children with (C) APD, in addition to the analysis of normal values for each test. The only test considered to be within normal patterns according to the average performance of the experimental group was the PSI test with sentences.

Table 2 shows the performance of the control group and the experimental group for the assessment of phonological awareness through the CONFIAS test battery[12]. Table 2 shows that the performance between the two groups for the assessment of phonological awareness is different and that there was a significant difference between the results of the groups. Thus, it categorizes the experimental group as children with (C) APD who have low performance in the assessment of phonological awareness.

Table 3 shows the performance comparison between the control group and the experimental group regarding the working memory tests. In Table 3, it can be observed that, according to the comparative analysis, the experimental group had lower performance in all tests that assessed working memory, with a significant difference. In all assessments of working memory, children in the experimental group performed better in the "nonexistent words" test, with non-linguistic stimuli, and had worse performance in the "word list" test, with linguistic stimuli, in the evaluation of the phonological loop.

Table 4 shows the performance comparison between the control group and the experimental group regarding the declarative memory test. In this table, besides the accuracy of answers, the reaction time is also described, in milliseconds, for the naming of the test figures, which is represented by the acronym RT (ms).

In the evaluation of declarative memory, Table 4 shows that the groups are different for the accuracy of responses and the reaction time, and that these differences are significant. The experimental group had worse performance on this assessment, and thus, it appears that children with (C) APD that have low performance in phonological awareness assessment also have lower performance in access to mental lexicon. In Table 4, it can be seen that the difference between the two groups was greater for reaction times than for the accuracy of responses.

Table 5 shows the performance comparison between the control group and the experimental group compared to the procedural memory test.

Table 2. Comparison between the control and experimental groups in the CONFIAS test

CONFIAS	Control	Experimental
Mean	69.27	45.93
Standard deviation	1.03	3.71
p-value	<0.001*	

*Significant value (p≤0.05) – ANOVA test

Table 4. Comparison between the control and experimental groups in the declarative memory test

Declarative memory	Correct answers		RT (ms)	
	Control	Experimental	Control	Experimental
Mean	94.87	86.53	431.15	877.32
Median	96	87	425	863
Standard deviation	3.23	3.31	58.5	185.9
VC	3%	4%	14%	21%
Min	88	81	331	642
Max	99	92	541	1.321
n	15	15	15	15
CI	1.63	1.68	29.6	94.1
p-value	<0.001*		<0.001*	

*Significant values (p≤0.05) – ANOVA test

Caption: RT = reaction time; ms: milliseconds; VC = variation coefficient; Min = minimum; Max = maximum; CI = confidence interval

Table 5. Comparison between the groups for the procedural memory test

Procedural memory	Control	Experimental
Mean	23.80	15.07
Median	24	14
Standard deviation	1.32	2.91
VC	6%	19%
Min	22	11
Max	26	19
n	15	15
CI	0.67	1.47
p-value	<0.001*	

*Significant value (p≤0.05) – ANOVA test

Caption: VC = variation coefficient; Min = minimum; Max = maximum; CI = confidence interval

Table 3. Comparison between control groups and experimental groups in the working memory tests

Working memory	Remembered phrases		Recovery of list of words		Nonexistent words	
	Control	Experimental	Control	Experimental	Control	Experimental
Mean	4.60	3.67	3.53	2.47	5.60	4.47
Median	5	4	4	3	6	4
Standard deviation	0.63	0.72	0.52	0.64	0.63	0.52
VC	14%	20%	15%	26%	11%	12%
Min	4	2	3	1	4	4
Max	6	5	4	3	6	5
CI	0.32	0.37	0.26	0.32	0.32	0.26
p-value	<0.001*		<0.001*		<0.001*	

*Significant values (p≤0.05) – ANOVA test

Caption: V = variation coefficient; Min = minimum; Max = maximum; CI = confidence interval

Data distributed in Table 5 show that the experimental group had lower performance when compared to the control group in the procedural memory test, with significant results.

DISCUSSION

The literature describes that children with (C) APD can present processing difficulties in cognitive systems[2], so it is important to investigate the working memory, declarative memory, and procedural memory systems in this population to try to understand the cognitive manifestations of this disorder, the language extensions that can be present and thus establish intervention processes when necessary.

In (central) auditory processing, it was found that the experimental group had results below the normal range in DDT with the right ear advantage in both groups, and in GIN that used normality criteria for adults[19], as the minimum age for inclusion in either group was nine. These different results, in conjunction with the normal criteria for each test, show that children in the experimental group show (C) APD.

The performance of the experimental group was lower with significant results when compared to the performance of the control group for the evaluation of phonological awareness (Table 2). The literature has described that children with (C) APD may present difficulties in tasks related to phonological awareness[3,4], so this research will only discuss the results in the evaluation of memory systems under study in children with (C) APD who have low performance in the assessment of phonological awareness. We emphasize that we found no experimental studies that relate phonological awareness with working, declarative and procedural memory systems in children with (C) APD.

The results shown in Table 3 for the control and experimental groups, in working memory tests, show that children in the experimental group present difficulties related to this memory system. The results suggest that children in the experimental group have difficulties regarding the storage and processing of linguistic information simultaneously and in the storage of verbal information. These results may have implications for the storage and processing of information that extend beyond aspects of school learning, such as reading comprehension, word recognition difficulties, slow learning of the mapping between the sounds, and difficulties in learning new words[19], which may get worse due to difficulties in phonological processing, which is apparently also damaged, according to the assessment of phonological awareness.

The central executive component of the working memory regulates the cognitive mechanism of selective attention and integrates information[9]. In this study, the PSI testing with sentences[14] and DDT[15] were applied, and according to the results reported in Table 1, the experimental group shows lower performance in DDT[15]. Based on this result, it appears that there may be a relationship between the regulation of selective attention, coordinated by the central executive component, and the auditory ability to focus attention on a stimulus presented aurally, ignoring the others. The PSI testing with sentences is within the normal criteria for both groups, and it is believed that, as a monotic test that demands the task of pointing one stimulus at a time, maybe the relationship with the working memory system is smaller.

DDT[15], being presented in dichotic form, demands that the individuals assessed divide the attention between the two ears, which probably requires the active participation of the central executive component, which is described as the basis of working memory[9], in addition to the fact that the individual has to discriminate the presented pairs of digits and store them in the phonological loop so that the information doesn't decline. Based on this description of the DDT[14], the results presented in Table 1 for this test and in Table 3 for the working memory tests are in line with a study using the functional neuroimaging technique, which showed a strong activation in the prefrontal cortex while performing dichotic hearing tests, and this area corresponds to higher cognitive functions, such as working memory[20]. The behavioral results of this study related to lower performance in the assessment of working memory and phonological awareness in children with (C) APD suggest that the storage and processing of linguistic information may be linked to the processing of auditory information, and the central auditory nervous system can perform a possible interaction with other mental modules, producing a "ripple effect" in other superior systems.

One relevant fact that strengthens the influence of the central auditory system compared with other mental modules is the result of GIN[15] (Table 1) in the experimental group, which may be related to the lower results of this group in the assessment of phonological awareness and in the "nonexistent words" working memory test (Table 3), in which the experimental group also showed lower performance. It can be inferred that the change in the GIN test[15], that is, the impaired ability of temporal resolution, may have influenced the low capacity of decoding words without meaning, such as the pseudowords in the "nonexistent words" working memory test. The imprecise phonological decoding may have influenced the results of this test, although the test with actual words, "recovery of the word list", may also present an inferior result, which leads us to believe that the phonological loop component of working memory was less accurate in the experimental group. Because this group also has a low performance in phonological awareness, there may be an inadequate mental phonological representation of phonemes, as pointed by the alterations in the GIN test[15] in the experimental group, as well as the low processing capacity of phonological information in the phonological loop component of working memory.

Another important issue on the results of GIN and working memory tests in the experimental group is the issue of attention, as the central executive component is a regulator of the attention span[10] that was evaluated in the "remembered phrases" test, and different results were obtained. For a reliable result of the temporal acuity threshold of GIN, attention is of utmost importance. It is believed that GIN presents more attention-related questions than those related to the working memory system, as the individual evaluated does not need to arrange responses with a certain number of elements, such as DDT, in which four-digit numbers are required as response, and for being the test that showed the greatest alteration in the experimental group. From these findings, it can be inferred that the central auditory system, being a sensory system (bottom-up), may be linked to higher mental processes such as memory and language (top-down). In the literature, there is still no consensus on how the tests that assess (central) auditory processing may be related to the higher processes such as attention, memory, and language[21] and studies still seek to understand the interaction of bottom-up and top-down processes in behavioral tests that assess (central) auditory processing[21,22].

Table 4 shows the lower performance of the experimental group compared to the control group for accuracy of responses and reaction time in declarative memory test. The results of this study can be interpreted as evidence that children with (C) APD who present low performance in phonological awareness, in a sense, also present difficulties to activate and retrieve information in declarative memory, allowing to infer that the experimental group accesses lexical information in long-term memory in a less precise manner.

The findings of this research that are described in Table 4 for the experimental group can be explained due to the inefficiency of the central auditory nervous system to analyze the sound information and thus undermine the extraction of acoustic features of phonemes, and these losses can cause difficulties in phonological representation in long-term memory, difficulties in understanding and learning for the manipulation of sounds, as in phonological awareness tests[23], and, in a way, it can be inferred that this inadequate phonological representation can apparently be related to the outcome of GIN (Table 1), generating possible difficulties in the processing of sound information and compromising the accuracy of the responses in the experimental group.

Children in the experimental group access information more slowly when compared to the control group (Table 4). These results can be justified according to the deficit in the fast lexical decoding, which can be found in individuals who do not analyze the acoustic features of phonemes appropriately, such as children with (C) APD[23]. These individuals may present an inability to perform precise neural firing when it comes to comparison of phonological representations in long-term memory. This difficulty may result in an inadequate auditory perception and in the extension of information-processing time, while the individual tries to understand sound information[23]. Another explanation for the results in Tables 2 and 4 in children with (C) APD in this study is that the child's phonological awareness level had impact not only on the performance of metaphonological tasks, but also on the effectiveness and accuracy of basic phonological processes, such as lexical access[24].

The results in Table 5 show the inferior performance of the experimental group compared to the control group for the procedural memory test. The results of this study can be interpreted as evidence that children in the experimental group had difficulties in carrying out operations related to mental automation of language rules, such as morphological inflection of regular verbs in the past. To explain these results, we start with the hypothesis of procedural deficit[25]. Some development disorders, such as specific language impairment, are associated with difficulties in the processing of procedural memory, together with grammatical abnormalities in these individuals. The hypothesis of procedural deficit has as its premise the possible functional abnormalities in brain structures that underlie the procedural memory, such as portions of the basal/frontal ganglia circuit and cerebellum in developmental disorder[25].

Perhaps, some structures that underlie procedural memory may be dysfunctional in (C) APD, since, in the literature, there is some evidence that the cerebellum is related to some auditory abilities, such as figure-background and sound discrimination[26,27]. From this view of the participation of the cerebellum in auditory information processing and procedural memory, this study used two tests that assess the auditory ability of figure-background presented in a monotic and dicotic way and different results were found between the groups (Table 1), as well as the outcome of the procedural memory test (Table 5), and perhaps these results are related. Future studies using functional neuroimaging may provide more evidence about the interference of cerebellar dysfunction in (central) auditory processing and the impairment of procedural memory in (C) APD, as the behavioral evaluation results point to a possible relationship.

Another way to justify the findings relating to Table 5 for the experimental group is that, apparently, the low performance of the assessment of phonological awareness seems to impair the operation of implicit computational rules of syntax, because the altered phonological processing can negatively impact the development of knowledge of the mother language. Difficulties to achieve higher levels of language abstraction were attributed to difficulties related to the analysis of auditory information. Achieving higher levels of language abstraction is related to the acquisition of basic language skills in phonology, morphology, and syntax[28].

To complete the discussion of the results in Tables 3 to 5, we found lower scores in tests that assess working memory, declarative memory, and procedural memory in the experimental group. The results of this study contribute to the view that such memory systems may be related, although they are distinct systems. It is suggested, therefore, that the deficiency of the three systems may interfere with other systems successively[29].

Because the performance of children in the experimental group was lower than the control group, both in short-term memory system test and in long-term memory system tests, this study stands as a first attempt to address the relationship between phonological awareness and memory systems under study and to propose that these aspects are considered the Speech-Language Pathology and Audiology clinical practice. Thus, taking into account the interaction between working, declarative, and procedural memory systems and phonological processing may contribute to better results in the intervention of individuals with (C) APD.

CONCLUSION

Based on the presented results, we found that children with (C) APD who have difficulties in phonological awareness assessment also present difficulties in certain cognitive aspects, such as working, declarative, and procedural memory systems.

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**MMP wrote the dissertation, adapted the tests, collected the data, and drafted the article; MBM supervised the research, gave material for its implementation, and revised the article; MMCP co-supervised the research, selected the participants through a project, contributed to the data collection, and revised the article.*

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