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Original articles

Correlation between auditory and visual perception in schoolchildren

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ABSTRACT

Purpose: to investigate the correlation between auditory and visual perception by analyzing the variation in visual perception of students with and without Central Auditory Processing Disorder (CAPD).

Methods: 26 children (11 males and 15 females), who underwent auditory assessment, central auditory processing assessment, and the Developmental Test of Visual Perception, were included. Correlations between auditory and visual skills in the general sample were analyzed using Pearson's correlation coefficient. The Mann-Whitney test was employed to compare visual composite scores and visual perception skills between groups with and without CAPD. The significance level for statistical tests was set at $p<0.05$.

Results: visual skills were correlated with the auditory skills of temporal ordering, binaural integration, and auditory closure in the general study sample. Significant differences were found in the three visual composites evaluated between the groups with and without CAPD. Differences in figure-ground visual skills, visual closure, and form constancy were observed between the two groups.

Conclusion: the students' auditory skills were correlated, and CAPD impacted visual skill performance.

Descriptors: Auditory Perception; Visual Perception; Child; Audiology; Neurosciences

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INTRODUCTION

Proper integration of information from different sensory modalities is fundamental to our ability to perceive the world accurately and meaningfully[1]. All information from the outside world and peripheral structures is initially received by the receptors and neurons that make up the peripheral nervous system and is then conducted to the central nervous system[2]. The hearing, vision, smell, taste, somesthesia (touch, pain, temperature, and proprioception), and vestibular sensory systems send this information to the central nervous system, where sensory processing occurs[3].

Regarding the processes of auditory and visual perception, they are particularly cited when learning issues are involved[4,5]. Acoustic information processing demonstrates that sound perception is not immediate, as the auditory system must receive and transmit the acoustic signal, which the auditory structures transform, organize, encode, and recode. In the first years of life, these structures are maturing for the normal development of auditory skills and language[6].

Several brain areas are responsible for the development of auditory function, requiring integration with other areas related to memory, attention, learning, and language, among others[7]. Central auditory processing (CAP) refers to the efficiency and effectiveness with which the central nervous system uses auditory information. When something adversely affects the processing of auditory information, it is characterized as a central auditory processing disorder (CAPD). This condition hinders the interpretation of sound patterns and can lead to impaired information comprehension, behavioral changes, and academic failure[8].

The earlier CAPD is detected, the better its prognosis and therapeutic process[8]. Furthermore, identification and monitoring of this disorder by a qualified professional helps to reduce the negative impacts of CAPD on this population's literacy and reading and writing skills[9].

Visual perception, one of the most elaborate and complex activities of the nervous system, provides us with knowledge of the world through the integration of various components of a visual scene, such as color, shape, movement, direction, distance, location, size, and so forth. Thus, visual scenes are constructed from information that enters the retina and reaches the cortex through various visual pathways, giving rise to a sensory construction process that ultimately results in our perception[10].

The central nervous system's visual capacity in humans develops progressively from birth, with the occipital region of the brain having a specific area for receiving and interpreting images captured by the eyes. The development of the visual system begins immediately after birth, through visual stimuli and interactions with the environment, accompanying the child's overall development – i.e., neuropsychomotor development, visual-motor coordination, cognitive skills, and behavioral, environmental, and sociocultural adaptation[11].

The literature describes that approximately 80% of what we learn is acquired through vision, making it the primary perceptual system for obtaining information[12]. Learning-related vision problems are often interpreted as decreased visual acuity. While visual acuity is relevant for tasks such as copying from the board, other aspects of vision involving the efficiency and processing of visual information are fundamental for certain activities such as reading, writing, and mathematics[13,14].

Studies generally show a correlation between auditory and visual perception in children[15,16]. Integral auditory processing is necessary for students to thoroughly master the oral and written linguistic systems. This refers to the efficiency and effectiveness with which the central nervous system uses auditory information, being responsible for grouping, identifying, and selecting sounds according to their similarity or difference[17]. Visual processing is also important in this regard, as it captures information from the visual environment, identifying, selecting, and distinguishing stimuli in an improved and detailed manner[18].

CAP assessment provides information regarding auditory perception, and some clinical and research settings in Brazil also apply tests for visual perception assessment[19], and evaluating these aspects is essential to investigate the state of schoolchildren's auditory and visual skills, and correlating them broadens the understanding of these skills' integration.

Thus, this study aimed to investigate the correlation between auditory and visual perception in schoolchildren, analyzing the variation in visual perception between children with and without CAPD. Understanding the correlation between these processes and potential difficulties can aid in diagnosis and early intervention, improving children's academic performance.

METHODS

This quantitative cross-sectional study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines and complied with the standards of Resolution 466/2012 of the Brazilian National Health Council. It was conducted after approval by the Research Ethics Committee of the Department of Health Sciences of the Universidade Federal da Paraíba (CEP/CCS), Brazil, under approval number 6,196,854 and CAAE number 71071323.5.0000.5188.

All parents/guardians of the children participating in the study signed an informed consent form, and the children signed an assent form before starting the assessments.

The study included 26 children (11 males and 15 females) who sought audiology services at the originating institution's speech-language-hearing teaching clinic, characterizing it as a convenience sample. The inclusion criteria were children aged 7 to 10 years with complaints of comprehension difficulties; pure-tone audiometry, speech audiometry, and immittance tests within normal limits; absence of recent or current complaints of auditory system disorders; no neurological changes, genetic syndromes, or other conditions that could influence the evaluations, as reported by their guardians; and with receptive and expressive language necessary to understand the test commands.

Initially, the children underwent an audiological evaluation, starting with otoscopy to inspect the external auditory canal and verify whether conditions were favorable for performing audiological exams.

The pure-tone and speech audiometry exams were performed in sequence in an acoustic booth, using Inventis' two-channel Harp audiometer to determine the auditory acuity, considering normal hearing with thresholds up to 15 dB. Finally, the immittance testing was performed using Interacoustics' AT 235 equipment to evaluate the functioning and integrity of the middle ear; normal results were those with a type A tympanogram.

After obtaining normal results in the basic audiological evaluation, a behavioral CAP assessment was performed to investigate auditory perception through auditory skills. All CAP assessment tests were performed in a sound booth with an Acústica Orlandi PA 2004 system, to which a laptop was attached to play the test tracks.

The CAP assessment battery included the following tests, one for each auditory skill: Pitch Pattern Sequence (PPS)[20], Masking-Level Difference (MLD)[21], Pediatric Speech Intelligibility Test (PSI), Dichotic Digits Test (DDT), Speech-in-Noise Test (SIN)[22], and Gap-In-Noise Test (GIN)[23]. They assess temporal ordering, binaural interaction, figure-ground, binaural integration and separation, auditory closure, and temporal resolution, respectively. The CAPD diagnosis was characterized by a performance ≥ 2 SD in relation to the mean in at least one ear in two or more tests in the CAP behavioral assessment[24].

The PPS[20] children's version was used with three-tone stimuli at high (1430 Hz) and low (880 Hz) frequencies. Each child was instructed to imitate the sequence of items they heard by murmuring and naming them as high and low.

The MLD test[21] used a pulsating pure tone at 50 Hz accompanied by a narrowband noise as a competitive stimulus. Children were instructed to raise their hands whenever they heard the tone amidst the noise.

The PSI test[22] involved identifying sentences with a competing message, with visual support for the correct answer. Children were told that they would listen to a story and, at the same time and in the same ear, would be asked to point to one of the drawings presented on the board in front of them, at signal-to-noise ratios of 0 and -15.

DDT[22] was applied in the binaural integration task, instructing children to repeat the four digits presented in both ears simultaneously. They would hear four digits in the directed listening stage, but should repeat only the one from the right or left ear as requested.

In the SIN test[22], children were instructed to hear a series of monosyllabic words accompanied by noise and to try to repeat the words they heard. A list of 25 monosyllables was presented simultaneously with ipsilateral white noise, at a speech-to-noise ratio of +5 dB. The same SIN words were presented in a different order to determine the speech recognition percentage index (SRPI).

In the GIN test[23], children were instructed to respond by raising their hand when they heard gaps (silent intervals) in the continuous monaural noise, indicating that they had identified the silent interval.

Finally, a behavioral assessment of visual perception was performed using the Developmental Test of Visual Perception (DTVP-2). Its main purposes are to document the degree of difficulty in visual perception, identify candidates for specific professional referrals, verify the effectiveness of intervention programs, and serve as a research instrument[19]. The assessment was conducted in a room with few stimuli and distractions, with only the lead researcher present, using the protocol to obtain the responses.

DTVP was applied in its entirety to evaluate the eight subtests, each measuring a visual perception skill, namely eye-hand coordination, position in space, copying, figure-ground, spatial relations, visual closure, visual-motor speed, and form constancy.

In addition to each visual skill, DTVP composite score data were also used to assess visual perception and subsequent analysis. Hence, the study used data from the General Visual Perception Quotient (GVP), which sums the scores of the eight visual skills and is considered the best measure to represent the expression “visual perception;” the Visual-Motor Integration Quotient (VMI), which sums the scores for eye-hand coordination, copying, spatial relations, and visual-motor speed, indicating the performance in visual-motor coordination tasks; and the Motor-Reduced Visual Perception Quotient (MRVP), which sums the scores of the other skills: position in space, figure-ground, visual closure, and form constancy, being considered the “purest” and most direct measure of visual perception because they require the least motor skills.

The assessment process lasted at least two sessions: the first comprised the audiological and CAP assessment, and the second had the behavioral assessment of visual perception. They were tailored to the child’s level of fatigue and were interrupted if the child showed signs of fatigue, inattention, or lack of interest. They could be completed in more sessions if necessary.

Measures of central tendency and dispersion, using mean and standard deviation, were used to visualize and describe descriptive data. Inferential tests were performed using SPSS version 24.0, and the significance level for the statistical tests was set at 5% ($p < 0.05$).

Data normality was analyzed using the Shapiro-Wilk test, with data within normal limits ($p > 0.05$). The Mann-Whitney test was used to compare visual perception scores between the group with and without CAPD.

RESULTS

The children who participated in this study had a mean age of 9.04 years (SD = 1.11), with 42.3% of the sample being females and 57.69% males. The CAP assessment diagnosed 69.23% of the children with CAPD, while 30.76% had a normal result.

Initially, this study proposed to analyze the correlation between the auditory and visual skills of all children in the sample, regardless of the CAPD diagnosis (Table 1). It was observed that temporal ordering was the auditory skill with the most correlations with visual skills. The PPS’ naming task resulted in a high positive correlation with the visual skills of eye-hand coordination ($r = 0.505$; $p = 0.009$) and position in space ($r = 0.591$, $p = 0.001$), and a moderate positive correlation with copying ($r = 0.424$, $p = 0.031$) and visual closure ($r = 0.452$, $p = 0.021$). The results of the imitation task in the same auditory test showed a high positive correlation with the visual skill of visual closure (PPS) ($r = 0.500$, $p = 0.009$) and a moderate correlation with figure-ground ($r = 0.479$, $p = 0.013$) and form constancy ($r = 0.403$, $p = 0.041$).

Binaural integration was the second auditory skill with the most correlations with visual skills, with moderate positive correlations in the right ear with the visual skills of copying ($r = 0.444$, $p = 0.023$) and spatial relations ($r = 0.472$, $p = 0.015$), and in the left ear with the visual skill of figure-ground. Finally, the auditory skill of auditory closure was highly positively correlated with the visual skill of figure-ground ($r = 0.523$, $p = 0.006$) in the left ear and moderately correlated with form constancy ($r = 0.402$, $p = 0.042$) in the right ear.

Table 1. Correlation between auditory processing and visual perception skills

Auditory Skills		Eye-hand coordination		Position in space		Copying		Figure-ground		Spatial relations		Visual closure		Visual-motor speed		Form Constancy	
		r	p	r	P	r	p	r	p	r	p	r	p	r	p	r	p
Auditory closure	RE	0.168	0.411	0.278	0.169	0.078	0.706	0.366	0.066	0.013	0.951	0.071	0.729	0.066	0.748	0.402	**0.042***
	LE	0.278	0.169	0.265	0.191	0.114	0.580	0.523	**0.006***	0.122	0.552	0.153	0.456	0.079	0.702	0.273	0.177
Figure-ground 0 ICM	RE	-0.030	0.885	-0.075	0.715	-0.206	0.312	-0.033	0.873	-0.118	0.564	0.120	0.560	0.276	0.173	0.055	0.788
	LE	0.039	0.848	-0.240	0.239	-0.109	0.595	-0.028	0.891	0.056	0.785	0.054	0.793	0.055	0.788	-0.128	0.534
Figure-ground -15 ICM	RE	0.208	0.308	-0.008	0.968	-0.206	0.313	0.015	0.941	-0.011	0.957	0.199	0.329	0.316	0.116	0.152	0.458
	LE	0.279	0.168	-0.020	0.924	-0.305	0.130	-0.054	0.794	-0.061	0.767	0.036	0.861	-0.025	0.902	-0.064	0.757
Binaural integration	RE	0.332	0.097	0.208	0.307	0.444	**0.023***	0.379	0.056	0.472	**0.015***	0.365	0.067	-0.163	0.426	0.169	0.409
	LE	0.170	0.407	0.169	0.408	0.248	0.222	0.0436	**0.026***	0.240	0.238	0.172	0.400	0.072	0.728	0.214	0.293
Binaural separation	RE	0.196	0.338	-0.175	0.393	0.031	0.880	-0.041	0.843	0.155	0.449	-0.043	0.834	-0.097	0.639	0.059	0.774
	LE	-0.046	0.824	-0.213	0.296	0.156	0.447	-0.195	0.339	0.209	0.307	-0.151	0.461	-0.050	0.810	0.027	0.897
Temporal ordering (Imitation)		0.187	0.359	0.381	0.055	0.310	0.123	0.479	**0.013***	0.290	0.151	0.500	**0.009***	0.055	0.789	0.403	**0.041***
Temporal ordering (Naming)		0.505	**0.009***	0.591	**0.001***	0.424	**0.031***	0.243	0.231	0.214	0.293	0.452	**0.021***	0.367	0.065	0.382	0.054
Temporal resolution		0.198	0.332	0.326	0.104	0.282	0.163	0.130	0.528	0.120	0.558	0.327	0.103	0.360	0.071	0.071	0.730
Interaction		-0.226	0.268	-0.095	0.646	-0.131	0.523	0.092	0.653	-0.207	0.310	0.027	0.894	0.331	0.099	0.164	0.423

Visual Skills spans all visual skill columns.

Captions: RE = right ear, LE = left ear, ICM = ipsilateral competing message.
* = statistically significant, r = correlation coefficient, p = p-value.
Statistical test used: Pearson's Correlation.

A significant difference was found between the groups with and without CAPD in the three visual assessment composite scores evaluated (Table 2).

Table 2. Comparison of visual composite scores between groups

Composite Scores	U	p-value
GVP quotient	-2.396	**.025***
MRVP quotient	-3.557	**.002***
VMI quotient	-2.155	**.041***

Captions: GVP = General Visual Perception, MRVP = Motor-Reduced Visual Perception, VMI = Visual-Motor Integration.
* = statistically significant, U = Mann-Whitney test value.
Statistical test used: Mann Whitney test.

The comparison of visual skills revealed differences between the groups with and without CAPD in figure-ground (p = 0.010), visual closure (p = 0.019), and form constancy (p < 0.001). Moreover, the group of children with CAPD had lower mean results than the group of children without CAPD in all visual skills (Table 3).

Table 3. Comparison of visual skills between groups

Visual Processing Tests	Group	Mean	SD	U	p-value
Eye-hand coordination	CPAD	9.72	3.98	-1.437	0.164
	No CPAD	12.25	4.49		
Position in space	CPAD	7.39	3.39	-1.743	0.094
	No CPAD	10.00	3.81		
Copying	CPAD	11.33	2.72	-1.869	0.074
	No CPAD	13.63	3.24		
Figure-ground	CPAD	6.17	2.71	-2.811	**0.010***
	No CPAD	9.75	3.29		
Spatial relations	CPAD	6.67	4.60	-1.761	0.091
	No CPAD	10.00	4.07		
Visual closure	CPAD	7.33	4.24	-2.514	**0.019***
	No CPAD	12.13	5.02		
Visual-motor speed	CPAD	12.78	2.53	0.026	0.979
	No CPAD	12.75	2.31		
Form constancy	CPAD	6.56	2.70	-4.255	**<0.001***
	No CPAD	11.13	2.03		

Caption: CAPD = central auditory processing disorder.
* = statistically significant; SD = standard deviation; U = Mann-Whitney test value.
Statistical test used: Mann-Whitney test.

DISCUSSION

The processes involving auditory and visual perception are knowingly related, especially for children's learning. Hence, a thorough investigation of their correlations is necessary, as such knowledge can help in the diagnosis and therapeutic process in schoolchildren.

The correlation results between auditory and visual skills corroborate the literature by indicating that temporal ordering skills correlate with eye-hand coordination, copying, position in space, visual closure, figure-ground, and form constancy (Table 1). The correspondence between temporal ordering and visual perception skills is important for good reading proficiency, since processing the temporal sequencing of auditory and visual information facilitates the formation of accurate representations of the sequence of sounds and letters in a word[25,26]. For this to occur, successful sequencing depends on the accurate timing of auditory and visual sensory inputs, whose nerve pathways are integrated in the thalamus by the medial and lateral geniculate bodies, respectively[27].

Binaural integration also correlated with some visual skills (Table 1). This auditory skill was assessed by the DDT, which analyzes figure-ground in the binaural integration and separation task for verbal sounds through a dichotic task. The child is asked to repeat the sequence they hear, regardless of the order, upon hearing a sequence of four digits, two of them in each ear simultaneously[22].

Figure-ground was one of the visual skills that correlated with binaural integration in the left ear. This refers to the ability to differentiate and distinguish the figure as the center of attention, highlighting it among many visual stimuli presented simultaneously[28]. The literature shows that figure-ground is present in all perceptual modalities[17]. This study correlated auditory figure-ground perception through DDT with visual figure-ground perception.

The literature demonstrates the importance of these two skills for a common goal, such as reading comprehension. In visual figure-ground, the child must focus attention on a specific figure, disregarding all other figures around them and avoiding distractions from irrelevant visual stimuli[29]. A child with poor figure-ground skills will appear inattentive and disorganized. They will have difficulty controlling their shifting of attention from one stimulus to another. Consequently, they may find it difficult to find the appropriate place in a text, omit sections, and be unable to solve known problems if they appear too compactly on a page, hindering reading comprehension, as they are unable to select important details[30]. Binaural integration occurs similarly, but through auditory stimulation, and directly influences the individual's ability to decode words and understand texts[31].

Binaural integration in the right ear correlated with copying and spatial relations, necessary for the acquisition of school skills (reading and writing) and activities of daily living[19]. Studies indicate that impaired visual perception, recognition of details, simultaneous processing, visuospatial organization, integration of parts into a whole, and spatial relations are part of the deficit in visuospatial integration[32,33]. Based on this, the literature observed that students with learning disorders had both perceptual-visuomotor and binaural integration impairments[4,34-36].

Finally, auditory closure correlated with form constancy in the right ear and figure-ground in the left ear (Table 1). Poor performance on auditory closure tests for linguistic sounds may indicate difficulties in blocking competing sounds and maintaining short-term auditory memory, hindering speech intelligibility and phoneme-grapheme association[37]. Thus, specific difficulties in auditory closure can generate sequelae in written representation, related to poor phonological representation. The signs presented by the students include the omission of graphemes and substitution of acoustically close phonemes[38].

Just as auditory closure provides important data associated with learning disabilities, the visual skills of figure-ground and form constancy, which have been correlated with this auditory skill, are also associated with issues in this same area. A study showed children's performance in form constancy, in which 96% of students with learning disabilities scored below or well below average[39]. When this skill is impaired, one may have difficulty recognizing the same symbol written in different ways[39].

Moreover, 83% of students with learning disabilities performed below or well below average in the visual skill of figure-ground[39]. Children with difficulties in this perceptual area have difficulty understanding information. They get lost in the details of a figure, are distracted by irrelevant stimuli, and become easily confused when reading texts with many letters. They have difficulty locating specific information in a text, affecting their levels of concentration and attention[30].

Both binaural integration and auditory closure correlated with visual skills in the left ear. Studies show that children with dyslexia and suspected learning disabilities present differences between their ears, demonstrating that the left ear performs worse than the right ear in DDT and SIN tests. This information agrees with research that suggests poorer left ear performance in children with learning disabilities, particularly those with dyslexia, which may be explained by the lack of hemispheric asymmetry, with the left hemisphere being responsible for language[40].

The study objective did not include the verification of performance and the difference between ears; therefore, they were not evaluated. Nonetheless, the correlation results provide relevant pertinent data for future scientific research, leading to the reflection that if worse results are investigated and found for the left ear in binaural integration and auditory closure associated with changes in visual skills, these are crucial aspects for therapy to address, aiming to improve learning difficulties.

Given the differences in all visual quotients between the groups of children with and without CAPD, it can be inferred that there is a difference in visual perception between these two groups (Table 2). In general, the literature reports significant differences in visual scores between groups of children with poor academic performance and those without academic issues, as groups with learning deficits present worse results[4,31]. Therefore, children with learning complaints may have worse impairments in visual perception than their peers without complaints. The results of this study also show significant differences between visual perception and CAP skills.

Finally, the analysis found differences in the visual skills of figure-ground, visual closure, and form constancy between the groups with and without CAPD, showing that children with CAPD perform worse in them. These are classified as motor-reduced visual perception skills – i.e., they are purely visual measures with minimal influence of motor skills[19].

The literature corroborates that the visual skills of figure-ground and visual closure are important for text reading comprehension. It requires the recognition of each part of the letters that form the words to decode them, while selecting a single image (in this case, the word) in a visual sensory context to extract meaning[40]. Form constancy allows the recognition of the same symbol regardless of orientation, shape, or size, and is also essential for learning issues[39].

In addition to figure-ground, visual closure, and form constancy, the CAPD group performed worse in all other visual skills when comparing the means between the two groups. In DTVP, the lower the values, the worse the performance classification for each skill[19], indicating important clinical data.

As far as this study is concerned, it is one of the first studies to characterize, correlate, and compare visual and auditory perception performance in children with and without CAPD. Thus, there were limitations in comparing the findings with the literature. Nevertheless, it can be inferred based on the assessment findings that changes in auditory and visual perception lead to similar impairments. In other words, learning difficulties are approached and studied as common complaints in CAPD, just as visual perception disorders are described and correlated with academic difficulties.

Therefore, knowing that auditory and visual perceptions are correlated and have academic consequences (including worse visual perception results in children with CAPD), this research suggests that instruments that assess visual perception should be part of the routine assessment after a CAPD diagnosis. Furthermore, future research considering this correlation should investigate the effect of auditory and visual interventions for this population, deepening the understanding of this relationship and aiding in the treatment of children with CAPD.

CONCLUSION

The findings of this study indicate correlations between auditory and visual skills. Children presented with CAPD had different scores in general visual perception, motor-reduced visual perception, and visual-motor integration from children without a CAPD diagnosis. Moreover, children with CAPD performed worse in visual skills than those without this disorder.

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Authors' contributions:

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DFF, NCOM, VLCC, VNM: Data curation; Investigation; Writing - Original draft.

MLM: Data analysis; Validation; Writing - Review & editing.

MRDR: Methodology; Project administration; Resources; Supervision; Validation; Writing - Review & editing.

DOL: Writing - Original draft; Writing - Review & editing.

Data sharing statement:

Individual participant data will be available. Participant assessment data will be shared, duly de-identified, ensuring privacy and anonymity. Additional documents related to the study, such as the informed consent form and the assent form, will be available. The data will be accessible immediately after the results are published and will remain available indefinitely, with no end date. Access will be open to anyone interested, regardless of their profile or the purpose of the analysis, and may be obtained through a public repository or by direct request to the authors.