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Research Article

Central Auditory Processes Disorders in Children with Language/Learning Disabilities and Perinatal Risk Factors

Yolanda R Peñaloza-López[1]*, Teodora C Campos[1], Adrián Poblano[2] and Felipe García-Pedroza[3]

[1]Laboratory of Central Auditory Processes Disorders, National Institute of Rehabilitation, Mexico City, México

[2]Laboratory of Cognitive Neurophysiology, National Institute of Rehabilitation, Mexico City, México

[3]Department of Epidemiology, National University of Mexico, Mexico City, México

***Corresponding Author**: Yolanda R Peñaloza-López, Laboratory of Central Auditory Processes Disorders, National Institute of Rehabilitation, Mexico City, México.

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Abstract

Purpose: To compare psychoacoustic performance in children with language/learning disorders (LLD) and perinatal risk factors (PRF) with healthy controls and search for correlations between PRF and psychoacoustic performance.

Methodology: We searched the PRF and used psychoacoustic tests in 16 children with LLD, the results were compared with the control group. We calculate the correlations between FRP and psychoacoustic tests.

Results: We observed a low central auditory processes psychoacoustics tests performance in children with LLD and PRF in both ears in: Identification of compressed words, words in noise, frequency patterns discrimination and environmental sounds; and only in the left ear in: binaural fusion and filtered words. We observe correlations between PRF and psychoacoustic tests.

Conclusion: The data suggest subtle alterations in the auditory pathway in children with LLD and PRF that can explain the language/learning developmental disorders.

Keywords: *Central Auditory Processing Disorders; Language Disorders; Complications of Pregnancy; Complications of Childbirth; Neonatal Risk Factors*

Introduction

Central auditory processing disorders (CAPD) are defined as "perceptual disorders of the central auditory system (CAS) and of its neurological activity" [1]. Hearing perception is integrated by the input from ear to auditory cortex, and interaction activity with other networks such as memory, attention, and others. There is considerable interest to study CAPD and its relationships with language and learning disabilities (LLD) in children [2], because hearing in infants is need for good cognitive development.

Perinatal risk factors (PRF) set infants in increased probability for brain injury: asphyxia results in depletion of metabolic storage, damage, and death of neurons or hair cells [3]; hyperbilirubinemia is associated with central auditory alterations in Brainstem auditory evoked potentials (BAEP) [4,5], other sequelae include subtle neurological signs.

Relationships between comorbidity of CAPD and LLD, and PRF and LLD are not well known, thus our objective is search in CAPD manifestations in children who had PRF and LLD by means of psychoacoustics tests and correlate their performance with central auditory dysfunction. CAPD had been related with learning disabilities [6], but researchers do not tell us why of this relationship? i.e. some authors observed in 778 school children with specific reading disability a high percentage of PRF [7]. Our objectives in this research was study psychoacoustics performance in children with LLD and PRF, excluding those with family history of LLD, and search for: 1. frequency of PRF, 2. compare psychoacoustics performance with a control group, and 3. weight correlations between PRF and CAPD that may suggest a CAS dysfunction.

Methods

Subjects

Children with LLD and PRF were selected with the following inclusion criteria: age between 6 - 15 years, full Intelligence quotient (IQ) ≥ 69 measured by the Wechsler intelligence scale for children, adequate hearing in both ears, school grade according to age, LLD and at least one PRF. Exclusion criteria were as follows: family antecedents of LLD, congenital malformations, metabolic diseases, prenatal drug exposure, psychiatric alterations. Sample was formed with 16 children. Control group was constructed with 15 healthy children from families of hospital workers and some children from the orthopedics department (with no-complicated broken bones) within the same age range and gender. Ethics and research committee of the institution approved the research protocol. Children and parents were widely informed about the importance of their participation, and parents signed a consent letter.

Procedure

We analyzed PRF frequency, motor and language development, reading and writing achievements in children from hospital records. We searched for CAPD by a questionnaire [8]. Children with PRF and LDD and controls were studied for possible CAPD by psychoacoustics tests. Material was recorded into an anechoic room at Laboratory of Acoustics (National University of Mexico, UNAM), in a multichannel recorder (Sony Inc., Tokyo, Japan).

Psychometric tests

All participants were studied by means of the Wechsler intelligence scale, to determine their full, executive and verbal IQ. We utilized the Bender visuo-motor test, and the Human figure drawing. All tests were performed by a certified psychologist.

Audiometry

Hearing was tested in a sound-proof chamber by a tonal audiometry in Equinox audiometer (Interacoustic Systems, Copenhagen, Denmark), daily calibrated according to international standards (ANSI S3.6 and S3.26). Pure tones between 125-8,000 Hertz were administered in descendent fashion, beginning at 60 decibels (dB) with TDH-39 headphones (Telephonics Co., Huntington, NY) till found the threshold. Both groups had binaural hearing thresholds ≤ 20 dB between 250 - 4,000 Hz. Stimuli for psychoacoustic tests were administered by headphones 50 dB sound level (SL, re/1 Kh threshold). In monoaural tests we used a contralateral white-noise masking 30 dB below stimuli intensity.

Psychoacoustic tests

The subjects were studied with nine psychoacoustic tests. They were classified as predominantly auditory processing in the left hemisphere, with predominance of auditory processing for the right hemisphere and interhemispheric relationship. The monaural tests were scored according to the correct percentage for the right or left ear. The binaural tests had their specific evaluation procedure for binaural Fusion, Dichotic Digits and MLD tests.

Tests to examine processing mainly of left hemisphere were:

- **Biaural fusion (BF):** We administered low frequencies filtered bi-syllabic words in one ear, and at high frequencies in opposite. Frequency cut was at 1,200 Hz with a falling slope of 46 dB per octave [9].
- **Filtered words (FW):** We presented at random at right or left ear, a list of the most common mono-syllabic words spoken in our country filtered between 125 - 1,200 Hz.
- **Compressed words (CW):** Word length was compressed at 75% of duration without alter other feature [10], and presented at each ear separately.
- **Words in noise (WN):** We presented a list of three-syllable word in either left or right ear simultaneously with a white noise < 10 dB lower than word intensity in the same ear.

Inter-hemispheric relationship was studied using:

- **Dichotic digits presentation (DDP):** We presented binaurally one, two, and three couples digits from 0 - 10 at random, at once at each ear. Subject repeated the first number heard, or the best perceived [11]. According to the percentage of right ear or left ear, both ears were scored as mixed items or the omission of digits.

Tests used to examine processing mainly from right hemisphere were:

- **Environment sounds tests (EST):** We presented monoaurally ten sounds found in children daily life, such as knocking door, dog barking, ambulance siren, car horn, or others [8].
- **Test of music (TM):** Included 10 monoaural brief fragments of instrumental melodies for children of 7 seconds of duration including guitar, piano, drums, or strings (without singing). Melodies were administered at random order, and were presented one more time modified in tone (low or high pitch). Subjects identified if melody pitch was the same or different [8].
- **Frequency patterns discrimination (FPD):** Mono-aural presentation of six items in each ear of three sounds of two different pure tones: i.e. 1,122 Hz, and 880 Hz. The order of tones was changed at random. Subjects must answer order: high-high-low or low-high-low [8], or humming (this test was originally described by Musiek).
- **Masking level difference (MLD):** We presented a white noise and a continuous 500 Hz pure tone at 50 dB, in either diotic or dichotic fashion. We searched for dB differences in threshold detection between diotic to dichotic condition [12].

Statistics

We calculated mean and Standard deviation (SD) of quantitative variables. We measured percentages of qualitative variables. Mean differences were compared by Student´s t test. Percentages were compared by X^2. We calculated variables correlations by the Spearman method. We chose a p value of ≤ 0.05 to accept differences as significant

Results

Overall data

The children with LLD and PRF included seven females and nine male subjects. Controls had seven females and eight males. One child with LLD and PRF was at kindergarden, 13 at elementary school, and two were at high-school. In the control group, 13 children were at the elementary school, and two at high-school. We observed no differences in the mean age of children with LLD and PRF (7.8 ± 3 years of age) and controls (8.1 ± 3 years of age).

Mean full-IQ in children with LLD and PRF was 91.5 ± 16; four patients had an IQ ≤ 78; three children with LLD and PFR had full-IQ ≥ 120. Mean full-IQ in control children was 101.9 ± 10 (p = 0.03). Academic performance in children with LLD and PRF was 7.9 ± 1; score < 7 was found in five children. In controls, mean score was 8.9 ± 0.5 and all children had score > 8 points (p = 0.002).

Mean gestational age at birth in children with LLD and PRF was 33.6 ± 4 gestation weeks (GW), while in controls was 37.6 ± 2 (p < 0.004). PRF frequency are showed in table 1, eight children presented more than one risk factor. We studied three couples of twins (G1 was the first born infant and G2 the second). When compared PRF between twins and observed that one minute Apgar score was < 5 in two G2 infants (2/3). Birthweight was < 800 grams in three G2 twins (3/3). Full-IQ was lower in G2 twins (mean = 85, vs 95 in G1 twins).

Pregnancy and prenatal risk-factors

The main PRF in pregnancy found in children with LLD and CAPD were: multi-fetal pregnancy, young or old mother, urinary infections, cephalic-pelvic disproportion, premature rupture of membranes, placental abruption, and pre-eclampsia (See Table 1).

Risk factor	**PRF (n = 16)**	**C (n = 15)**
Multifetal pregnancy	6	1
Younger and older pregnancy*	5	2
Multiple pregnancies (≥ 4)	0	1
Urinary infections	3	0
Cephalic-pelvic disproportion	1	0
Placental abruption	2	0
Rupture premature of membranes (≥ 18h)	3	0
Preeclampsia	2	0

Table 1: *Frequency of Perinatal risk factors (PRF) in the group of children with neurological high-risk and control group (C).*
**mother or father < 20 or > 35 years of age*

Delivery and postnatal risk-factors

Seven children born ≤ 33 GW, and six among 34 - 37 GW. In control group we observed only four children born < 37 GW and one at 34 GW. Eleven children in the group of LLD and CAPD had a birth-weight < 2,500g, while in control group was only one. In children with LLD and CAPD mean birthweight was 2,056 ± 746g (range 820 - 3,200g), while in control group was 3,032 ± 387g (range 2,400 - 3,900g, $p < 0.05$). In the group of children with LLD we found that 12 children born by cesarean section and one with forceps help (infant presented clavicle fracture, conjunctival hemorrhage, and bilateral intra-cranial hemorrhage). In control group ten children born by cesarean section.

Six children with LLD and CAPD need mechanical ventilation after birth while in control children none. Three infants from the group of LLD and CAPD required exchange-transfusion, while in the control group none. One minute Apgar score in the group of children with LLD was ≤ 6 in three infants, and ≤ 3 at five minutes in two infants. In the control group all children had one minute Apgar score > 7. Days of staying in the Neonatal care unit in the group of infants with LLD and CAPD had a range of 14 - 30 days, while in the control group none went to NICU. Five infants in the group with LLD and CAPD had a late crying while in the control group none. One child in the group with LLD had an accidental out-hospital delivery.

	Age Gender		Gestational age		Intelligence quotient		School performance		Risk factors	
	PRF/C	PRF/C	PRF	C	PRF	C	PRF	C	PRF	C
1	15/6	F/M	29	39	100	98	9	9	Twin 2, gastroschisis-hyperbilirubinemia	0
2	6/15	M/M	36	37	76	121	9	9	Oligohidroamnios, fetal distress	0
3	6/6	F/M	37	39	99	95	8	9	Abruptio placental	0
4	6/6	F/M	39	40	101	102	8	9	Accidental out-hospital delivery	0
5	6/6	M/M	39	39	95	101	8	10	Circular umbilical cord, fetal distress	0
6	6/6	F/F	39	37	74	102	8	9	Preeclampsia	0
7	8/6	M/F	28	37	102	96	9	9	Premature rupture of membranes, abruptio placental, neonatal asphyxia, low Apgar score, mechanical ventilation	0
8	7/10	M/F	39	36	83	96	6	9	Cephalic-pelvic disproportion, abruptio placental, mechanical ventilation	0
9	15/6	M/F	29	36	120	111	9	9	Twin 1, abruptio placental	0
10	7/8	M/F	36	38	124	96	9	9	Preeclampsia	0
11	6/8	M/F	34	34	78	121	7	9	Premature rupture of membranes, mechanical ventilation, adolescent parents	0
12	10/15	F/F	32	36	95	100	8	9	Abruptio placental, fetal distress, forceps use, mechanical ventilation	0
13	7/7	M/M	27	37	85	92	9	8	Abruptio placental, premature rupture of membranes, twin 1	0
14	7/7	M/M	27	40	83	111	7	9	Abruptio placental, premature rupture of membranes, twin 2, mechanical ventilation	0
15	7/7	F/M	34	40	81	87	7	8	Twin 1, low birthweight	0
16	7/	F/	34		69		6		Twin 2, low birthweight	

Table 2: *Demographic variables and risk-factors in children with Perinatal risk factors (PRF) and the control group (C).*

Developmental alterations

Thirteen children with LLD and PRF and CAPD presented language retard, nine had school learning disability, and four presented motor delay. In the control group only one child presented a transient mild motor delay (See Table 3). G2 showed a greater frequency of school learning disabilities than G1 (ratio: 2/1), developmental language delay (3/2), and positive symptoms of CAPD (3/1).

	PRF (n = 16)	C (n = 15)
Language retard	8	0
Motor retard	6	1
Central auditory processes alterations symptoms		
1-7	14	0
+7	2	0
Handedness		
Right handedness	12	13
Mixed	4	2
Learning disabilities	9	0
Language retard	13	0
Early intervention	8	0
Speech therapy	12	0

Table 3: *Neurodevelopmental alterations in children with Perinatal risk factors (PRF) and control group (C).*

Psychoacoustic tests

We observed low overall performance of children with PRF and LLD and CAPD than controls. Significant differences were found in the following tests: CW (right ear $t = 5.14$, left ear $t = 3.64$), WN (right ear $t = 3.33$, left ear $t = 3.58$), FPD (right ear $t = 3.09$, left ear $t = 3.81$), and TES (right ear $t = 2.10$, left ear $t = 3.24$). We found significant low performance only in the left ear in BF ($t = 2.59$) and FW tests ($t = 2.19$) (See Table 4). We found that G2 had a lower performance than G1 in the following tests: BF, WN, and TES. We also compared children with LLD and PRF and CAPD, and controls at 6 years of age (n = 6/7) and observed significant differences in the following tests: BF left ear ($p = 0.02$), FW left ear ($p = 0.005$), CW right ear ($p = 0.01$) and left ear ($p = 0.02$), WN right ear ($p = 0.05$) and left ear ($p = 0.02$), FPD right ear ($p = 0.04$) and left ear ($p = 0.03$), and TES left ear ($p = 0.05$).

Test	Right ear	Left ear
Binaural fusion		0.01*
Filtered words		0.03*
Compressed words	< 0.001**	0.002**
Word in noise	0.004**	0.002**
Frequency patterns discrimination	0.04*	0.006*
Environmental sounds	0.04*	0.003**

Table 4: *Psychoacoustic tests, differences in performance among children with Perinatal risk factors (PRF) and control group.*
$*p < 0.05$, $**p < 0.01$ Student t test

Correlations

We found significant correlations in children with LLD and PRF and CAPD as follows: full-IQ with parents´ age ($r = 0.65$, $p < 0.05$), and with mothers´ age ($r = 0.61$, $p < 0.05$). Weight at birth correlated negatively with days of staying in NICU ($r = -0.80$, $p < 0.01$). Height at birth correlated negatively with days of staying at NICU ($r = -0.80$, $p < 0.01$). One minute Apgar score had a correlation with school performance ($r = 0.62$, $p < 0.01$). Number of CAPD symptoms correlated negatively with one minute Apgar score ($r = -0.62$, $p < 0.01$). Significant correlations between PRF, clinical features, and psychoacoustics tests are presented in table 5, correlations were observed mainly with TM, WN and MLD tests.

	Mothers age	Fathers age	Age at birth	Birth-weight	Height	Apgar 1	Apgar 5	Days at NICU	n CAPD symptoms	Full IQ
BF							R: ns L: 0.63#		R: 0.70* L: ns	R: 0.69# L: ns
FW			R: ns L: -0.58”	R: 0.54” L: 0.59”	R: ns L: -0.58”					
CW									R: 0.71* L: 0.64#	
WN				R: 0.49´ L: 0.51”	R: -0.56” L: ns		R: 0.55” L: ns		R: 0.58” L: 0.53”	R: 0.64# L: 0.59”
DDP					R: 0.60# L: ns	R: 0.51” L: 0.51”				
TM				R: -0.57” L: -0.74*	R. -0.60# L: ns			R: 0.65# L: 0.60#	R: 0.55” L: ns	
FPD									R: 0.60# L: 0.70*	
MLD	B: 0.61#	B: 0.61#	B:-0.75*	B: -0.67#	B: -0.72*			B: 0.55”	B: 0.70*	B: 0.65#

Table 5: *Significant correlations between Perinatal risk factors (PRF), clinical features and psychoacoustics tests used to identify Central auditory processes disorders (CAPD).*

*NICU: Neonatal Intensive Care Unit, IQ: Intelligence Quotient; R: Right Side; L: Left Side; B: Both Sides; BF: Biaural Fusion; FW: Filtered Words; CW: Compressed Words; WN: Words in Noise; DDP: Dichotic Digits Presentation; ES: Environmental Sounds; TM: Test of Music; FPD: Frequency Pattern Discrimination; MLD: Masking Level Difference. ´p: 0.05. “p < 0.05. #p: 0.01. *p < 0.01. ns: no significant.*

Discussion

Main findings

In this study we observed: 1. high frequency of PRF associated to CAS dysfunction, 2. usefulness of psychoacoustics test to early identify CAS dysfunction and 3. significant correlations among PRF and CAPD.

Clinical usefulness

Despite a known association between PRF with neuro-cognitive deviations [13], the reason of this alteration is poor explained. Our interest to measure CAPD in children < 7 years of age was to explain relationship and improve diagnosis and rehabilitation. Because we used psychoacoustics tests in children = 5 years of age in previous research [8], data from this study support the use of psychoacoustics tests for CAPD for children with PRF and LLD.

Comparison with other studies and explanations

WN (left hemisphere), TM (right hemisphere), and MLD (binaural) were the most significant tests to identify CAPD. This fact is in agreement with symptoms reported by parents, and in some cases by children. We observed significant correlations between: age at birth, birthweight, height, and days of staying at NICU with MLD. One minute Apgar score showed a correlation with number of CAPD. Five minutes Apgar score correlated with school performance, BF, and WN. Parents´ age correlated with full-IQ, MLD, and FPD. These results highlights importance of neurological risk factors for develop of alterations in hearing perception in children with CAPD related to language, reading, and writing disabilities.

MLD presented major number of correlations with PRF and full-IQ. MLD demand stimuli detection in complex conditions. We observed an improvement in stimuli threshold detection from homophasic to antiphasic conditions. Our data and from other authors supports hypothesis of CAPD in children with LLD and PRF, i.e. other authors found activation of: temporal and insular cortex in fMRI during MLD [14]. Other researchers disclosed by electrophysiological recordings the cortical participation in MLD [15].

We found significant right hemisphere compromise in TM correlated with age and height at birth, birthweight, days of staying at NICU, and number of CAPD symptoms. These observations could be of clinical interest, suggesting the need to search for symptoms of right hemisphere damage after PRF [16], and suggests music-therapy use.

We also found correlations between parents´ age, gestational age, weight and height at birth with several psychoacoustics tests in both ears. This fact was observed by other authors in children with LLD by means of CAP tests [17-21]. Relationship among CAPD and learning disabilities made us to search for correlations between PRF and CAPD [22]. Our objective here was to determine the role of CAS perinatal injury in CAPD and learning disabilities genesis.

In the group of children with LLD and PRF, none presented Cerebral palsy, although four children had a transitory delayed motor development, all children studied at regular elementary school, although, presented low performance and demanding speech therapy. Some researchers found long lasting effects of PRF even after 14 years of follow-up, high-risk infants continue present CAPD [23]. Learning disabilities were characterized by lifespan reading and writing errors [24], however, we don´t know yet how many CAPD can influence quality of life?

In twins, the second twins were identified at a more risk for developmental alterations. According to this observation, birthweight, height, and other variables at delivery could be predictive for twin neurodevelopment [25]. We found that the second twins had a higher frequency of CAPD symptoms, lower full-IQ, and worst scores in psychoacoustic tests.

Other researchers highlight importance of late gestational period lost when infants born preterm [26]. Results from our study goes in the same direction, adverse conditions damage cortical hearing perception of infants from NICU, resulting in cognitive alterations, and adverse consequences in social and school environments.

Other authors had investigated the role of cognitive functions in the integrations of auditory inputs [27]. However, this point of view is not shared by all researchers. Although one important group had recently accepted importance of cognitive factors in hearing [3].

Infants with cardio-respiratory arrest, respiratory distress, seizures, fetal nuchal cord, forceps use, cesarean delivery, toxemia, and miscarriage were follow-up in other study. At kinder age, children presented anxiety, impulsivity, irritability, and language delay. At elementary school all children had learning disabilities [28]. Difference with our results is that in our sample we observed a higher number of cesarean sections (12/16 in PRF group and 10/15 for control group), suggesting that in our country there are no correspondence among neurological risk factors and the surgery; and that mothers´ age in our study range from adolescents to youths.

Life support at NICU and neurologic sequelae in high-risk newborns were studied, because these infants received care at an important period of brain growth. Authors observed motor and cognitive delay with full IQ ≤ 85 in 38% of followed children. These authors claimed for skin to skin care as therapeutic method [29]. In our study we observed gestational age at birth < 37 weeks of pregnancy in 10 of 16 children, all but three came from NICU, five children had a gestational age at birth 25 - 27 GW, and four children 34 - 37. Gestational age at birth correlated significantly with MLD. Because high-risk infants are in increase frequency, we must take care for prevent, detect, and follow these children with the objective to bring adequate rehabilitation to close to normal neurodevelopment.

Comorbidity among language, reading and writing disorders, and CAPD is not well defined. Nonetheless, relationships among these disorders are more and more evident. Cognitive functions are important factors for central auditory processes development associated with afferent and efferent hearing functions.

The more frequent risk-factor present in our sample was the premature delivery, which is frequently associated to other risk factors such as infections, inflammation, mother smoking and psychological risk factors [30]. Several researches tried to determine developmental alterations of infants born at preterm. One study carried-out in adolescents observed increased activation of left superior temporal gyri and left parietal supramarginal gyri; associated to cortical dysfunction [31]. These areas are important in central auditory processing for psychoacoustics tests, supporting our observation of low performance in BF, FW, WN, FDP, and ES in children with LLD and PRF and CAPD.

The significant frequency of CAPD in around 50% of abnormal psychoacoustics tests suggested a close relationship of LLD and PRF. This relationship lacks today of a pathophysiological explanation, however, this comorbidity was highlighted from data of this research. Is necessary to study larger samples of children with PRF by means of psychoacoustics tests, specially for those children coming from multi-fetal pregnancies. CW, WN, FPD, and TES were the most frequent tests in shown abnormal results. Psychoacoustics tests with more strong correlation with PRF were MLD, WN, and TM. From these results therapist could design rehabilitation measurements taking into account the altered abilities.

Limitations of the study

Our study was cross-sectional. A long-term follow-up bring us stronger conclusions. The number of subjects is short, in forthcoming studies a greater number of infants will be studied, thus our conclusions highlight only tendencies. It is necessary include functional neuroimaging studies to identify cortical networks associated with abnormal mechanisms of CAPD. However, our data are important because for first time weight an unknown relationship.

Conclusion

We observed CAPD, and significant correlation between LLD and PRF with psychoacoustic alterations. Our data call attention of clinicians to explore CAS processes in high-risk infants before they develop perceptual and cognitive sequelae.

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