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Effect of passive smoking on auditory temporal resolution in children

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ABSTRACT

Objective: To determine the effect of passive smoking on auditory temporal resolution in primary school children, based on the hypothesis that individuals who are exposed to smoking exhibit impaired performance.

Design: Auditory temporal resolution was evaluated using the Gaps In Noise (GIN) test. Exposure to passive smoking was assessed by measuring nicotine metabolite (cotinine) excreted in the first urine of the day.

Study sample: The study included 90 children with mean age of 10.2 ± 0.1 years old from a public school in São Paulo. Participants were divided into two groups: a study group, comprising 45 children exposed to passive smoking (cotinine > 5 ng/mL); and a control group, constituting 45 children who were not exposed to passive smoking. All participants had normal audiometry and immittance test results.

Results: Statistically significant differences ($p < 0.005$) in performance on the GIN test were found between the two groups, with mean thresholds of 5.3 ms and 68.9% correct responses in the study group versus 4.6 ms and 74.0% in the control group.

Conclusion: The children exposed to passive smoking had poorer performance both in terms of thresholds and correct responses percentage on auditory temporal resolution assessment.

1. Introduction

National antismoking laws cover 16% of the global population. However, significant exposure of many individuals remains. The World Health Organization (WHO) has estimated that around 6 million people die each year from tobacco use including 600,000 who die from exposure to tobacco smoke. The global average of children exposed to passive smoking is estimated to be 41%. The highest level, almost 68%, is found in the Western Pacific Region. In the Americas the exposure is estimated to be about 25% and in Europe about 51%. Exposure to passive smoking can be extremely harmful to health, particularly among children, and is associated with increased rates of lower respiratory tract diseases. These conditions can lead to problems such as asthma, bronchiolitis, pneumonia, bronchitis and also cases of upper respiratory tract infection, increasing the incidence of acute otitis media [1–3].

The vulnerability of the auditory system to tobacco smoke is evident and the exposure to second-hand smoke during childhood has been established as a risk factor for hearing loss [4]. Talaat et al. [5] conducted a study involving 411 children aged between 5 and 11 grouped as follows: 131-no exposure (Group 1), 155-mild exposure (Group 2) and 125-heavy exposure (Group 3) to passive smoking. Comparison of the results for pure tone and speech audiometry, and immittance among the three groups revealed an increasing degree of hearing loss: 3.8% in Group 1; 4.5% in Group 2 and 15% in Group 3. A previous study reported with the same population presented in this study revealed a markedly reduced otoacoustic emissions response level in the exposed children [6], which is consistent with previous reports in neonates [7,8].

Although tobacco smoke exposure still lacks an ideal method of measurement, relying on self-report may lead to inaccurate measures of nicotine exposure, so the use of biomarkers have been suggested with the cotinine being the most used available method [9]. Cotinine is used in research as a reliable marker for determining smoking status, it is the main metabolite of nicotine, shows a high correlation between its concentration on blood and urine and a half time life of approximately 17 h [10].

The impact of the adverse effects of smoking and its consequences for child development in the medium and long terms has

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yet to be established.

Measurements of auditory processing, particularly temporal processing, may be useful for assessing this impact on auditory development. Temporal resolution can be defined as the ability to detect time gaps between sound stimuli or the shortest time gap an individual can discriminate between two audible sound signals [11,12]. Children with impaired temporal resolution have a greater likelihood of having language learning difficulties than children with normal temporal resolution [13] once temporal processing skills are related to phonemic, lexical and prosodic discrimination and underlies most other auditory processes (localization, discrimination, binaural integration and separation). Temporal resolution is typically evaluated through a psychoacoustic measurement known as gap detection in tonal or click stimulus (Random Gap Detection Test, Keith, 2000) [14] or in noise (Gap in noise, Musiek, 2005) [15]. The Gap in noise procedure has been proven to be a clinically feasible and sensitive measure for both adult [15] and pediatric [16] population.

Although several studies have determined normative values for auditory temporal resolution tests in the pediatric population, no studies have closed related second-hand smoke to auditory temporal processing in children [16–18]. Evidence from animal studies revealed that nicotine concentration can affect normal development of gap detection. A high concentration of nicotine (5 mg/kg) was associated with lower detection of gaps and a higher detection threshold, indicating impaired auditory temporal processing [19].

Thus, the objective of the present study is to determine the effect of passive smoking on auditory temporal resolution in primary school children, based on the hypothesis that individuals exposed to nicotine passively exhibit impaired performance.

2. Method

Approval for the study was granted by the local Research Ethics Committee. After a full explanation about the aims and procedures of this research with children and parents, the free and informed consent was signed by the parents or guardians and all the children signed the Assent Term.

2.1. Casuistic

A team of 4 researchers from the School of Medical Sciences involved in this project selected the nearest public elementary school for the study. Authorizations were obtained to inform and invite children from 4th and 5th years of elementary school to participate in the study (n = 200). The public elementary school is located in a central region of São Paulo, the largest city in Latin America. According to the *Socioeconomic Index of Brazilian Basic Education Schools* students at this public school location had a low socio-economic level [20].

Children with similar age and school grade were selected for the two groups from individuals who agreed to participate (n = 186). Parents filled out a simple questionnaire with questions about language development, hearing abilities and history of neurological or psychiatric syndromes or disorders. For been included on this research, it was observed that the parents have no appointments about these topics. Parents were also asked about smoke habits.

All children with no history of the syndromes or disorders mentioned above were included. The children were then tested by basic audiological evaluation (including pure tone and speech audiometry, and immittance testing). Audiometrically normal subjects were defined as those with thresholds for air-conducted stimuli ≤15 dB hearing level (HL) at all frequencies 0.25–8 kHz, tympanometry result type A (with compliance peak between −99 and 50 daPa) [21] and acoustic reflex present from 0.5, 1 and 2 kHz.

Individuals with normal results were tested for auditory temporal resolution. The children were classified into the “exposed” and “not exposed” groups based on the cotinine levels measured. Individuals with cotinine concentration <5.0 ng/mL were assigned to the Control group and those with levels >5.0 ng/mL to the Study group. The overall study sample comprised 90 children selected through the inclusion and exclusion criteria and they were divided into the two study groups: Control group (n = 45, not exposed) and Study group (n = 45, exposed) according to passive smoking exposure. The age range for both groups was 10.2 ± 0.1 years of age, and the gender was also balanced.

2.2. Procedure

Audiologic assessments were carried out at the Clinic of Speech-Language Pathology and Audiology. Urinary cotinine concentration was determined at the Department of Physiological Sciences.

The Gap in Noise (GIN) [11,15] test was applied using a CD recording played on headphones via an Itera model audiometer connected to the CD player, inside a sound-proof booth. The stimulus was applied monaurally at 50 dB SL, based on average hearing thresholds of 500, 1000 and 2000 Hz. Both ears were tested.

In the GIN test, sound stimuli are placed on four test tracks and one training track. The stimuli consist of six-second segments of white noise randomly interspersed with gaps (periods of silence). The gaps are randomized and of different durations (2, 3, 4, 5, 6, 8, 10, 12, 15 and 20 ms). The training track was applied prior to commencing the test, making sure that the child being tested understood the task instructions.

The participants were instructed to press a response button upon hearing the gaps within the noise.

Performance on the GIN test was calculated based on two measurements [11]. The first measurement was approximate gap threshold, defined as the shortest gap duration identified in four out of six trials; while the second measurement was the correct identification of gaps of any length, expressed in a percentage.

2.3. Determination of the nicotine metabolite – cotinine

Cotinine urine concentrations were used as a biomarker for nicotine smoke exposure. The Abnova ELISA kit [22] was used to determine urinary cotinine concentration. The first urine of the day was collected from the children at their homes in an appropriate vessel. The vessels containing the urine samples were brought to school and delivered to the researchers. This collection and delivery procedure took no longer than 2 h. The samples were immediately stored in a freezer at −20 °C for further use in the ELISA assay procedure (1–6 months). A urinary cotinine concentration of 5 ng/mL was adopted as the cut-off point for discriminating between exposure and non-exposure to passive smoking [22,23].

2.4. Learning difficulties – questionnaire completed by teachers

The teachers filled out a questionnaire collecting information about the students considering all of the following aspects: 1) below expected academic performance; 2) reading and writing difficulties; 3) mathematics reasoning difficulties; or 4) school failure. The presence of each aspect was scored with 1 point and absence with 0 points. The scores for all four aspects were summed up to provide an overall level of the learning difficulties of the student, as follows: a) zero: No difficulty; b) 1: minimum difficulty; c) 2: little difficulty; c) 3: medium difficulty and d) 4: maximum difficulty. The teacher was not aware if the students belonged to the study group or the control group.

3. Data analysis

Differences in cotinine concentrations, auditory temporal resolution threshold, correct responses on the GIN and degree of learning difficulty between children in the Control and Study groups were analyzed using Student's *t*-test. The level of statistical significance adopted was $p = 0.05$. Subsequently, the D'Agostino and Pearson normality test. All this data passed on the normality test (alpha >0.05, data not shown).

Pearson correlations between GIN results and cotinine concentration were performed. The coefficients and p values were obtained and just after it was plot the extrapolation of the linear regression.

All analysis was performed using the GraphPad Prism 5.0 software.

4. Results

4.1. Sample selection

Selection of the participants for the sample was done based on cotinine level (marker of nicotine metabolism found in active or passive smokers) detected in the urine sample collected from the children ($n = 90$), allowing separation into the following groups: Control group ($n = 45$) with cotinine levels < 5.0 ng/mL; and study group ($n = 45$) with values > 5.0 ng/mL. There is a strong relationship between parental reports on smoke habits and cotinine concentration investigated. From 90 parents that have their child included on this research, 86 (95.5%) children showed cotinine concentrations compatible with questionnaire answers. Only 4 parents reported being non-smokers and the cotinine concentration showed the opposite.

4.2. Auditory temporal resolution

Auditory temporal resolution threshold was statistically higher in the group of children exposed to smoking average 5.1 ± 0.2 ms in right ear and 5.5 ± 0.2 ms in left ear) than in the group which was not exposed (average 4.5 ± 0.1 ms in right ear and 4.6 ± 0.1 ms in left ear). The percentage of correct responses in the group exposed to smoking was statistically lower (68 ± 2%in right ear and 69 ± 2% in left ear versus 73 ± 1%in right ear and 74 ± 1% in left ear in Control Group) (Fig. 1).

The percentage of children from both groups whose GIN test results were below normative values was determined (Fig. 2). The Study group contained a higher percentage of children below normative values for the pediatric population.

4.3. Correlation between degree of nicotine exposure and auditory temporal resolution

In order to quantify the impact of nicotine exposure on auditory processing, individual data on cotinine concentration (measure of intensity of nicotine exposure) was correlated with auditory temporal resolution threshold (measure of auditory processing). The data and analyses are depicted in Fig. 3.

The greater the cotinine level found in the first urine of school

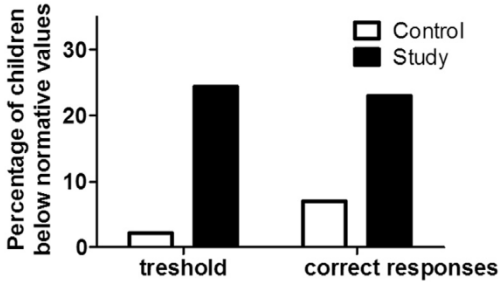

Fig. 2. Percentage of children with GIN test results below normative values for thresholds and for correct responses (CR) for children exposed (Study) and not exposed (Control) to passive smoking. Normative Values: Shinn, Chermak and Musiek (2009): Threshold 5.30 ± 1.25 ms for right ear and 4.90 ± 0.99 ms for left ear; Amaral and Colella-Santos (2010): 60% of correct responses.

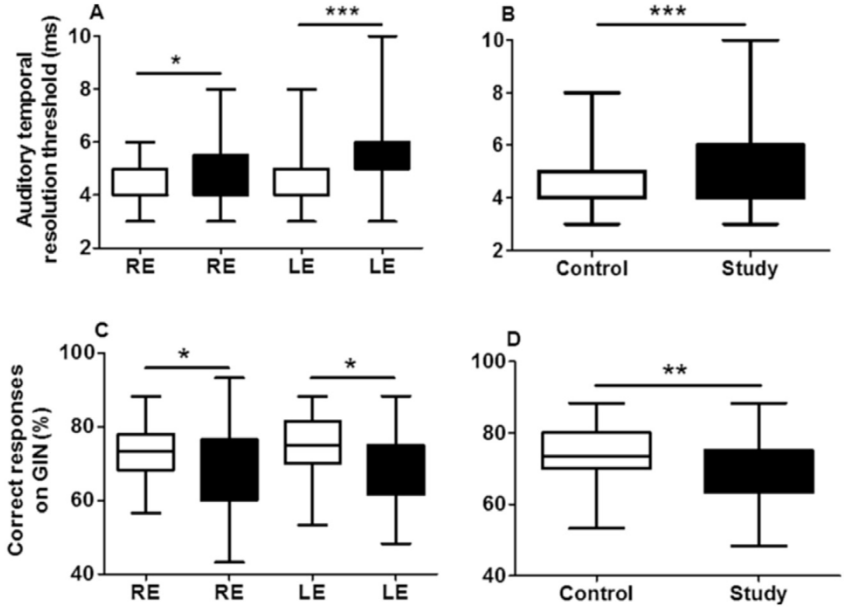

Fig. 1. Results of GIN: temporal resolution thresholds (ms) and correct responses (%). A) comparison of thresholds of Control and Study groups by ear – right (RE) and left (LE); B) comparison of thresholds between the groups; C) comparison of correct responses of Control and Study groups by ear – right (RE) and left (LE); D) comparison of correct responses between groups. Unshaded column represents Control group and shaded column Study group. Upper bars indicate comparison between groups. *$p \leq 0.05$, **$p \leq 0.005$ and ***$p \leq 0.001$.

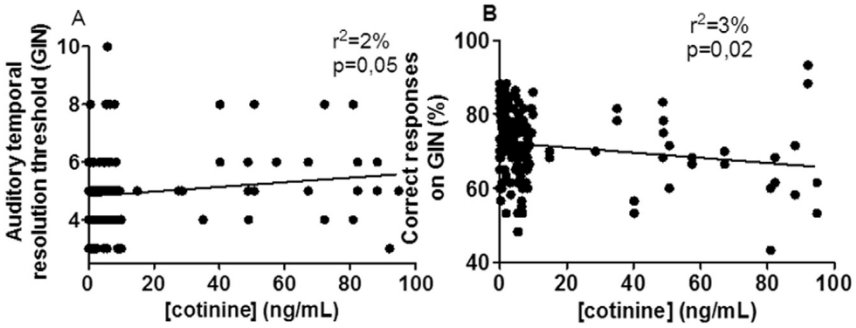

Fig. 3. Correlation between cotinine levels in first morning urine of school children exposed or not exposed to passive smoking and auditory temporal resolution and correct responses on the GIN test. A positive correlation was detected for resolution threshold and a negative correlation for correct responses. r^2 and p value shown in Figures.

children, the higher the temporal resolution threshold and the lower the percentage of correct responses on the GIN. These relationships can be determined based on the positive correlation between cotinine level and resolution threshold ($r = 0.146$, $p = 0.05$) and negative correlation between cotinine level and correct responses on the GIN ($r = -0.178$, $p = 0.02$). However, when observing the square of the correlation coefficients, it was found a weak correlation ($r^2 = 2\%$ and $r^2 = 3\%$, respectively) indicating that for every unit increase in smoking exposure, there is a 2% increase in auditory resolution threshold and a 3% decrease in correct responses. This correlation was obtained based on urinary cotinine measurement in a sample collected in a single day, reflecting exposure to nicotine during the hours leading up to collection.

4.4. Learning difficulties assessed by teachers

The majority of children of both groups, exposed (27) or not (35) to smoking, showed no difficulties in learning process. When looking for minimum difficulties in learning, it was found more children exposed to smoking (9) than no exposed (6). The number of children with medium difficulties was similar on both groups (4). Only children exposed to smoke showed medium difficulties (5), indicating that smoke exposure may negatively impact school performance (Fig. 4).

5. Discussion

Passive smoking can cause numerous health problems [1–3,24,25]. The effect of passive smoking on auditory measurements has previously been reported, including cochlear physiology

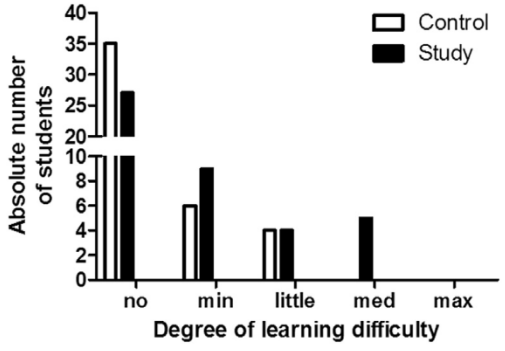

Fig. 4. Absolute number of children versus learning difficulty, rated by current teacher of the child, expressed as a degrees (maximum 4 points, medium 3 points, little 2 points, minimum 1 point, no zero point). Comparison between children exposed (Study) and not exposed (Control) to passive smoking.

[6–8], auditory nerve responses [26–28], audiometry [4,29] and auditory processing tests [19,30]. All of these studies reveal auditory impairments resulting from passive exposure to smoking across different age groups, including the neonatal stage. Examining these data raises the hypothesis that exposure to passive smoking during early childhood may lead to impairments in auditory function at school age.

Our first approach, pursued in another investigation prior to the present study, examined cochlear physiology in the same children. Significantly lower otoacoustic emissions were observed in those school children exposed to smoking compared to non-exposed individuals. This result provided the first evidence of changes in auditory function induced by exposure to passive smoking in school children [6].

In the present study, the effect of exposure to passive smoking on auditory processing was assessed, and measured by auditory temporal resolution, in the same group of children. Temporal resolution is essential for the development of language and speech comprehension in children. In this study, the school children not exposed to smoking and thus serving as controls, attained an average auditory temporal resolution threshold of 4.6 ± 0.1 ms and correct responses of $74.0 \pm 1.1\%$. This finding is in line with normative values for the test previously reported in the literature. In the study by Amaral and Colella-Santos [17] involving children aged 8 to10, the authors found threshold values of 4.7 ms and 73.6% correct responses. The authors established cut-off values for normality in this age group of 6.1 ms and 60% of correct responses (95% confidence interval). According to Chermak and Lee [18], the threshold in children of an average age of 8.7 on the GIN test was 4.6 ms for the right ear and 4.9 ms for the left ear. However, for the children exposed to smoking, auditory temporal resolution threshold and correct response values were 5.3 ± 0.2 ms and $69 \pm 1\%$, respectively.

According to Shinn, Chermak and Musiek, [16], children as young as age 7 are able to complete the GIN test with the same performance that adults. The authors recommend normative cutoff with 2 standard deviations, for 10 years of age the means thresholds were 5.30 ± 1.25 ms for the right ear and 4.90 ± 0.99 ms for the left ear, results very similar to the other studies presented before. Although the normative data reported in the above study overlapped with the data of exposed children in the present study, compared to controls in the same study, smoking-exposed individuals had higher thresholds ($p < 0.001$) and lower percentages of correct responses ($p < 0.01$), revealing a group effect.

In the present study, the effect of smoking exposure on auditory temporal resolution thresholds and percentage of correct responses in the GIN were quantified by correlating these parameters with urinary cotinine concentration. Both of the parameters showed

weak but significant correlations. High cotinine concentration was used as a measure of exposure to passive smoking. Elevated cotinine level was associated with higher resolution threshold and fewer correct responses on the GIN. The low strength of these correlations indicates that exposure to smoking had an impact on auditory temporal processing of around 2%–3%. In addition, it is important to take into account that exposure to passive smoking can involve different patterns of exposure. The habits of parents, grandparents or other individuals living with the child may differ widely, such as only smoking at open balconies. In order to assess this exposure, the concentration of the most stable metabolite of nicotine, cotinine, was measured in the first morning urine of one day. This value provides a biological notion of the child's exposure in the last 24 h but not throughout life. Nevertheless, the measure serves as objective evidence, gathered on a normal day, of these individuals' exposure to smoking. Smoking is only one of the environmental factors to which children are exposed during their development that can affect hearing, and in this context, 2–3% for a single factor has biological significance. Although clinical implications are limited it is suggested that smoke exposure can be consider one more risk factor on hearing abilities development.

A biological significance for temporal auditory resolution is the ability to process complex acoustic signals, such as speech and music [31,32]. Having good temporal resolution ability is essential for normal development and understanding of language and speech in children [33]. These abilities have an impact on school performance. In this context, a questionnaire was applied to the children's teachers to assess the degree of learning difficulties of each individual. The comparison between exposed and non-exposed children showed that exposed individuals had greater observations of teachers regarding children's learning difficulties.This result suggests that passive exposure to smoking may play a role in learning difficulties.

Studies of literature review have correlated exposure to passive smoking with poorer performance in attention deficit and hyperactivity disorder [2,34]. At this research, to ensure the reliability of the results at the GIN test, initially a training range for testing was performed, ensuring that the child understood the instructions. The result was included only when the child remained cooperative throughout the test. Besides, none of the children included in the study had been diagnosed with attention deficit or hyperactivity.

Future studies are needed to be done to clarify the underlying mechanisms between these exposures and the increased risk for attention and hyperactivity disorder and associated behaviors, and verify the risk to develop auditory processing disorder. This study has some limitations. It must be explored if all results presented herein could be obtained with different ages, socio economical classes, school grades and pedagogical assistance.

Although beyond the scope of the present study, it is noteworthy that the parents appeared to be unaware of the consequences of passive smoking for the auditory health of the children, half of the children who had never smoked were exposed to second-hand smoke at home [1–3]. The results of this study contribute to the dissemination of information on strategies for tackling passive smoking in the domestic setting.

6. Conclusions

Exposure to smoking in children aged about 10 was found to influence lower auditory temporal resolution.

Conflicts of interest

None.

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