Analysis of salivary cortisol levels and listening effort in school-age children with unilateral hearing loss: investigating the impact of hearing aid use

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Research Article

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Abstract

Arm: Listening effort is one of the consequences of Unilateral Hearing Loss (UHL). The aim of this clinical study was to assess the listening effort of school-aged children with UHL with salivary cortisol collection and a behavioral dual task assessment, with and without the use of hearing aid (HA) technology.

Results: There was no difference between speech recognition in silence and noise. Both conditions did not present statistically significant results with and without hearing aids. Greater statistically significant results \((p= 0.013)\) were found before the HA fitting with the secondary set of dual-task. After the hearing aid fitting, a decreased response time was noted, and this result was statistically significant \((p= 0.019)\) when compared to the response time before the HA fitting.

Conclusion: Results suggested that children fit with a HA in their affected ear performed better in the dual-task condition than without use of a hearing aid. Most participants showed a better response rate in the secondary task, mainly with regards to the number of correct answers and a better response time. Overall, a decrease of listening effort in the dual-task condition was found. Salivary cortisol measures of listening effort with our participants did not show any statistically significant findings after the use of a HA.

Introduction

International studies have shared for decades about the importance of binaural hearing for the development of all listening skills, speech and the overall development of the child. As has already been shown by several authors, auditory processing and certain auditory benefits require binaural hearing ability, therefore, elements such as redundancy and head shadow can allow sound localization, speech perception in background noise and spatial hearing [1].

By contrast, child with unilateral hearing loss (UHL) experience hearing difficulties among other damages, due to the condition of having hearing deficit in one ear, with varying type, degree and configuration [2]. It is described in the literature that this population have higher rates of grade failure [3] and lower scores on speech/language and intelligence quotient testing when compared with children with typical hearing [4, 5, 6].

Impairments in quality of life are also reported. These include poor outcomes in school and the development of social-psycho and emotional issues [7]. For decades, children with UHL have received less attention than their peers with bilateral hearing loss. When intervention is provided, many times it is late, and does not occur until children are in school [8].

Listening effort is one of the consequences of UHL described in the studies, which can be described as the amount of perceptual process resources, (cognitive and attentional) allocated to an auditory task [9]. Performing dual listening tasks requires greater listening effort in adults or children with hearing loss, independent of the degree of hearing loss [10]. There has been growing interest in improving our management of these children [11]. Although, despite there is an increasing interest in the area of
listening effort, few studies have suggested an objective, clinically feasible test to complement the basic audiological assessment [12].

A literature review published in 2018, found there are a range of behavioral methods to assess listening effort. Results showed that variables such as degree of hearing loss, subjects age, test stimulus, and, the fitting method of a hearing aid (HA) may contribute to a more sensitive assessment [12]. The salivary cortisol test is an objective measure to assess listening effort. It has been used in listening effort research in the United States of America and in Brazil as it can be collected with a non-invasive, easy and simple procedure [13].

When reviewing these literature data about children and UHL, the research on school-age children and listening effort [1], we observed the scarcity of studies. Therefore, the aim of this clinical study was to assess the listening effort of school-aged children with UHL with salivary cortisol collection and a behavioral dual task assessment, with and without the use of HA technology.

**Methods**

Was performed an clinical trial uncontrolled in the Speech Therapist Clinic, Bauru School of Dentistry, University of Sao Paulo (USP), with the approvals of Ethics Committee of this Institution, under the number 2.332.836/2017. The parents or the participants assigned the Informed Consent Form. Participants were recruited by the DRS VI (Regional Health Department) to the Hearing Health Service of this University. Twelve participants, eight male and four female were included in the study. Participants were selected based on the following criteria:

**Inclusion criteria:**

- Unilateral sensorineural hearing loss
- Medical approval for hearing aid fitting by an ear, nose and throat specialist
- Children who attend a regular school
- Children with an age range from 7 to 12 years
- Children with no identified cognitive disability
- Children who communicate through spoken language
- Desire to wear a hearing aid

**Exclusion criteria:**

- Children with autism spectrum disorder;
- Children with a linear metabolic or endocrine disorder;
- Children with a chronic medical condition;
- Children who utilized medications that might alter HPA axis responses (e.g., stimulant medications).
*The exclusion criteria were selected based on the fatigue influence factors [14].

Participants received a complete audiological assessment to document their current hearing levels. Salivary cortisol collection was performed, the listening effort assessments, and the selection and fitting of a hearing aid. Cortisol collection and assessments were repeated after a three-month acclimatization period of wearing the hearing aid [15, 16].

**Salivary cortisol collection:**

The collection of salivary cortisol was performed using Salivette® (SARSTEDT). This kit was available to the parents with instructions for use and an illustrated flyer with directions on the correct collection of the saliva samples (Appendix 1). The participants were advised not eat, drink or brush the teeth before the salivary cortisol collection [14]. The analysis of cortisol levels was performed at Pharmacology Laboratory at the University of Bauru with the aid of the ELISA kit from Salimetrics. The participant was instructed to place the cotton roll inside the mouth and chew it for sixty seconds. It was then removed and placed in the Salivette® plastic tube. The tube was labeled with a participant code, and the date and hour of the salivary collection. All the salivary samples were stored inside a plastic tube, wrapped by a plastic bag individually and were packaged with ice in a polystyrene box to be sent to the laboratory for analysis.

The salivary collection was performed twice, at six different intervals [14] during a typical day of the participant (party or trip days were excluded). Before the hearing aid fitting, the salivary was collected six times and after the hearing aid fitting, the salivary was collected six times. The first, second and, third salivary collection were performed by the parents. A member of the study research group was the responsible for the collection of fourth, fifth and sixth salivary samples at the Clinic. The salivary collection intervals were:

- 1st : upon waking (T1);
- 2nd : 30 minutes after waking (T2);
- 3rd : at 11:00 a.m. (T3);
- 4th : before the beginning of dual-task assessment (T4);
- 5th : immediately after the dual-task assessment (T5);
- 6th : at the afternoon, in the last possible hour (T6).

**Assessment of the listening effort (PALETA):**

The assessment of listening effort was performed using a dual-task set-up, where a primary task is associated with a secondary task. To assess the listening task (primary), the participant should repeat the sentences heard from Portuguese Sentence List [17]. The visual task (secondary) was performed with PALETA [18], a platform developed for use with dual-task tests.
The Portuguese Sentence List was used for the listening task and has 7 lists with 10 phonetically balanced sentences. The sentences were presented in free field and in two conditions: speech in the quiet and speech in the noise. Speech was presented at 65dBLH while noise was presented at a signal to noise ratio (S/N) of +5.

Six sentence lists were presented: four lists in the listening condition with a single task (two in the silence and two in the noise); and to assess the dual-task, two lists were presented for the speech in noise condition (listening task-primary + visual task-secondary). The speech and the noise were presented in the same speaker at one meter and 0º azimuth from the participant. The participant was instructed to repeat the sentence heard, and sentences were randomized to avoid participant memorization of the sentences.

PALETA was utilized and administered with a tablet for the secondary visual task using memory recognition of colors. A sequence of four random colors was presented to the participant and this sequence was to be reproduced by the participant using the tablet. Twenty sequences of colors were presented. The number of correct answers and the response time to complete the dual-task were registered by the platform. Under the dual-task condition, the speech recognition in noise and the memorization and recognition of colors task were performed simultaneously. Previous studies showed that the response time may be a key measure when looking at listening effort (Downs, 1982; Hicks and Tharpe, 2002).

**Fitting of HA:**

The fitting of the hearing aid was completed and followed the Listening Rehabilitation Instructive related to the Portaria GM 793 from 2012, April 24th and Portaria GM 835 from 2012, April 25th. Study participants were fitted with an behind-the-ear hearing aid with a silicone earmold. The hearing aid was fit to the participant using the Desired Sensation Level (DSL) prescriptive method and utilizing real ear measurements with the Interacoustics Callisto. Tests included Real-Ear Unaided Response (REUR), Real-Ear Occluded Response (REOR) and Real-Ear Aided Response (REAR) measures. Participants were requested to wear the hearing aid for three months, for at least 8 hours per day. This usage was confirmed through the hearing aid datalogging program. Participants were periodically assisted during the three months period to verify correct hearing aid usage and make adjustments as needed. After the three-month period of hearing aid use, listening effort and salivatory cortisol collection measures were repeated.

**Statistical analysis:**

Shapiro-Wilk test was performed to analyze the data normality. The homogeneity of the variances was assessed by the Levene test. The groups were not normally distributed (p > 0.05), then a comparison of scores between different times was performed using the Wilcoxon test. For salivary cortisol, the comparison between the different times was performed using the Friedman test, and when the data presented statistical difference, the Durbin Conover multiple comparison test was used. All analyzes were performed using the statistical software Jasp version 0.14.1, and a significance level of 5% was adopted.
Results

Single tasks results

Speech recognition:

There was no difference between speech recognition in silence and noise. Both conditions did not present statistically significant results with and without HA ($p > 0.05$) (Fig. 1) (Table 1).

Secondary task (PALETA):

Results of the secondary task (PALETA) are described in Fig. 2. No statistically significant results were found with and without hearing aid.

Response time of secondary task (PALETA):

The mean response time, with and without hearing aid before and after HA fitting, while performing the secondary task is shown in Fig. 3. Statistically significant results were not found between these two conditions.

Dual-task results

Analysis of correct answers for the Portuguese Sentence List:

The percentage of correct answers with and without HA are presented in Fig. 4. No statistically significant results were found.

Analysis of correct answers for the secondary task (PALETA):

Greater statistically significant results ($p = 0.013$) were found before the HA fitting with the secondary set of dual-task (Fig. 5).

Dual-task response time analysis:

After the hearing aid fitting, a decreased response time was noted, and this result was statistically significant ($p = 0.019$) when compared to the response time before the HA fitting (Fig. 6).

Salivary cortisol analysis:

The comparison of salivary cortisol at different moments of assessment presented a statistical difference ($p < 0.001$) between the first and the second times of assessment. The remaining times of assessment showed higher values at T1 and T2 (Fig. 7), and the peak of cortisol located in T2. When considering the differences between groups, a higher level of cortisol was observed in the afternoon, in the last possible hour (T6), when the HA was fitted ($p = 0.004$) (Table 2).
Discussion

The present study aimed to fulfill the lack of scientific evidence about listening effort in school-age children with UHL [19], and investigating the impact of a HA fitting. The single task of speech recognition in quiet and noise did not show any significant differences (Table 1). This outcome is different from a similar test design in older children with bilateral hearing loss. Their study showed significant results when performed utilizing the HINT with adolescents with normal hearing (group 1) and with bilateral hearing loss (group 2) [18].

This study found that those with bilateral hearing loss required a better S/N ratio than those with normal hearing. This suggests that children with UHL may not experience the same difficulties as those with hearing loss in both ears. This lack of difficulty may contribute to late or no intervention, and the late fitting of hearing aids to children with UHL [8]. This is because children with UHL can present with listening abilities less noticeable than those with bilateral hearing loss.

No significant results were found in the speech recognition task, the secondary task analysis, and the response time in the single condition (Figs. 1 and 2). These results were expected as they were performed in the single task condition and were independent of listening effort [20]. The most important results were those for the dual-task analysis. The speech recognition results in the dual-task condition were not different from the results found in the single task condition (Fig. 3). Although better results with speech recognition in children fitted with the hearing aid were observed, no statistically significant results were found (p = 0.148). A possible explanation for these results is that the patient receives instructions to improve his/her performance only in the primary task for the single and dual task conditions [21, 22].

The number of correct answers in the secondary task was significantly greater after the fitting of the HA (p = 0.013) (Fig. 4). A tendency of consistency was observed between the number of correct answers in PALETA and response time of the same test also documented in a previous study [18]. The main measure of listening effort, the dual-task response time results [23, 24] showed a statistically significant decrease of response time after the HA fitting (p = 0.019). The children had more difficulties completing the secondary task without the hearing aid. This may be due to the impairment of listening to the speech signal and impacting the speed at which they could answer the secondary task (Figs. 5 and 7).

These findings are consistent with a previous study that included twenty-three adults with bilateral hearing loss. They also showed a lower response time in the secondary task after the HA fitting [25]. In addition, this study described the importance of the response time measures, because they help to observe the differences between monaural and binaural fittings. They further noted that measures of listening improvement of subjects already using hearing technology can also be used to assess the quality of the HA fitting.

Fatigue analysis may be performed to assess and the level of salivary cortisol [23]. The hypothalamus-pituitary-adrenocortical axis controls the cortisol level during the stressful situations and induces the production of corticotropin factor, hence this factor stimulates the secretion of adrenocorticotropic
hormone. Thus, this hormone stimulates the adrenal gland, which induces the cortisol production [26]. Therefore, the cortisol has been used to measure the fatigue level due to the stressful listening situations such as in subjects with UHL.

The present study performed the cortisol collection before and after the HA fitting in four different moments. Only the fourth salivary tube presented statistically significant results with a greater cortisol level being observed after the HA fitting (Fig. 6). These results show the sensitivity of salivary cortisol to capture fatigue changes or stress related to the speech recognition task [23]. Another explanation for the found results could be that atypical stressful situations during the scholar period may cause changes in the cortisol levels [14]. There was a great variance of cortisol level despite attempts to control external factors. Previous studies that included children with hearing loss and those with normal hearing have cortisol levels which were higher in the morning and that was present in this study [14, 23].

While this study yielded some positive findings, there are some limitations that are important to acknowledge. First, although saliva collection was controlled in the clinic environment, this could not be standardized with home collection. It was not possible to control atypical stressful situations in the lives of our participants, and this could explain the high standard deviation in the salivary cortisol analysis (Fig. 6). Second, the small sample size is also a factor to be considered during the analysis of the present study. Children with UHL do not represent a large proportion of the clinical caseload, and recruitment for this study was difficult. Data analysis across all conditions, examining all variables should be viewed as a whole, and not evaluated in isolation.

**Conclusion**

The present study aimed to better understand the impact of a HA fitting on listening effort in school-aged children with UHL. This study used behavioural and objective, physiological test measures to assess listening effort. Results suggested that children fit with a hearing aid in their affected ear performed better in the dual-task condition than without use of a hearing aid. Most participants showed a better response rate in the secondary task, mainly with regards to the number of correct answers and a better response time. Overall, a decrease of listening effort in the dual-task condition was found. Salivary cortisol measures of listening effort with our participants did not show any statistically significant findings after the use of a HA.

**Abbreviations**

- DRS VI: Regional Health Department
- DSL: Desired Sensation Level
- FAPESP: Sao Paulo Research Foundation
- HA: hearing aid
- HINT: Hearing in Noise Test
• REAR: Real-Ear Aided Response
• REOR: Real-Ear Occluded Response
• REUR: Real-Ear Unaided Response
• SN: Signal to noise ratio
• UHL: Unilateral Hearing Loss
• USP: University of Sao Paulo

Declarations

The authors contributed equally to this work. Matos, IL and Ferreira, MC performed the experiments, analyzed the data and written the study. Dionísio, JT performed the analysis and interpretation of salivary cortisol. De Araujo, CM performed the statistical analysis and interpretation. Santos, CF and Mondelli, MFCG designed, analyzed the data and provided a critical review of the study.

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References


Tables

<table>
<thead>
<tr>
<th>Variable</th>
<th>With HA Median</th>
<th>IQR</th>
<th>Without HA Median</th>
<th>IQR</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speech recognition - Silence</td>
<td>100</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Speech recognition - Noise</td>
<td>100</td>
<td>10</td>
<td>100</td>
<td>10</td>
<td>0.792</td>
</tr>
<tr>
<td>Secondary task</td>
<td>10</td>
<td>0.25</td>
<td>10</td>
<td>0.25</td>
<td>0.789</td>
</tr>
<tr>
<td>Response time of secondary task</td>
<td>2.5</td>
<td>0.77</td>
<td>2.7</td>
<td>1.17</td>
<td>0.082</td>
</tr>
<tr>
<td>Correct answers for the Portuguese Sentence List</td>
<td>100</td>
<td>10</td>
<td>85</td>
<td>22.5</td>
<td>0.154</td>
</tr>
<tr>
<td>Correct answers for the secondary task</td>
<td>10</td>
<td>0.25</td>
<td>8.5</td>
<td>2.25</td>
<td>0.013*</td>
</tr>
<tr>
<td>Dual-task response time</td>
<td>2.4</td>
<td>1.1</td>
<td>3.4</td>
<td>1.6</td>
<td>0.019*</td>
</tr>
</tbody>
</table>

Wilcoxon Test. Significance level was p < 0.05.
Table 2- Median cortisol level at each time of assessment, collected before and after HA adjustment

<table>
<thead>
<tr>
<th></th>
<th>1st Assessment</th>
<th>2nd Assessment</th>
<th>3rd Assessment</th>
<th>4th Assessment</th>
<th>5th Assessment</th>
<th>6th Assessment</th>
<th>p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>With HA</td>
<td>0.201&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.069&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.285&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.459&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>0.102&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>0.090&lt;sup&gt;d&lt;/sup&gt;</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Without HA</td>
<td>0.070&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.100&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.563&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.096&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.071&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.080&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>p-value**</td>
<td>0.414</td>
<td>0.870</td>
<td>0.513</td>
<td>0.178</td>
<td>0.967</td>
<td>0.004</td>
<td></td>
</tr>
</tbody>
</table>

* p-value between assessment
** p-value between groups

Friedman test: Significance level of the Durbin Conover test was p < 0.05. Different letters in the same line indicate statistically significant differences.

Figures

A) [Figure 1a]

B) [Figure 1b]

**Figure 1**

Descriptive graphics of speech recognition with and without hearing aids: a) silence; b) noise.
Figure 2

Descriptive graphic of the results obtained in the secondary task PALETA, with and without hearing aids.
Figure 3

Descriptive graphic of comparison between the response time for the secondary task PALETA, with and without hearing aid.
Figure 4

Descriptive graphic of correct answers in the Portuguese Sentence List, with and without hearing aids.
Figure 5

Descriptive graphic correct answers in the secondary task PALETA, with and without hearing aids.
Figure 6

Descriptive graphic of response time, with and without hearing aids.
Figure 7

Mean values and 95% confidence interval for salivary cortisol levels during the different assessment moments.