IMPLICATIONS OF EXECUTIVE FUNCTIONS IN READING COMPREHENSION OF DEAF ADOLESCENTS WITH COCHLEAR IMPLANT

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Abstract

The appearance of the cochlear implant has allowed deaf adolescents (DA) to have an enhanced development of language and, therefore, an improved level of reading comprehension during early years of hearing, as a result. Nevertheless, few studies have assessed reading comprehension nor the other processes that may also be involved in it. The aim of this study is to analyse the difference between DA and typical hearing development (THD) in reading comprehension and their relationship with executive functions (EF). Three tests sessions were performed on two groups of adolescents between 12 and 14 years old: one formed by 10 DA implanted before 4 years of age and the other formed by 16 THD. The evaluation was focused in reading comprehension and cognitive processes: reading comprehension was assessed by PROLEC-SE-R (Catalan version) and cognitive processes were assessed by computerized tests from the Psychology Experiment Building Language battery (Stroop, Plus-minus, Digit Span and Corsi Task) and Letter Memory Task. Results could indicate that DA performance on reading comprehension is lower than THD. Furthermore, reading comprehension seems to have a relation with some cognitive processes such as inhibition and shifting. This relation between EF and reading comprehension could be different between the two groups. Although their hearing age is higher in the adolescence and the implantation is precocious, DA continue to have difficulties with text comprehension. Some EF could play a fundamental role in the development of reading comprehension and its relationship with EF could be explained by their lower level of reading. Future research is necessary to confirm our results.

Keywords: reading comprehension, executive functions, adolescence, cochlear implant, deaf.

1 INTRODUCTION

Reading is a requirement for an individual to fully understand their environment and to achieve academic success. When an individual reads, they undergo a process which requires a variety of abilities and acquired knowledge. The most frequently used process is working memory; however, this cognitive system is not responsible for the success or failure of text comprehension. If there are a significant number of factors can influence in a text comprehension in typical hearing development (THD), those factors increase exponentially in the deaf. Although the cochlear implant (CI) has improved educational outcomes, deaf adolescents (DA) have not achieved the same level of reading competence as normal hearing people up to now [1]. Nevertheless, some researchers have found that at least 40-47% of DA perform as well as THD [2], [3].

Executive functions (EF) are a group of cognitive processes which allow for the voluntary control of behaviors, thoughts, emotions. Together, all of these processes are necessary to achieve an objective. They each exhibit special importance when conducting less conventional tasks, or tasks where an individual may not possess the skillset to complete them automatically. As Goldberg states [4], EF act as an orchestra director trying to conduct processes correctly, with great coordination. This activity is normally associated within the prefrontal cortex, however, there are no specialized regions for each EF [5].

Currently, there is some disagreement around the question of unity or heterogeneity with EF, as well as their meanings and their nomenclature. The most accepted organization of EF is the model suggested by Miyake et al. [6]. Miyake's model establishes a multimodal system with three different, but related components: inhibition, updating and shifting. Some authors accept this model, but further expanded it claiming the relationships between the components change over the years [7], [8]. In childhood and early adolescence (until 13 years old) inhibition, updating and shifting are not dissociable, therefore, they could not be grouped in either unique or two components. Furthermore, EF have a development peak during the adolescent years (12 to 18 years old) [5]. In fact, adolescence is essential due to the structural changes are producing in the prefrontal cortex, like the proliferation of synapses and the global increase in the myelinization process [9]. These changes have a fundamental impact on a variety of cognitive abilities, including EF.

When an individual reads, the most important information is selected to fully understand the text or book. Other information is set aside in order to avoid overloading working memory [10]. This is accomplished by inhibition, the capacity to deliberately suppress a dominant or automatic response in favour of a more goal-appropriate [6]. Besides inhibiting responses, the reader must further update the information with new material to fully incorporate it to their memory.

Subsequently, updating is maintaining and processing incoming information which gives further coherence to the text. It is important remember that working memory, short-term memory and updating are not the same thing, despite the failure of some researchers to make this distinction [11]. Working memory implies manipulation of information, while short-term memory refers to the maintenance of information without requiring mental manipulation [12].

Lastly, shifting, for its part, is the capacity to flexibly change the attention to a relevant task or strategy, disengaging an irrelevant mental operation. Shifting are required to connect long-term knowledge and reading, simultaneously mixing the information from the two tasks [9]. Yeniad et al. [13] found children who perform better in switching between rules and tasks also have better reading results.

In secondary years, when demands on comprehension skills and text complexity increases, the need to understand the relationship between reading and EF in DA becomes even more relevant. Actual evidence with respect to language development and, concretely, reading comprehension show that secondary students obtain profit from their CI. Their reading comprehension level in some cases is comparable to adolescents of the same age [3].

Similarly, studies in adolescents indicate that deafness is a risk factor for EF difficulties [14], [15], and even Hintermair [16] established a relationship between behaviour disorders and EF amongst a sample of 214 participants in childhood and adolescence. However, there is a study that not observe differences in reading span task, a verbal memory task, in late adolescence between students with CI and THD [17].

Among deaf individuals, the relationship between EF and language acquisition has been studied in childhood. However, studies of this relationship solely in adolescence are scarce. Some findings suggest that in adolescence, the auditory stimulation after a period of auditory deprivation is not enough to overcome the impact of deafness, both mnemonically and linguistically [18]. Memory capacity is not restored by CI and this deficit caused in childhood provokes reading skill delays with respect to THD.

Some studies with a sample of children and adolescents claim that language and EF development are widely linked. They state that a delay in one of these aspects could cause problems in concept formation, that is, categorization, abstraction, derivation of semantic-linguistic meaning or development of cognitive representations for complex thoughts [19]. Furthermore, Castellanos [19] considered that these aspects are involved in reading comprehension. Other studies found a different pattern of correlations between EF and language [20]. These authors remark that this reciprocal relationship could have development effects in deaf people, so deafness could be a factor which shapes the relationships between reading comprehension and EF. Indeed, inhibition and memory would have a relevant function in children and adolescent's reading, where even inhibition or memory training can improve an individual's reading comprehension ability [20], [21].

In childhood, Lyxell et al. [22] found that verbal working memory has an essential role in reading acquisition and DA verbal memory. According to Kyle & Cain [23], when reading comprehension performance in deaf and hearing children is compared, results among deaf individuals is similar to a group of children with poor comprehnsion. Recent studies show deaf reading difficulties are lessened in adolescence [2]. Therefore, DA could reach the same reading level as THD, leading to delayed reading abilities, not a permanent disability. This delay can be improved even further when oral language competences progress due to a CI, with appropriate educational conditions.

Due to the lack of research in cochlear implanted adolescents, the aim of this study is to observe reading performance EF in DA and the relationship between these cognitive processes. Thus, the following research questions were addressed: Is DA performance in reading comprehension comparable to their classmates? Is the DA performance in EF similar to THD performance? Are reading comprehension and EF related in both DA and THD? Can an EF deficit be related to a reading comprehension delay?

2 METHODOLOGY & PROCEDURE

In order to include the participation of a deaf sample, the study collaborated with the *Centre de Recursos Educatius per a Deficients Auditius* and get their collaboration. This institution provided the initial contact with the sample group and assisted in obtaining parental and participant informed consent. The inclusion criteria for deaf participants was that a CI was implanted before five years old. All must be prelingually deaf, but fluent in oral communication and without neurological disorders. THD participants were recruited from the same schools as DA group with the purpose of maintaining consistent similarities between the two groups regarding age, gender and academical performance. Consent was obtained for THD and the study was approved by the UAB Ethics Committee on Animal and Human Experimentation.

A total of 26 adolescents aged 12-14 were included in the study. The group of adolescents with CIs was formed by 10 participants (6 males and 4 females) with a mean age of 13,1 ± 0,23. One of them had unilateral implant and hearing aid, two had bilateral implants and the other seven had unilateral implants. They have received their first CI at mean age of 2,36 ± 0,251 and their hearing age was 10,67 ± 0,368. THD group comprised 16 adolescents (9 males and 7 females) and their mean age was 12,63 ± 0,12.

Two sessions were necessary to evaluate each participant. To make the evaluation process comfortable, the assessment took place in the schools where the participants attended. The first session was conducted in groups and the second was individual. The first one had a duration of 75 minutes and the participants was evaluated with the following: first part of PROLEC-SE-R, Letter Memory, Plus-minus and Stroop task. The duration of the second session was 45 minutes and was made up of the second part of PROLEC-SE-R.

In relation to the materials, to evaluate reading the PROLEC-SE-R [24] was used. This battery includes tests which assess different essential processes necessary for reading comprehension like semantic processes, syntactic processes and lexical processes. Semantic processes comprised five subtests to evaluate reading comprehension: expositive comprehension (with memory influence), narrative comprehension (with no memory influence), pure reading comprehension (an expositive text with inferential questions and no memory influence), mnemonic reading comprehension (an expositive text) and oral comprehension (an expositive text with inferential questions). Also, all these measures form a Global Index of Reading.

Following the model of EF designed by Miyake et al. [6], three tasks were used to assess inhibition, shifting and updating. All three tasks were computerized from the Psychology Experiment Building Language battery [25]. One task was used to measure each EF. Stroop [26] was used to assess inhibition, Plus-minus [27] to assess shifting and the ability to updating was assessed with Letter Memory [6]. These tasks are considered reliable and appropriate measures to evaluate the three EF.

In the Stroop task, participants must name the colors (red, blue, green or yellow) of the words which could be colors or other words (e.g., bread or chair). This task must be done as quickly and accurately as possible. When the word is not a color, it is the neutral condition because there is no relation between word and color. The incongruent condition is referred to words with a color name, but the word is written in another color (e.g., the word “GREEN” written in yellow). The other condition is the congruent condition which is referred to color-name words written with the same colors (e.g. the word “GREEN” written in green). Reaction time and accuracy were recorded by each condition (neutral, incongruent and congruent). The variables were the difference between congruent and incongruent accuracy (CI-A), neutral and incongruent accuracy (NI-A), congruent and incongruent reaction time (CI-RT) and neutral and incongruent reaction time (NI-RT). These variables measure the ability to inhibit the incongruent stimulus. If their reaction time and the accuracy is near to zero means the incongruent stimulus has no effect in their performance, so their inhibition is good.

Regarding Plus-minus task is divided in three blocks of 30 items. The first block consists in add three to 2-digit numbers, in the second block participants must subtract three to 2-digit numbers and, finally, in the third block they must add and subtract three alternatively. Reaction time, total time, accuracy was recorded for the three tasks, but only it was considered the third block (PLUS-A for accuracy and PLUS-MRT for mean reaction time) because the first two blocks do not evaluate shifting. Furthermore, it was registered the time cost (PLUS-TC) and error cost (PLUS-EC) in the third block with respect to the other two blocks. Participants should respond as quickly and accurately as possible.

In Letter Memory task (LM) is showed a list of letters with a rate of 2000 ms per letter [6]. List length could be shorter or longer, participants do not know the length and must recall the last three letters so they need to update their memory permanently. Although the list of letters was presented in a screen, they must note the three letters in a paper. Number of correct responses were counted so that each correct response worth one point (maximum of 12 points).

For data analysis SPSS Statistics Software was used [28]. Reading and EF scores were analyzed by means of an analysis of variance (ANOVA) using hearing conditions as a between-groups factor (two levels, DA and THD). Partial eta squared ($\eta 2$) has been included in order to provide effect size estimations. Moreover, correlation analyses between reading variables and EF scores were performed. Significance was set at P=0.05 and data are shown as mean ± SEM.

3 RESULTS

3.1 Reading and Reading Comprehension

Reading data analysis revealed that hearing status affected the reading performance. THD obtained higher scores in the Global Index of Reading ($F_{(1,24)}$=6,81; p=0,015; $\eta 2$=0,221, see Table 1 for means). However, a more detailed analysis showed that these differences were not generalized to other index such as the Lexical Processes Index or Semantic Processes Index ($F_{(1,24)}$=2,541; p=0,124 and $F_{(1,24)}$=1,824; p=0,189, respectively; see Figure 1). A third index, the Syntactic Processes Index, indicated that DA scores were strongly impoverished relative to their peers ($F_{(1,24)}$=10,348; p=0,004; $\eta 2$=0,301).

Table 1. Descriptive statistics on reading.

	DA group	THD group
Global Index of Reading	87,80 ± 5,41	104,44 ± 3,74
Lexical Processes Index	94,30 ± 4,35	102,19 ± 2,81
Syntactic Processes Index	88,10 ± 6,45	112,88 ± 4,56
Semantic Processes Index	91,60 ± 4,89	98,94 ± 3,02
Expositive Comprehension	5,70 ± 0,79	6,13 ± 0,48
Narrative Comprehension	4,10 ± 0,58	4,56 ± 0,36
Pure Reading Comprehension	4,40 ± 0,60	6,31 ± 0,37
Mnemonic Reading Comprehension	5,20 ± 0,74	5,81 ± 0,48
Oral Comprehension	4,10 ± 0,90	6,88 ± 0,37

Despite the lack of differences in THD in Semantic Processes Index, when reading comprehension tasks are analysed meticulously these differences appear (see Figure 1). DA showed a poorer Pure Reading Comprehension compared to THD ($F_{(1,24)}$=8,205; p<0,01; $\eta 2$=0,255). However, other reading comprehension tasks with memory influence such as Expositive Comprehension and Mnemonic Reading Comprehension did not show significant difference ($F_{(1,24)}$=0,239 and $F_{(1,24)}$=0,523, respectively). In the same way, the deaf condition was not determinate to have a better comprehension in a narrative text ($F_{(1,24)}$=0,503). Oral Comprehension in DA was also lower than in THD ($F_{(1,24)}$=10,664; p<0,01; η2=0,308).

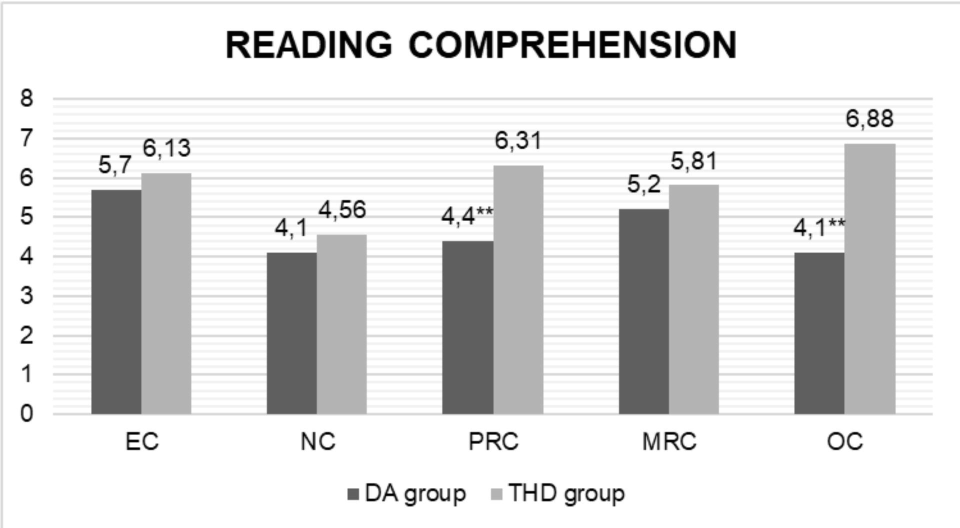

Figure 1. Means of reading comprehension.

Note. DA group (Deaf adolescents group) and THD (Typical Hearing Development group). EC (Expositive Comprehension), NC (Narrative Comprehension), PRC (Pure Reading Comprehension), MRC (Mnemonic Reading Comprehension), OC (Oral Reading Comprehension). ** = p < 0,01

3.2 Executive functions

EF data were analysed to clarify the possible differences between two groups and no revealed significant differences in updating ($F_{(1,24)}$=0,001, see Table 3 for means). Additionally, DA group scores were not statistically distinguishable from their classmates on inhibition accuracy (CI-A and NI-A; $F_{(1,24)}$=1,431 and $F_{(1,24)}$=0,088, respectively). Taking into account that CI-RT and NI-RT scores in the Stroop task were not found to have a significant difference between DA and THD ($F_{(1,24)}$=1,163 and $F_{(1,24)}$=0,155, respectively), the hearing status has no affect to inhibition in adolescence.

Table 2. Descriptive statistics on EF.

Task	Variable	DA group	THD group
Inhibition	CI Reaction time	51,73 ± 19,49	23,83 ± 16,4
	NI Reaction time	64,42 ± 18,45	54,17 ± 17,99
	CI Accuracy	-0,006 ±0,02	0,03 ± 0,02
	NI Accuracy	0,04 ± 0,05	0,03 ± 0,02
Shifting	Accuracy	0,92 ± 0,025	0,91 ± 0,029
	Mean reaction time	5511,25 ± 758,2	4118,12 ± 242,11
	Time cost	19,49 ± 9,29	16,49 ± 3,41
	Error cost	0,35 ± 0,48	1,25 ± 0,94
Updating	Correct responses	7,1 ± 1,01	7,06 ± 0,77

Shifting was the unique EF with significant difference between the two groups (see Figure 3). Concretely, THD scores in PLUS-MRT was significantly higher than DA scores $F_{(1,24)}$=4,356; p=0,048; η2=0,154). Nevertheless, no significant differences were observed in PLUS-CT and PLUS-EC ($F_{(1,24)}$=0,126; p=NS and $F_{(1,24)}$=1,163, p=NS, respectively).

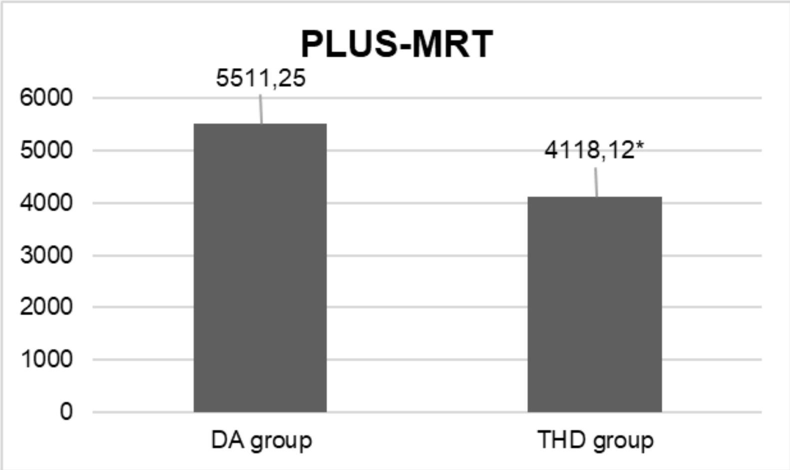

Figure 1. Means on shifting mean reaction time expressed in ms.

Note. PLUS-MRT (Plus-minus mean reaction time), DA group (Deaf adolescents group) and THD (Typical Hearing Development group). * = p < 0,05;

3.3 Relationship between Executive Functions and Reading Comprehension

Finally, additional correlational analyses were performed separately for DA and THD. Regarding DA group, several associations were observed between reading performance and EF scores. Inhibition accuracy positive and significantly correlated with several reading indexes (see Table 4), especially Global Index (r=0,780; p=0,008).

Table 4. Pearson correlations between executive functions and reading variables in DA.

Reading variables	Inhibition				Shifting				Updating
	CI-Reaction time	NI-Reaction time	CI-Accuracy	NI-Accuracy	Accuracy	Mean reaction time	Time cost	Error cost	Correct responses
Global Index	,339	-,438	,780**	,185	,451	-,420	-,598	-,600	,523
Lexical Index	-,045	-,642*	,745*	,150	,338	-,567	-,428	-,348	,376
Syntactic Index	,218	-,365	,730*	,304	,595	-,462	-,628	-,717*	,747*
Semantic Index	,648*	-,147	,489	-,023	,222	-,078	-,467	-,465	,260
Expressive Comprehension	,779**	,153	,456	,068	,093	-,007	-,498	-,363	,004
Narrative Comprehension	-,090	-,460	,303	-,262	,448	-,377	-,329	-,485	,465
Pure Reading Comprehension	,476	-,052	,634*	,263	,315	,025	-,447	-,552	,540
Mnemonic Reading Comprehension	,556	-,072	,491	-,108	,282	-,300	-,567	-,502	,085
Oral Comprehension	,477	,104	,477	-,098	,482	-,250	-,783**	-,622	,120

Even though inhibition accuracy was not associated significantly with the Semantic Index, there was a positive correlation with Pure Reading Comprehension (r=0,634; p=0,49) in which DA scored significantly lower than THD. In addition, a positive correlation was found between the reaction time in inhibition task and the Expressive Comprehension (r=0,779; p=0,008).

In relation to shifting and updating (i.e. the error cost of Plus-Minus and correct responses of Letter Memory) were associated with the Syntactic Index (r=0,717; p=0,013 and r=747; p=0,020, respectively). The rest of EF variables had no significant relation with the reading variables, except the time cost of Plus-Minus that was markedly correlated with the Oral Comprehension (r=0,783; p=0,007).

In THD, however, there were not many correlations (see Table 5). Findings suggested that shifting is associated with Expressive Comprehension (r=-0,588; p=0,017) and Oral Comprehension (r=0,591; p=0,016). One positively correlation was also found between Pure Reading Comprehension and the reaction time of Stroop (r=0,504; p=0,047).

Table 5. Pearson correlations between executive functions and reading variables in THD.

Reading variables	Inhibition				Shifting				Updating
	CI-Reaction time	NI-Reaction time	CI-Accuracy	NI-Accuracy	Accuracy	Mean reaction time	Time cost	Error cost	Correct responses
Global Index	-,162	,126	,256	,347	-,081	,419	,347	,030	,306
Lexical Index	,006	,225	,255	,289	-,369	,267	,140	,279	,081
Syntactic Index	-,375	,108	,131	,316	,068	,399	,437	-,053	,429
Semantic Index	,083	,015	,381	,318	,056	,416	,293	-,153	,220
Expressive comprehension	,127	-,328	,267	,170	,462	,224	,032	-,588*	,410
Narrative comprehension	,066	-,148	,319	,300	-,222	,235	,225	,203	-,023
Pure Reading comprehension	-,255	,504*	,002	,214	,019	,239	,299	,015	,283
Mnemonic Reading comprehension	,289	,052	,100	-,096	,301	,093	-,035	-,413	,124
Oral comprehension	,016	,100	-,088	-,228	,334	,591*	,396	-,401	,088

4 DISCUSSION & CONCLUSIONS

The purpose of the present study was to understand the reading competence and EF in DA in comparison with THD. Our results showed that the poor performance in reading in DA is partly due to their low scores in syntactic process. DA are known to have problems with the syntactic influence which can considerably impact reading comprehension during childhood [29], [30], but there are no current studies that observe this relationship in adolescence. Surprisingly, the findings suggest that DA results were not significantly below THD in mnemonic reading comprehension and expositive reading comprehension, despite the need for mnemonic resources were needed to satisfactorily complete these tasks. Moreover, results are consistent with previous data reported [23]. However, there must be other causes that justify the lower performance of DA in some texts.

In this regard, it could be interesting to observe DA performance in non-purely linguistic tasks. The results reported here suggest DA scores were below THD in the reaction time of shifting task. DA would require more time than their peers when performing two tasks simultaneously. Since the time cost was not different in shifting and non-shifting tasks, DA would spend more time when focus their attention both in shifting and non-shifting tasks. Up to date, Kronenberger et al. [15], found that risk for

EF deficit was a rate of two to five times higher in DA compared to a matched THD sample. These data, however, were obtained using a two parent-reported questionnaire. There are few studies that have evaluated EF with neuropsychological tests in adolescence. It has been reported that DA performance was significantly lower than their pairs group using Stroop task [31]. Contrarily, no significant differences in inhibition between DA and THS were obtained in our study.

Despite the lack of differences between DA and THD in EF, complementary correlation analysis indicates that DA with better EF had better reading comprehension. Thus, why are EF and reading not linked in THD? Why are DA' EF similar to THD?

One plausible explanation could be that the relationship between reading comprehension and EF could becoming less necessary during adolescence among good readers similarly to that of other cognitive functions such as Theory of Mind [32]. In this way, despite THD having the same EF level as DA, THD can reach high reading comprehension levels. While deaf people require a greater neurocognitive effort to compensate their linguistic deficit, THD can face these tasks without a great effort. According to this hypothesis, DA with high EF performance could have better reading comprehension and, consequently, less risk of school failure. So, even though our findings no revealed an EF delayed as group, the importance of EF in reading development is highlighted in our study.

It must be noted that the largest difference in reading comprehension was among the inferential questions. Reading inferences connect text elements with important background knowledge. Weakness in inferential ability could be caused by the lack of prior knowledge [33]. In relation to this point, Convertino et al. [34] discussed that deaf individuals with and without CIs both have problems accessing other environmental information. Deaf with CI have more opportunities for incidental learning compared with other deaf people [34], but these opportunities could not be enough to obtain better text comprehension or language comprehension. Even though these authors compare deaf with and without CI, our findings reflect that the auditory improvement is not enough to obtain better scores. In addition, our results coincide with Kyle and Cain [23] who found identical comprehension problems during inferential question tasks among 10 to 11 years old deaf children.

In conclusion, results could indicate a difference of reading and EF implications in DA and THD. Our results also show reading problems in DA for text comprehension. DA performance in reading comprehension are significantly lower than their pairs, especially in reading tasks with inference influence or inference questions, such as pure reading comprehension. Some EF could play a fundamental role in the reading development in DA and its relationship with EF could be explained by their lower level of reading, however more research is needed.

The present study had some limitations. The first and most important limitation is the sample size in a deaf group. Deaf reading level is characterized to be very heterogenous, so future studies are needed to obtain more reliable data and extrapolate the results. In addition, tests selected for this study have been widely used in clinical and investigation, but EF tasks could not adequately assess some cognitive processes without reading interference.

Finally, these preliminary results lead to two suggestions. On the one hand, the convenience of exploring other cognitive skills, such as those involved in the Theory of Mind, which may be related to the ability to make inferences during the reading comprehension activity, especially in narrative texts. On the other hand, in relation to educational implications, this study emphasizes the need to promote FE in poor readers, especially in students with deafness.

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