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Adapting a Technology Tool to Assess Executive Functions in Visually Impaired Children: Does Changing Modality Affect Their Ability to Discriminate?

La adaptación de una herramienta tecnológica para evaluar funciones ejecutivas en niños con discapacidad visual: ¿el cambio de modalidad afecta su capacidad de discriminación?

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Abstract

The auditory version of the Cats & Dogs test is an adaptation of the visual test that is used for the evaluation of children's executive functions. The auditory version was created to assess preschoolers with moderate and profound visual impairment and students with typical development. Analysis indicates that the new test is not equivalent to the standardized version. Specifics analysis shows that the test discriminates in all phases against visually impaired and typically developed students and that this trend is reinforced by the result obtained in a third test (Digit Retention). The proposal is to use the auditory version with the visually impaired population and consider its application in older subjects to avoid the floor effect.

Keywords: Executive Functions, Instrument Validation, Visual Impairment.

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Resumen

La prueba Gatos y Perros versión auditiva corresponde a una adaptación de la misma prueba que se presenta en modalidad visual para la evaluación de las funciones ejecutivas de niños. La versión auditiva fue creada con el objetivo de evaluar a niños preescolares que presentan discapacidad visual moderada y profunda y, eventualmente, a alumnos con desarrollo típico. Los análisis indican que la nueva prueba no es equivalente a la versión estandarizada. El análisis específico demuestra que la prueba discrimina en todas sus fases el rendimiento entre alumnos con discapacidad visual y desarrollo típico y que esta tendencia se ve reforzada por el mismo resultado obtenido en una tercera prueba (Retención de dígitos). Se propone utilizar la versión auditiva con la población con discapacidad visual y considerar su aplicación en sujetos de mayor edad para evitar el efecto suelo.

Palabras clave: discapacidad visual, funciones ejecutivas, validación instrumentos.

Introduction

Given the increasing number of studies that demonstrate the importance of early development of executive functions (hereinafter EF) for subsequent success in various areas of life, interest in studying EV and, consequently, the creation of instruments that allow it to be measured, has recently grown significantly (Day, Freiberg, Hayes, & Homel, 2019; McCoy, 2019; Zelazo & Carlson, 2012). It is in this context that the initiative has come about to create a battery of digital instruments that have standardization norms for the Chilean population, which has been called Yellow-Red (Rosas, Espinoza, Aparicio, Diamond, & Oberauer, 2017). Within the framework to assess the cognitive abilities of specific populations—in this case children with visual impairment (VI)—there is a need to adapt the Cats and Dogs subtest (hereinafter C&D), which belongs to that newly named battery.

In spite of the relevance that EF have been given in children with typical development (TD), the assessment of these abilities in children with VI has been researched less, even though there is evidence showing that the development of these cognitive functions is also essential for children with VI, particularly those for whom the development of their EF could be at risk, so their early evaluation is essential to avoid further deficiencies (Heyl & Hintermair, 2015). As a consequence, it is necessary to begin investigating resources that allow us to progress with the measurement and comprehension of the development of EF in visually impaired people.

What are EF and why are they important?

Although EF have been defined in various ways according to the focus of the subject or the underlying conceptual framework, for the purposes of this paper we understand them as a phenomenon that encompasses a series of skills used to set and achieve a particular goal (Santa-Cruz, 2015). These skills enable us to plan and track an objective, as well as to restrict the thoughts, behaviors, and emotions that interfere with the achievement of that goal (Santa-Cruz & Rosas, 2017). In this regard, EF are a high-order cognitive ability, related to the concepts of cognitive control and emotional self-regulation, both of which are essential for one to develop in the 21st century.

With respect to the cognitive abilities or functions that comprise the EF, we understand that this is a term around which three elements are grouped that progressively develop from infancy to adolescence: *inhibitory control*, *working memory*, and *cognitive flexibility*, which are differentiable, but act together when we are faced with tasks that involve cognitive control and planning (Blair & Raver, 2014; Blair, Zelazo, & Greenberg, 2005; Diamond, 2013; Santa-Cruz & Rosas, 2017; Ursache, Blair, & Raver, 2012).

Inhibitory control is defined as the ability to resist a powerful inclination to do something rather than what is most appropriate or necessary. This allows us to consciously focus our attention, behavior, and emotions while we follow a line of thought. In short, inhibitory control allows us to manage our attention and actions rather than being controlled by emotions or habitual behavioral tendencies (Blair, 2015; Diamond, 2013; Santa-Cruz & Rosas, 2017).

Working memory is the ability to operate with representations or, in other words, the ability to maintain or retain information visibly in the mind, in order to work with it or manipulate it. This ability allows us to remember our plans, follow instructions, consider alternatives, and even make calculations and understand a text (Diamond, 2013; Diamond, Barnett, Thomas, & Munro, 2007a; Santa-Cruz & Rosas, 2017).

Finally, cognitive flexibility is the ability that allows us to create and use alternative strategies in order to solve problems. Using this capacity, we are able to observe certain situations through multiple perspectives and, consequently, create new solutions and think creatively (Santa-Cruz & Rosas, 2017).

Since the EF undergo accelerated development during childhood, there has been speculation that this vital period could be a window of opportunity to intervene and enhance their development. From this viewpoint, preschool education has been suggested as a space where the development of skills and knowledge that facilitate the acquisition of this later learning should be enhanced (Blair, 2002; Santa-Cruz, 2015).

Similarly, there has been special study of EF over the last two decades, because high performance on the tasks that assess these skills has been associated with a wide range of positive behaviors and results, such as academic success, healthy social relationships, higher employment rates, and lower tendency to conduct risky behaviors (such as using drugs) (Blair, Gamson, Thorne, & Baker, 2005; Casey et al., 2011; Diamond, 2013; Nisbett et al., 2012; Rosas, Espinoza, Garolera, & San-Martín, 2017; Santa-Cruz & Rosas, 2017; Shoda, Mischel, & Peake, 1990; Van Lier & Deater-Deckard, 2016).

Development of EF in children with VI

Generation of evidence that allows us to shed light on how the auditory and non-auditory modalities interact in the development of EF is of special relevance to understand how we should work on EF in children with VI. That is to say, we are looking at a problem in which there is still no evidence as to whether the modality in which an EF task is carried out affects its performance and, on the other hand, whether having a sensory disability affects the development of EF in general or, rather, if development is compensated by other sensory pathways. This is why existing research has not yet been able to clearly verify how visual experience affects the development of executive skills (and the integration of neural networks in the brain associated with these functions). Nor is there sufficient evidence to determine whether experiences related to other non-visual modalities (auditory and tactile) are sufficient to develop EF when a child does not have visual ability (Bathelt, De Haan, Salt, & Dale, 2018). Although there are some small-scale studies that suggest that the behaviors associated with EF could be affected in children with VI (Heyl & Hintermair, 2015), there are other investigations whose results do not show significant differences or deficits in assessments of EF in blind children versus their peers with TD (Bathelt et al., 2018; Brambring, 2005; Pring, 2008). In this vein, it is not clear how such disability affects EFs or which specific aspects of EF are more vulnerable than others (Bathelt et al., 2018). Because of this, creation of instruments that allow the effective assessment of cognitive abilities in people with VI is therefore essential as a means of identifying which cognitive abilities could be underdeveloped (due to a lack of stimulation because of the disability) and, therefore, stimulate their development. In addition, understanding the development of EF in visually impaired people implies beginning lines of research that seek to understand how vision, or the lack of it, interferes with the development of EF.

Measurement of EF

The evidence shows that EFs are malleable and can be stimulated with practice. Therefore, early interventions, designed to improve these abilities, generate positive and lasting impacts on the development of EF and even their corresponding neuronal correlations (Davis et al. 2011; Diamond et al., 2007a; Zelazo & Carlson 2012; Zelazo & Müller, 2011). Thus, the creation of measuring instruments to identify possible deficiencies in the development of EF is an essential requirement for effective intervention in educational contexts. This is because the assessment instruments allow us not only to identify whether the EF are at risk and what type of people are affected, but also help to make estimates of the interventions. As regards children with VI, since it is not yet known how the lack of vision affects EF or which specific aspects of EF are more vulnerable than others (Bathelt et al., 2018), it is particularly important to create effective instruments that allow assessment of this for the inclusion of these students in educational contexts, which would allow us to identify whether the EF are diminished for this group in particular, follow up on strategies that seek to compensate for this development, and shed light on how the visual and non-visual modalities (auditory and tactile) interfere in the development of EF.

Within the range of different instruments for the assessment of EF, *direct assessments* are tasks in which the performance of the subjects is measured—often described to the participants as "games"—which are applied in person to children, either individually or in groups (McCoy, 2019). These assessments have various advantages, including their relative objectivity and conceptual accuracy.

On the other hand, as Day and collaborators (2019) state, the present time requires the creation of innovative technological proposals, based on experiences that are fun and interactive. In this vein, the digitalization of the assessments simplifies not only the process of applying tests, but also their scoring, producing a series of associated benefits, such as saving time and resources. Likewise, computerization of the assessments means they can provide more accurate data regarding response times and the responses themselves (Mcoy, 2019).

Sánchez (2015), meanwhile, states that instruments that use technology adapted through a user-centered design approach can contribute to the cognitive development of blind children. Along these lines, the adaptation of the test to the auditory modality as a tool for digital evaluation of EF in children with VI is a proposal that allows us to join these initiatives.

Assessment of children with VI implies going beyond the mere application of instruments that are regularly used in children with TD. Along with the creation of new tools and the adaptation of existing ones, it generally becomes necessary that there is also validation of these tests (using larger samples and moving from the laboratory to real environments), so that they can be used reliably in the community of children with VI (Kitchin & Jacobson, 1997; Nelson, Dial & Joyce, 2002).

With respect to the assessment of EF, although there are some studies where these functions are assessed in blind children using different instruments—interviews with parents or auditory tests (Bathelt et al., 2018). However, the same authors state the importance of continuing research and working on the creation and validation of instruments to assess this subgroup (Bathelt et al., 2018). In fact, the skills associated with EF are generally measured with instruments that use visual resources, so little is known about the role that vision plays or the consequences that the lack of vision could have on EF (Bathelt et al., 2018). In this vein, we once again state the need to generate and validate new instruments that allow us to measure EF in people with VI, understand whether VI interferes with the development of any of the EF, and investigate effective compensatory strategies, if necessary, to be able to stimulate the development of EFs that are deficient in this population.

In this article we seek to answer two main questions based on the results of the adaptation of the C&D test to an auditory version, part of the Yellow-Red battery of instruments. First, we want to establish whether the visual and auditory versions assess EF in an equivalent manner. Second, we want to look for evidence about the assessment of EF in students with VI. Our hypotheses indicate that both modalities behave in the same way for the population with TD, that is, the tests could be used interchangeably. The second hypothesis indicates that the test discriminates in terms of the level of development of EF for students with VI and, therefore, is a test that can be used in this type of population.

Methodology

Participants

This research is part of a longitudinal study developed by the Centro de Justicia Educacional (Center for Educational Justice), which seeks to assess precursors of reading and arithmetic in people with auditory or visual disabilities, and those with TD. In this case, only the sample with TD and with VI will be considered, since the participants took the adapted visual and auditory test.

The subjects in the group dubbed TD, that is, students who do not have VI or auditory impairment, were contacted through their schools, which were classified according to their vulnerability index (belonging to the high or low socioeconomic level).

The children with VI were contacted through their respective schools (in the case of those who attend special schools or foundations) or were referred by health professionals (in the case of those who participate in regular school integration programs).

Each of the parents or guardians involved received an informed consent and only those students whose parents or guardians approved their children's participation were allowed to take part in the study. Likewise, the students signed an agreement before beginning each assessment, emphasizing the possibility of withdrawing from the study if they so desired. The children who were contacted through the schools were assessed in their educational units in areas allocated for this task. Those who were contacted individually were assessed individually at their homes. At the end of each evaluation, the children received a reward to thank them for their participation (a set of stickers). The participating schools were offered a training talk for their educators given by experts in different pedagogical areas (universal learning design and EF, among others). Finally, those who carried out the assessments of the students were professionals in education or psychology, who had two training sessions and were observed in person to ensure the quality of their assessments.

The sample N was estimated based on two national reports: the data from the 2015 Casen survey was used for students with TD and for students with disabilities information was used from the *II Estudio Nacional de la Discapacidad* (II National Study of Disability) conducted in 2015 (Ministerio de Desarrollo Social y Familia, 2017a; 2017b). In order to calculate the sample number of students with VI, we estimated the number of children corresponding to the cohort assessed, who by 2015 were between two and three years old. If these data were not available, as a consequence of the N of the original survey, those children who by 2015 were between five and six years old, corresponding to the assessment age in our study, were used as the total N of the cohort. Thus, the universe of this age group was 412,866 children, while the population declared to have been diagnosed by a doctor with "loss of vision" (the datum that turns out to be most reliable, according to direct communication with technical staff of the Servicio Nacional de la Discapacidad [National Disability Service, Senadis]) was 0.7% of the total, or 2,890 children. The sample N was then estimated considering a significance level of 0.05 and a standard error of 0.03. This produced a sample N of 11 children, who would represent the population with VI. Finally—and considering an attrition rate of 20% per year—at least five more subjects were added to carry out the study. Therefore, the total of 29 students representing those with disability exceeded by seven the minimum amount established to determine some type of result. For students with TD, the same procedure was followed, this time using a more recent survey (Casen 2015).

In short, this study involved the participation of a total of 169 children, who were in the process prior to the acquisition of reading, which, in the case of children with TD, are students who are at the second level of transition and, in the case of students with disabilities, are children of various levels, depending on their previous schooling. Although the instruments considered (Digit Retention and C&D) are applied by protocol from the age of six, the same version was applied to all the children in the sample, since they met the study inclusion criteria and then we analyzed the raw scores, transformed into a Z score if necessary, in order to avoid underestimating the results for the youngest children and also for the particularities of the sample of children with VI, for which there are no standardized norms for the Chilean population.

So, of the total sample, 29 students have partial or total VI and attend special schools, or participate in integration programs at regular schools in Chile, specifically residents of the Metropolitan Region and the Biobío Region. The ages of the subjects in this sample range from 47 to 103 months. On the other hand, the remaining 140 students do not have other disabilities, as reported by their parents. All of the students in this sample reside in the Metropolitan Region and their ages range from 51 to 88 months. Table 1 below shows a summary of the sociodemographic characteristics of the groups that participated in the study.

Table 1. Characteristics of the sample by comparison group

		VI Group		TD Group	
		N	%	N	%
Gender	Male	15	51.7	64	45.7
	Female	14	48.3	76	54.3
SES	High	2	6.9	65	46.4
	Medium	19	65.5	19	13.6
	Low	8	27.6	56	40
		M	SD	M	SD
Age (months)		76	15.2	68	4.4

Note: Group VI = Group with visual impairment; TD Group = Group with typical development; *N* = Frequency; % = Percentage; *M* = Average; *SD* = Standard deviation; *SES* = Socioeconomic status (comprised by family income, level of mother's education, and vulnerability index of educational establishment).
Source: Prepared by the authors.

Instruments

It should be noted that all of the students in the sample were given the Digit Retention test. For students with VI, only the auditory version of the C&D test was applied, while the auditory and visual versions of the C&D test were applied to children with TD. Table 2 below summarizes the groups and instruments applied.

Table 2. Instruments applied by comparison group

	VI Group	TD Group
C&D - visual version		X
C&D – auditory version	X	X
Digit Retention	X	X

Source: Prepared by the authors.

Yellow-Red - G&P

Two versions of the C&D subtest of the Yellow-Red battery were used, which is in the process of standardization in Chile and other countries including Argentina, Australia, the United Kingdom, and Norway (Rosas et al., 2017). Preliminary analyses indicate that the battery has high reliability (Cronbach's α between 0.7 and 0.9). In addition, the difference in performance between countries is very low, which would allow the application of the battery using international standards. Similarly, as an indicator of the validity of the test—and based on Carlson's (2005) recommendations—this shows increases in performance by age, which is consistent among the subjects from the different countries assessed.

C&D-visual version. This subtest is the original version of the Yellow-Red battery and is an adaptation of the H&F test (Davidson, Amso, Anderson, & Diamond, 2006; Diamond et al., 2007a; 2007b), which represents the "gold standard" of the assessment of EF in children. The instructions appear on the screen by stage and before each

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phase. Therefore, these instructions can be provided verbally (given by the person assessing), or self-administered depending on whether the child can read or not. In the first two phases of the test—consistent and inconsistent, respectively—there are four practice items to ensure that the child understands the instructions, where each of these elements is fed back in a particular way. The assessment phases are applied without considering the results obtained on the practice items. Since the specific stimulus appears for each stage, the subject has one second to respond before it automatically moves on to the next item. A centering cross appears between the items. The time between stimuli was established as suggested by Davidson et al., (2006) and Diamond et al., (2007b).

Figure 1 below describes each of the three phases comprising the test.

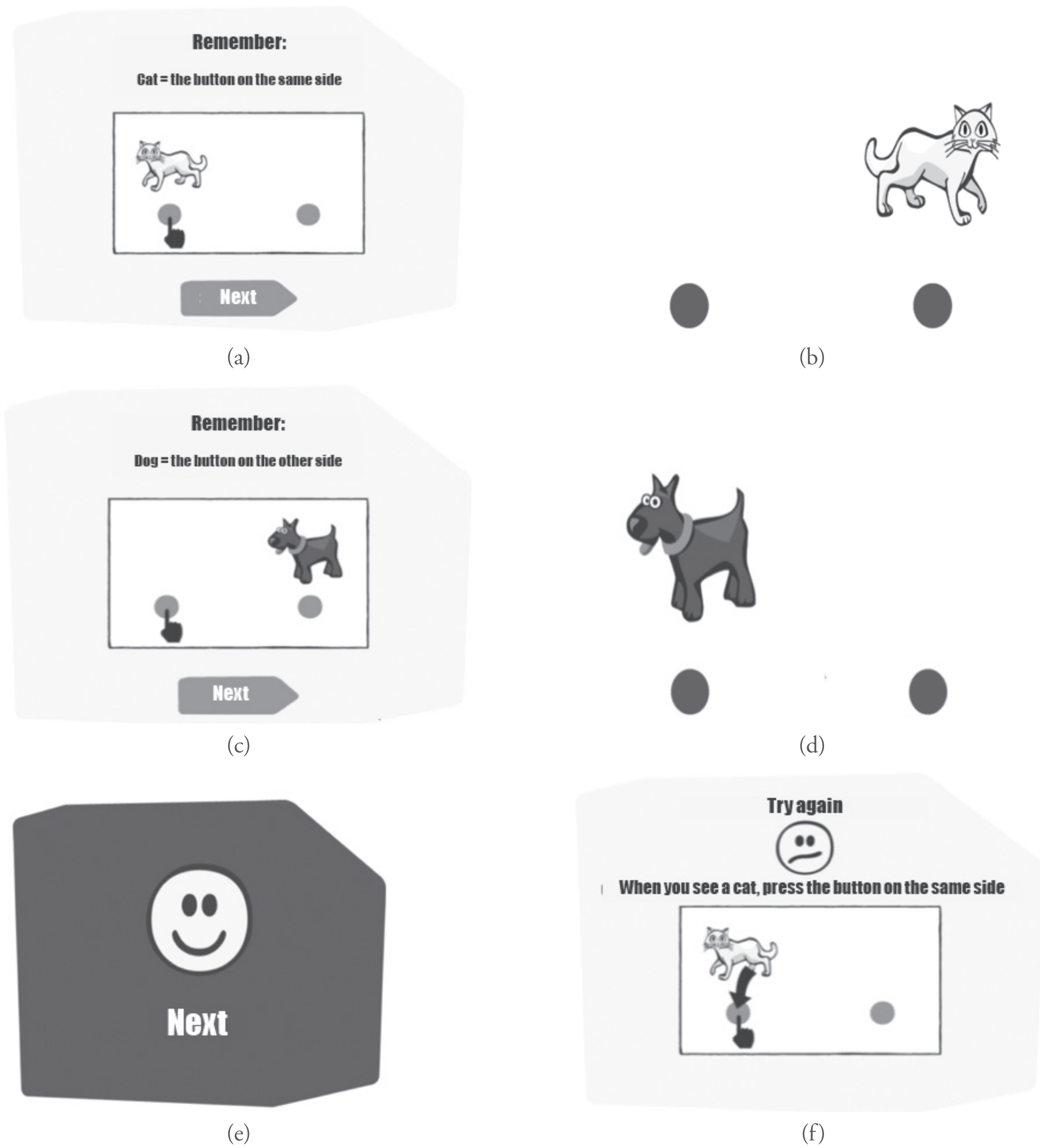

Figure 1. Graphic representation of the phases of the assessment. C&D, visual version.
Note: Examples of C&D images: (a) Instructions for consistent phase; (b) Test item and response zone for consistent stage; (c) Instructions for inconsistent stage; (d) Test item and response zone for inconsistent stage; (e) Positive feedback after correct response for test of consistent and inconsistent phases; (f) Negative feedback after incorrect response for test of consistent and inconsistent phases.
Source: Prepared by the authors.

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Consistent phase. It is called this because the subject must press the button on the same side on which the stimulus appears, in this case, a cat. The instructions given to the child on successive screens are: "Welcome to Cats and Dogs. "Cat" is the same as pressing the button on the same side. Remember: look at the cross in the middle. Let's practice!". After the practice they are told: "This time the game will go faster and it won't tell you if you are right or wrong." The consistent assessment includes 12 items.

Inconsistent phase. It is called this because the subject must press the button on the opposite side to which the stimulus appears, in this case, a dog. The instructions given to the child on successive screens are: "Remember, dog is the same as the button on the opposite side. Let's practice!". After the practice they are told: "Let's play! This time the game will go faster and it won't tell you if you are right or wrong." The inconsistent assessment includes 12 items.

Mixed phase. It is called this because during this stage consistent and inconsistent items are mixed, that is, cats and dogs appear alternately, which implies that when a cat appears, the child presses the button on the same side on which the cat is seen and, if a dog appears, the subject presses the button on the opposite side to the one where the dog appears. This stage consists of 33 assessment items and the instructions are: "Remember: [a cat appears] the same, and [a dog appears] opposite. This time the game will go faster."

C&D-Auditory version. This adaptation was created in order to be able to evaluate EF in children with moderate and severe VI. However, it was also applied to the subjects with TD who participated in the study, in order to perform comparative analyses between the original test and the auditory version. In terms of structure and theoretical basis, the test is the same as the visual version. The adaptation consisted of changing all visual stimuli to auditory stimuli, which are perceived on different literalities by means of earphones. Thus, in the consistent phase the child must press the side of the screen consistent with the side from which he or she hears the sound of the cat ("meow") and on the opposite side to that from which the stimulus is perceived in the case of the dog ("woof"). In this version the tactile space was expanded for the response, with half of the screen for each laterality. The screen is black during the assessment and practice items, which avoids intermodal interference with additional stimuli in individuals with low vision and with TD. Only the instructions were maintained in visual format so that the assessor could read them. It should be noted that the assessors were told that they should assist the students in placing their hands on the screen, to establish a framework for physical response.

With respect to the score, the visual and auditory versions of C&D yield two types of results: accuracy or precision in the response and reaction time. The original test provides three types of scores: one (1) point corresponds to correct answers, zero (0) points corresponds to omitted answers—for which the subject does not record a response in the time established—and minus two (-2) points represents an error in the response. This last score punishes the subject for not having correctly inhibited themselves after the correct answer and differs from those that did inhibit themselves, but did not respond in time. For the Chilean standardization sample, C&D showed a high level of internal consistency (Cronbach's α = 0.78).

The assessments were carried out in two different sessions for all students. The application was counterbalanced in order to avoid the learning effect. It is necessary to state that, for this study, only the reaction times for the correct and incorrect answers that were executed in a time greater than 200 ms[1] were considered, since a response in a shorter time is considered anticipatory.

1. Milliseconds.

Digit Retention – WISC-V (Wechsler Intelligence Scale for Children-Fifth Edition)

We used the version of the WISC-V test in the standardization process for Chilean norms, considered the gold standard for cognitive evaluation (Rosas & Pizarro, 2017). One of the tests in the WISC-V battery that assesses the EFs, specifically the memory component of auditory work, is the Digit Retention subtest (Miller et al., 2016; Weiss, Saklofske, & Holdnack, 2016).

In the recent version of the WISC battery, the Digit Retention subtest entails three parts:

> A. Direct digit retention: consists of repeating growing series of digits in the same order. It assesses auditory practice and temporary storage capacity in working memory.
>
> B. Retention of inverse digits: consists of saying a growing sequence of digits in reverse order. This section evaluates working memory, information transformation, and mental manipulation.
>
> C. The third part only appears in the most recent version of the WISC battery and is called Sequenced Digit Retention; it requires children to remember, in ascending order, a growing series of numbers.

The sequenced digits section was included in order to increase the demand in terms of the working memory of the subtest compared with the part with retention of reverse digits, as well due to criticism about the diversity of cognitive demands between the direct and inverse stages. The former requires the initial registration of the verbal stimulus—a requirement for mental manipulation of the stimulus—so the direct digits stage was retained in order to reflect the role of the auditory register in working memory, as a precursor to working memory and to maintain a set of items of lesser difficulty for the assessment of students who have lower cognitive functioning (Reynolds, 1997; Weiss, Holdnack, Saklofske & Prifitera, 2016).

In addition to the skills that each subtest assesses—and as noted by Weiss, Saklofske, et al. (2016)—the change between one and another task in this subtest implies the use of cognitive flexibility and mental alertness. Similarly, the full version of the test makes use of skills such as registering information, brief attention focus, auditory discrimination, and auditory practice.

Results

The results are presented below in accordance with the research questions proposed previously. First, we will contrast the hypothesis that the performance in the auditory version of the test is equivalent to that of the visual version for the population with TD, in order to establish whether the auditory or visual version can be applied interchangeably. In order to do this, the response types (correct, incorrect, and omitted) were analyzed according to the accuracy and reaction time in both modalities. It is assumed that if the tests assess the EF in the same way, the subjects will have comparable performances on both versions for each type of response. For the comparisons Student *t*-tests were used for paired samples.

Table 3 shows the general descriptive statistics for each type of response on both tests, both in terms of the accuracy of the response and the reaction times.

Table 3. Descriptive statistics on accuracy and average reaction time for visual and auditory versions.

			Average	Standard deviation	Min.	Max.	N	
							Valid	Lost
Correct	GS	Visual	24.24	8.55	0	46	138	2
		Auditory	16.62	7.46	0	33	138	2
	RT	Average Visual	740.3	107.35	287.69	907.15	137	3
		Average Auditory	529.52	164.42	226.16	948.55	128	12
Incorrect	GS	Visual	7.33	6.83	0	29	138	2
		Auditory	15.25	7.44	0	31	138	2
	RT	Average Visual	566.37	202.35	35.49	1028.50	124	16
		Average Auditory	468.77	148.20	132.35	870.44	128	12
Omitted	GS	Visual	25.43	9.36	3	57	138	2
		Auditory	25.12	13.82	3	57	138	2

Note: ** *GS* = Gross score; *RT* = Reaction time.
Source: Prepared by the authors

Before each analysis shown, we tested the assumptions based on the statistical test used. With respect to the extreme values, we decided to exclude those cases in which the difference between each pair to be compared was greater than three SD and, in addition, if that condition was repeated in more than one type of response. Thus, two cases were excluded. Meanwhile, the normality analyses were carried out using a Q-Q normality graph and we determined that even though for the omitted answers the distribution moved slightly away from that expected, this was minor and did not influence the type of analysis to be performed.

When comparing the number of correct answers, we observed that the visual test produced 7.5 more correct answers than the auditory version for the same subjects (95% CI [5.66-9.40]). On the other hand, the reaction times when the response is correct are significantly lower ($t(126) = 14.04$, $p < .0005$) in the case of the auditory version of the test, reaching an average of 529.14 ms, while for the visual version it is 736.56 ms, so the difference is 207.41 ms (95% CI [178.18-236.64])

As regards the comparison of the number of incorrect answers—and in the opposite direction to what occurs with the correct answers—there are more incorrect answers for the auditory version, with a difference in the average of 7.85 responses (95% CI [6.43-9.26]), which is statistically significant ($t(135) = 10.98$, $p < .0005$). For the reaction time, in the case of the incorrect responses, the average for the visual version is 527.27 ms, while for the auditory version it is 464.38 ms. Regarding the reaction times, the auditory test again shows a significantly lower average time when the incorrect answers are compared ($t(113) = 3.81$, $p < .0005$), with a difference of 82.89 ms between them (95% CI [39.76-126.02]).

Finally, the omitted responses can only be analyzed by their frequency for the two test versions, since, by definition, the omitted responses are those that exceed the response time of 1,000 ms or are under 200 ms, so they are not recorded. In this case, the number of omitted responses does not differ between the two modalities ($t(135) = 0.26$, $p = 0.80$). The difference is 0.32 omitted responses between the visual and auditory versions (95% CI [-2.11-2.74]).

For the visual test, the difference between the average reaction times of the correct and incorrect responses is 166.30 ms (95% CI [130.53- 202.07]), which is a statistically significant difference ($t(123) = 9.20$, $p < .0005$). Likewise, the average difference in the average reaction time for the correct and incorrect responses for the auditory version of the test is 60.75 ms; 95% CI [29.58-91.93], which is statistically significant ($t(127) = 3.86$, $p < .0005$).

Similarly, the difference in the average reaction times for the correct and incorrect responses for the auditory version is 60.75 ms; 95% CI [29.58-91.93], which is statistically significant ($t(127) = 3.86$, $p < .0005$).

As we can see in Figure 2, there is the same trend in the two tests. On the one hand, students with TD show a better performance on the Digit Retention test and on the auditory version of the C&D test. The tests do not assess exactly the same skills, but the respective performances are related and both discriminate in the same direction between the two groups assessed. The variance obtained in C&D-A with a standard difference in score of 0.50 (95% CI [0.06-0.94]) is greater than that in Digit Retention, which is 0.18 (95% CI [-0.24-0.60]) in the same type of score. C&D-A shows significant differences between the group that has VI and the group with TD ($t(157) = 2.24$, $p = 0.03$). However, for the trend in which the group with TD obtains a higher score than the population with VI for the Digit Retention test, this difference is not statistically significant ($t(144) = 0.86$, $p = 0.39$).

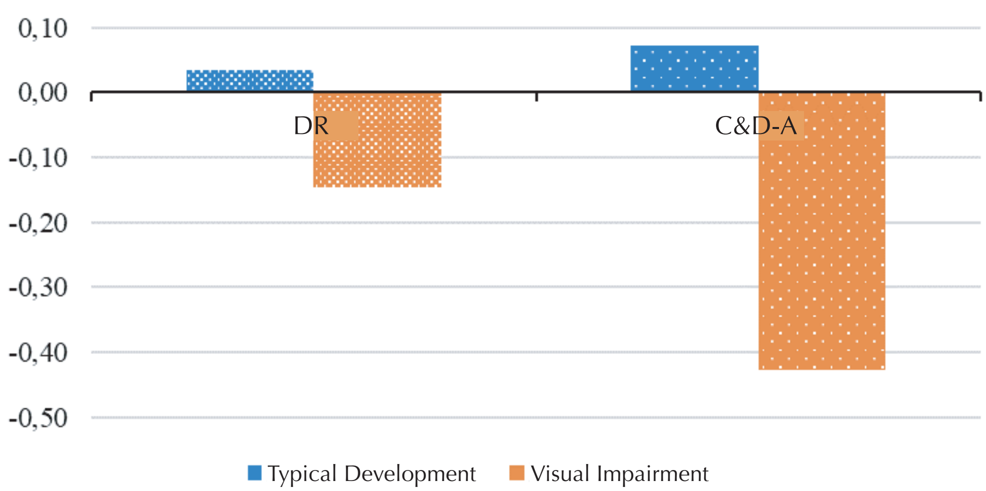

Figure 2. Comparison of scores on Digit Retention and C&D-A, according to disability.
Note: Average on score Z, for students with TD and students with VI; DR = Digit Retention; C&D-A= C&D-Auditory.
Source: Prepared by the authors.

In order to establish whether the differences in the scores are seen in all phases of the test, we compared the results of both populations for each of the stages and the performance by phase in the visual version of the test for students with TD. Figure 3 shows the proportion of correct to incorrect responses in each of the phases, which is reported as an index that can be comparable between all phases.

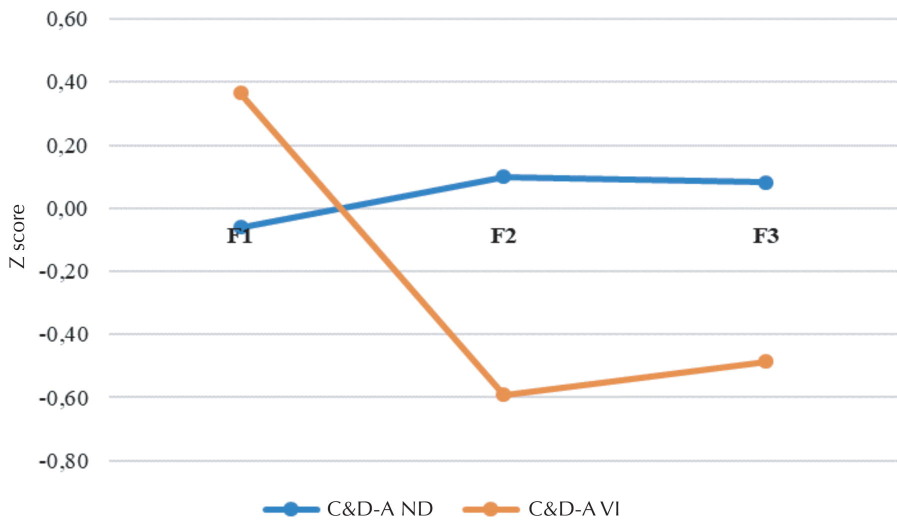

Figure 3. C&D-Auditory for phase of students with VI and TD.
Note: Z-score performance in each phase of the C&D tests for students with TD and students with VI; C&D-A ND = C&D-Auditory students with no disabilities; C&D-A VI = C&D-Auditory students with visual impairment; F1 = Phase 1; F2 = Phase 2; F3 = Phase 3.
Source: Prepared by the authors.

The analyses show that for all phases the difference between the population with and without VI is not statistically significant: for Phase 1, there is an average difference of 1.18 more correct responses than for students with VI ($t(24) = -1.74$, $p = 0.10$). In Phase 2, students with VI perform slightly better—on average 0.11 more correct than incorrect responses—than their peers without VI, even though this difference is again not significant ($t(25.18) = -0.28$, $p = 0.78$). Finally, in Phase 3, the difference is reversed, being slightly greater for students with TD, which produce an average of 0.13 more correct responses than students with VI, which once again is not statistically significant ($t(159) = 0.54$, $p = 0.60$).

Finally, performance was assessed by stage of the adapted test, according to the type of disability. As can be seen in Figure 3, students with VI obtained 0.4 more points on the Z score in Phase 1. However, this difference is not statistically significant ($t(159) = -1.91$, $p = 0.06$). For Phase 2, the results are reversed and the ND students obtain 0.6 points more than those with VI ($t(24.91) = 2.26$, $p = 0.03$). In Phase 3, this trend is maintained and ND students obtain 0.57 points more than the other group ($t(159) = 2.56$, $p = 0.01$).

Discussion

To answer the question of whether the results of the auditory and visual versions of the C&D test are equivalent for students with TD, the results indicate that, according to the frequency of correct, incorrect, and omitted responses, the auditory version seems to be more difficult than the visual version. Likewise, the reaction times for the correct responses in both test versions significantly exceed those for the incorrect responses, a situation that has been reported in the literature as evidence of the cognitive cost that is particularly represented by inhibition as a component of EF (Davidson et al., 2006; Diamond, 2013; Diamond et al., 2007b; Draheim, Mashburn, Martin, & Engle, 2019). Therefore, the fact that this phenomenon is replicated tells us about the validity of both versions of the test. These results could indicate that the test requires greater cognitive resources in the auditory modality versus the visual modality. Therefore, it is not possible to consider the two versions as being equivalent or interchangeable. However, the fact that the same exercise aimed at measuring EF is more difficult if measured with an auditory modality than a visual one—regardless of whether the population has TD or VI—could make us consider initial development of the EF that allow tasks associated with the visual to be performed and subsequent development of the EF linked to tasks of an auditory type, which are probably more complex, given their cognitive load.

In order to establish whether the auditory version of the test is adequate to assess EF in children with VI, it is not possible to directly compare the scores or proportion of correct versus incorrect responses obtained by the subjects who have TD, due to the lack of previous studies on this matter. To overcome this difficulty and establish equivalences in performance that would allow us to make comparisons, we analyzed the performance of students with VI and TD in the Digit Retention test. This test primarily assesses auditory working memory, a skill highly used in C&D, but not the other two components of the EF. Even so, it was postulated that the level reached in the Digit Retention test can act as a compound variable and serves as an external measure of reference. In this sense, this allowed us to elucidate by using a standardized test if the population with TD has a different performance to the population with VI and if the difference is replicated in the new instrument. Specifically, in the Digit Retention test we saw that students with TD obtain better scores than those with VI and although this difference is not significant it is useful to establish that the C&D-A test discriminates in the same direction, this time with significant statistically differences in favor of students with TD.

Finally, we sought to establish whether the difference found in terms of performance between students with VI and TD occurs specifically in one or more stages of the test, as this would indicate trends in cognitive skills associated with each phase. The results suggest that the two groups perform at the same level in Phase 1—as indicated by Diamond et al. (2007a)—generating minimum demands of EF and assessing auditory attention span and short-term memory. The results for Phase 1 are supported by the findings by Pring (2008), who mentions how individuals with VI show performances equivalent and sometimes superior to people with TD in some memory measurements, specifically those of the auditory type (like the one that Phase 1 assesses). The author justifies this phenomenon based on the theory of focusing cognitive resources, which would be greater for those who have VI, concluding that this greater effort in attention entails better retention of the material, which is reflected in advantages on tests that assess short-term memory.

It is understood that Phase 1 serves to exert a primacy effect for Phase 2 (or inconsistent), in which inhibitory control is required—which is not present in Phase 1—and that materializes in the inhibition of the tendency to press the button on the same side. That is, when the cognitive system is minimally overloaded—as in Phase 1—students with VI perform at the same level as those with TD. However, when the cognitive demands increase, students with TD outperform those with VI. As Ely, Meadan-Kaplansky, and Ostrosky (2017) state, the differences in the results of tasks that require divergent thinking (that is to say of EF) seem to mature later in children with VI compared to those with TD, which would explain the results obtained in Phases 2 and 3 of C&D-A. Likewise, Heyl and Hintermair (2018) found results that indicate the same trend as those obtained in this study, but in 12-year-old students and assessed using a questionnaire applied to educators, which indicates that C&D-A discriminates in the same way as the tests applied previously.

The differences in the results of the different phases of C&D-A obtained by the groups with TD and VI could also suggest that, in the case of inhibitory control and cognitive flexibility, their greater cognitive load produces differences in the results between the two populations. However, in terms of working memory, there were no significant differences in inhibitory control and cognitive flexibility with respect to working memory.

Along these lines, based on the fact that the differences in performance between children with VI versus those with TD on the Digit Retention test are not significant, as well as that for the first phase of the adapted C&D test there are no performance differences between the two groups, this could reinforce the idea that, in the case of working memory—both for the auditory and visual modalities—it could be an equally effective means of assessment. On the other hand, the fact that in the following two phases, in which inhibitory control and cognitive flexibility are measured, the performance of children with VI is always lower could suggest that the development of these functions could be affected by the test version through which these functions are being put into practice. Similarly, the fact that the test adapted to the auditory modality is more difficult for the children, regardless of whether they have TD or VI, suggests even more directly that the problem associated with the development of these EF seems to be more linked to the modality through which tasks that require EF (auditory or visual) are carried out.

Conclusions

Going beyond the differences found between the two populations studied and the modality in which this assessment is presented, we conclude that there is sufficient evidence to consider the auditory version of the C&D test a valid instrument to assess EF in students who have TD as well as those who have VI. We believe that one of its weaknesses is that this is clearly more difficult than the standardized version, so we propose that this study be replicated in the future with older subjects.

The above acquires particular relevance at a time when, although the development of EF has been shown to predict a series of auspicious results in the life of the individual, we have still made progress in the creation of instruments that allow the development of EF to be measured and promoted in people with VI.

In this vein, the fact that the auditory version of the C&D test is considered a valid instrument to measure EF in the population with LV could allow us to identify cases in which their development is at risk and, therefore, to make appropriate interventions to prevent this group from being at a disadvantage.

It is important to consider that the creation of effective strategies that enable the development of EF in the population with VI necessarily implies expanding the currently limited field of research related to the interference of the different modalities (auditory and non-auditory) in the development of EF (Bathelt et al., 2018). Under this same criterion, the C&D auditory version also acquires relevance as an instrument that could contribute—along with other tools such as Digit Retention—to the production of evidence on the influence that vision or the lack of it has on the development of the EF.

In accordance with the latter, we can see how the different results (differences in difficulty in the auditory and visual modality, differences in the different stages in the auditory modality for children with VI and TD) lead to new questions, mainly related to the possibility of using the auditory version of the test as a continuation of the visual version and how to create an auditory-type instrument for populations with VI, but in earlier stages of development.

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