Heliyon 6 (2020) e05585

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Executive function in down syndrome children in Bogotá, Colombia

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ARTICLE INFO

Keywords:
Executive function
Down syndrome
Children
BRIEF-P
Battelle behavioral phenotype
Behavioral neuroscience
Cognition
Emotion
Behavioral medicine
Pediatrics

ABSTRACT

The study aim was to characterize executive function in 114 children with Down syndrome from a reference institution in Bogotá, Colombia. Children were screened with the Battelle Developmental Inventory to establish their developmental age. Eighty children with an equivalent mental age of 2–5.11 years were allocated to groups of 20 according to their mental age. Parents and teachers then completed the Behavior Rating Inventory of Executive Function-Preschool Version. We found a high variability and a low correlation between parent and teacher ratings. In general, children showed a specific profile characterized by weakness in the domains of working memory, shifting, planning, and organization, and strengths in the emotional control domain. These findings indicate a characteristic pattern of executive function in children with Down syndrome. This profile could form the basis for the planning of clinical assessment programs.

1. Introduction

Down syndrome (DS) is the most common genetic condition associated with intellectual disability and has an estimated incidence of 1/691 live births worldwide (Parker et al., 2010). Genetic imbalance, variation, and epigenetic factors influence the phenotypic expression of DS (Jiang et al., 2013; Letourneau et al., 2014; Lott and Dierssen, 2010). Although DS can result in cognitive variability and does not affect all individuals in the same way, it has been associated with a specific cognitive phenotype (Chapman and Hesketh, 2000) characterized by delays in expressive language, motor development, and verbal short-term and working memory (Lee et al., 2011, 2015; Nadel, 2003).

Recently, research has increased on executive function (EF) as a measure of overall performance, academic achievement, and adaptive functioning in children and adults with DS (Daunhauer et al., 2014). EF is an umbrella term that encompasses a range of processes, including planning, working memory, inhibition and flexibility, and is mediated mostly by the frontal lobes (Goldstein et al., 2014). Several authors classify EF in terms of "hot" or "cool" in relation to the complexity degree or to the emotional and affective engagement of the task performed (Metcalfe and Mischel, 1999; Zelazo and Müller, 2002). Those abilities required to follow instructions, understanding rules according to developmental age, and problem solving strategies are known as cool EF. Whereas, hot EFs involve abilities related to affective and emotional control. Both hot and cool EF allow individuals to respond adaptively to different stimuli and anticipate future goals and are therefore essential for everyday activities, social interactions, and academic success (Anderson, 2002). However, not all authors have found consistent results. For example, a study found that cool EF were positively correlated to mathematical achievement and learning related behaviors, but no association was identified regarding reading performance (Brock et al., 2009). The study of brain lesions and the use of functional neuroimaging with the performance of specific tasks have located structures related to cognitive function. The prefrontal cortex is the main region associated with EFs and drives multiple processes including cognition, behavior, language, and reasoning. Hot EFs, such as emotional control and inhibition, are linked to the ventromedial prefrontal cortex (VMPFC), which is associated with affection and motivation. The VMPFC connects to the hypothalamus, thalamus, and limbic structures that drive the effective evaluation of behavior. Cool EFs, such as working memory, plan and organize, and cognitive flexibility, are related to the dorsolateral prefrontal cortex (DLPFC), which is stimulated by cognitive demands and selective information related to memory tasks, and retains operational memory to plan appropriate actions via specific objectives. The DLPFC connects structures of the basal ganglia with the cortices of the occipital, parietal, and temporal lobes (Fuster, 2002).

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https://doi.org/10.1016/j.heliyon.2020.e05585
Received 19 February 2020; Received in revised form 1 June 2020; Accepted 19 November 2020

In children with DS, there are anatomic differences from the first months of life in regions often associated with EF. Notable changes are the reduction in the size of the frontal lobes, brainstem, and cerebellum; the narrowing of the superior temporal gyrus; late demyelination; and a 20%–50% reduction in cortical neurons (Liogier d'Ardhuy et al., 2015; Schmidt-Sidor et al., 1990).

EFs are assessed using a wide range of tests according to the skills measured. To evaluate planning and organization frequently used tests include London Tower (Unterrainer et al., 2020), Hanoi Tower (Shuai et al., 2017), and Mexico Tower which is specifically designed for neuropsychological evaluation in Latin American children. Digit span subtest and Corsi Block-Tapping Test are used to evaluate working memory, Stroop test for inhibition, and Trail Making Tests and Wisconsin Card Sorting Test for cognitive flexibility (Rabinovici et al., 2015) (Shuai et al., 2017). For children, the most commonly used scales are the Leiter international performance scale, the School Function Assessment, the Pediatric Evaluation Of Disability Inventory, and the Behavior Rating Inventory of Executive Function-Preschool Version (BRIEF-P) (Coster et al., 1998; Haley et al., 1992; Roid et al., 1997; Sherman and Brooks, 2010). Regarding EF evaluation in patients with DS, different assessment tools have been standardized for intellectual disability and DS specifically. For example, London Tower, NIH Toolbox cognitive battery for intellectual disability (Shields et al., 2020) and the Stroop and Digit Span tasks (Sabat et al., 2020). However, Daunhauer et al. (2014) suggests that population rating-based tests are superior to tasks performed in the laboratory because they predict adaptive function better. Among these, the BRIEF-P has demonstrated its utility in the characterization of EF in a population with DS (Gioia et al., 2003). This scale provides an accurate assessment of individuals' performance on different EF-related tasks and has therefore been used in several studies to demonstrate patterns of strengths and weaknesses in DS (Amado et al., 2016; Daunhauer et al., 2014; Daunhauer, Gerlach-McDonald, Will and Fidler, 2017; Lee et al., 2011; Loveall et al., 2017; Pritchard et al., 2015; Wilde and Oliver, 2017). However, such patterns can vary depending on who conducts the evaluation, whether it is the teachers or the children's parents. Comparing parent versus teacher BRIEF-P reports allows a better approach to the children's overall performance in EF tasks as both represent different contexts in which these are developed. Tamm and Peugh (2019) established that children in school face higher demands for EF behaviors which, in addition to a structured classroom environment, facilitates evaluation of EF functions in this setting. Furthermore, teacher evaluation can be influenced by the comparison between the subjects and their classmates, providing teachers with a better sense of normative behavior (Tamm and Peugh, 2019).

Previous study findings have shown that children and adolescents with DS have an appropriate performance according to their developmental age in EF domains related to affection, visual processing, receptive language and social behavior (Di Nuovo and Buono, 2011; Dieleman et al., 2018; Fidler, 2005; Marchal et al., 2016). On the other hand, parents and teachers of children and adolescents with DS report a perception of underperformance in working memory and in domains like inhibition, shifting and attention (Amadó et al., 2016; Borella et al., 2013; Daunhauer and Fidler, 2011; Daunhauer et al., 2014; Daunhauer, Gerlach-McDonald, Will and Fidler, 2017; Esbensen et al., 2019; Lee et al., 2011).

It is unclear whether social, ethnic, and cultural aspects are associated with differences in performance. To our knowledge there have been no studies on EF performance in the DS population in Bogotá or other cities in Colombia. Such information could elucidate the strengths and weaknesses in the daily performance of children and adolescents with DS and would allow parents and teachers to better stimulate the development of EF.

This investigation aimed to use the BRIEF-P questionnaire to identify the EF profile in children and adolescents with DS aged 4–17 years receiving therapy at a reference institution in Bogotá, Colombia. The main questions to analyze are how working memory, shifting, inhibition, attention, adaptive behaviors and planning and organize executive functions perform in Down syndrome according to their developmental age. Additionally, on the basis of previous study findings (Daunhauer et al., 2014; Esbensen et al., 2019; Lee et al., 2011), we hypothesized that there would be differences in the overall perception of parents and teachers evidenced by a stronger clinical concern for the Global Executive Composite in teacher reports.

2. Methods

2.1. Population

Children and adolescents with a chronological age of 4–17.11 years were selected from the *Corporación Síndrome de Down* (CSD) in Bogotá, Colombia, between January and July 2019. The CSD institution offers multidisciplinary therapy to 400 children and adolescents with DS. Most of the children assist to the institution since the first year of age and are included in specific programs for DS with professionals with great experience in education and rehabilitation.

Children and adolescents with DS, experience delays in the acquisition of developmental skills compared with typically developing children. Nevertheless, they have a progressive profile of maturation of developmental items. Therefore, it is important to evaluate children with DS according to their developmental age (DA) skills with parameters taken from the typical population, instead of their chronological age. Therefore, the Battelle Developmental Inventory, 2nd Edition, Screening Test (BDI-2ST) was used to establish children's DA.

EF was evaluated in a sample of 80 children; the sample size was calculated with a confidence level and power of 99%. The inclusion criteria were DS diagnosis confirmed by medical record or genetic test and parents' written consent to participate. Participants were excluded if they had a history of traumatic head injury or psychiatric disorders.

All potential candidates in the institution were randomized prior to Battelle assessment. Once DA was established, children and adolescents were allocated to the following age groups until each group had 20 children: 2–2.11 years (2y-DA), 3–3.11 years (3y-DA), 4–4.11 years (4y-DA), and 5–5.11 years (5y-DA). This made the sample equitable and helped to match children with the BRIEF-P normative sample age of 2–5.11 years.

Two experienced clinicians completed all evaluations at the CSD institution. Appointments with parents and therapists were scheduled to administer the clinical BRIEF-P questionnaire, and time with the children and adolescents was scheduled to complete the BDI-2ST. Relevant clinical and demographic information was obtained using a parental questionnaire.

2.2. Assessment tools

2.2.1. Battelle Developmental Inventory, 2nd Edition, Screening Test (BDI-2ST)

The BDI-2ST assesses developmental skills in typically developing children from birth to 7 years 11 months using observation and an informant report. The BDI-2ST comprises 100 items grouped into five domains: adaptive, personal/social, communication, motor, and cognitive. Items are answered on a three-point scale: 0, "no ability in this skill"; 1, "emerging ability"; and 2, "ability in this skill." Each domain has its own score, and scores on the five domains are summed to obtain a total score that is matched with the DA. This test has an acceptable level of reliability and excellent internal consistency, as well as a good level of validity (Bliss, 2007; Matson et al., 2010).

2.2.2. Behavior Rating Inventory of Executive Function-Preschool Version (BRIEF-P)

The BRIEF-P is a standardized questionnaire that measures the range of EF in children aged 2–5.11 years within the context of their everyday environments (home and preschool). The questionnaire contains 63 items on five non-overlapping scales: Inhibit, Shift, Emotional Control, Working Memory, and Plan/Organize. The combination of subscale scores creates a Global Executive Composite, and three composite indexes: the Inhibitory Self-Control Index that comprises the Inhibit and Emotional Control subscales, the Flexibility Index that comprises the Shift and Emotional Control subscales, and the Emergent Metacognition Index that results from the Working Memory and Plan/Organize subscale scores. Items are presented on a standardized questionnaire and both parents and teachers complete the items in relation to their children's everyday behavior (Gioia et al., 2003; Gioia et al., 2016).

According to Gioia et al., the internal consistency of the test (as measured by Cronbach's alpha) is high for parents (r = 0.8–0.9) and very high for teachers (r = 0.9–0.97) (Gioia et al., 2003). Furthermore, Bausela-Herreras and Luque-Cuenca validated a Spanish version of the test and obtained a reliability coefficient higher than 0.90 for both parents and teachers. To assess validity, they conducted a principal component analysis and obtained three factors that explained more than 91% of the variance in a sample of parents and teachers (Bausela-Herreras and Luque-Cuenca, 2017).

2.3. Data analysis

Microsoft Excel was used to record the data, and IBM SPSS Version 25 (IBM Corp., Armonk, NY, USA) was used to perform the statistical analysis. Qualitative variables were analyzed using frequencies, absolute values, and percentages, and measures of central tendency and dispersion were used to analyze quantitative variables. T-scores were used to provide information about the BRIEF-P scores of the children and adolescents in all groups in relation to the standardized BRIEF-P scores for age and sex. To evaluate differences between parents and teachers T scores a t-test or Wilcoxon signed-ranked test was performed for all dependent variables according to their distribution. Bivariate statistical analysis was performed using chi-square and Fisher's test to examine the associations between composite indexes and demographic variables including mother and father education, socio-economic level, sex, prematurity, low weight at birth, presence of cardiopathy, hypothyroidism, number of sibling and if children and adolescents were in school. Higher T-scores with a cut point above 65 indicate significant clinical impairment of the assessed executive functions. We also evaluated the differences of these results between teachers and parents by a McNemmar Test and the concordance or the two samples by a Kappa test. P-values < 0.05 were considered statistically significant.

3. Ethical considerations

Ethical principles were established according to the Declaration of Helsinki and local laws (Resolution 008430/1993). Data were maintained according to the Habeas Data Law (Statutory law 1581/2012). The university ethics committee approved the study. All the children's parents gave their written consent.

4. Results

To establish their DA, 114 children and adolescents with DS completed the Battelle test. After allocation, 80 participated in the evaluation of EF. The mean chronological age of the evaluated children and adolescents was 11.3 years (standard deviation [SD] ±3.04; range 5.3–17.1), and 37 (46.25%) were female. Parents' educational level and socioeconomic status according to local classification were also assessed.

The mean chronological age of the children and adolescents allocated to the four DA groups and assessed using the BDI-2ST was as follows: 2y-DA group = 7.74 years (SD ± 2.35), 3y-DA group = 11.83 years (SD ± 2.20), 4y-DA group = 12.49 years (SD ± 2.61), and 5y-DA group = 13.2 years (SD ± 1.50), as can be seen in Figure 1.

Both the teachers and parents' BRIEF-P ratings were evaluated for validity, inconsistency, and negativity. Only four cases were positive for inconsistency on the parent tests, and all those parents were asked to review their answers and correct them. The overall results are shown as medians and the 25 and 75 T-score percentiles, taking into account that subtests did not meet the normal distribution on the Kolmogorov–Smirnov test. As can be seen in Table 1, there are significant differences in parents and teachers median T-scores. Furthermore, there was substantial variation statistically significant between the ratings of parents and teachers and small concordance between them when evaluated with the cut point above 65 as can be seen in Figure 2. As a result, parent and teacher reports were analyzed separately.

4.1. Parent reports

The parent reports showed that children and adolescents with DS had a working memory median T-score of 66, suggesting significant clinical impairment. Subsequently, with a result slightly below the cutoff point of 65, both Shift and Plan/Organize had median scores of 59. The medians of the three indexes were Emergent Metacognition Index = 65, Flexibility Index = 56, and Inhibitory Self-Control Index = 53, and the Global Executive Composite median was 59, as shown in Table 1.

Analysis using percentages showed that 88.7% and 86.3% of children and adolescents performed within the range of typical development (T-score <65) on Inhibit and Emotional Control, respectively, demonstrating that these two domains demonstrated the greatest EF strengths of children and adolescents with DS. They also showed a good level of performance on Plan/Organize and Shift (71.3% and 67.5%, respectively). The index with the best performance was Inhibitory Self-Control Index, on which 88.8% of children and adolescents had a T-score <65, followed by Flexibility Index with 77.5% (within the range of typical development). Conversely, more than half the children and adolescents demonstrated clinical impairment scores on Working Memory and Emergent Metacognition Index (55% and 51.2%, respectively), which indicates greater difficulty in performing related tasks. Only one-quarter of children and adolescents (25%) showed difficulties on EF, considering the Global Executive Composite score.

The bivariate analysis between abnormal composite indexes and demographic variables showed the following associations: low maternal education and Emergent Metacognition Index (odds ratio [OR] = 3.48; 95% confidence interval [CI], 1.33–9.07), low paternal education and Emergent Metacognition Index (OR = 3.1; 95% CI, 1.18–8.15), and non-attendance at school and Inhibit (p = 0.011) and Inhibitory Self-Control Index (p = 0.04). Assessment of the impact of these two last associations was not possible because most of the children and adolescents were attending school. There were no differences between sex and socioeconomic status on any of the abnormal composite indexes.

4.2. Teacher reports

Data analysis of the teacher ratings showed that children and adolescents had greater difficulty with Flexibility, Working Memory, and Plan/Organize than with Inhibit and Emotional Control (the latter two did not exceed the cutoff point). The median values were as follows: Shift = 69, Working Memory = 67, Plan/Organize = 66, Inhibit = 58, and Emotional Control = 57. The medians of the three indexes were as follows: Emergent Metacognition Index = 66, Flexibility Index = 64, Inhibitory Self-Control Index = 58.6, and Global Executive Composite = 66, as shown in Table 1. This global index showed a general difficulty in EFs in these children.

Data analysis according to T-scores, and their clinical significance, showed that 62.5% of the children and adolescents had clinical impairment in Working Memory, 56.2% in Shift, and 53.7% in Plan/Organize. In contrast, they performed correctly for their DA on Emotional Control and Inhibit (61.3% and 65%, respectively).

A clinically significant low performance was observed for 62.5% of children and adolescents on the Emergent Metacognition Index. A total of 47.5% and 36.3%, respectively, displayed clinical impairment on the

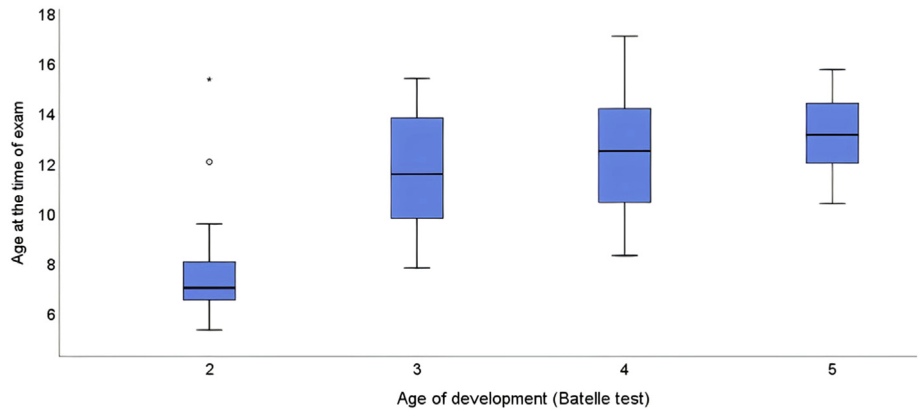

Figure 1. Correlation between chronological age and developmental age (BDI-2ST). BDI-2ST: Battelle Developmental Inventory, 2nd Edition, Screening Test.

Table 1. BRIEF-P Median T Scores (25 and 75 percentil) by teachers and parents and by DA groups.

BRIEF-P Domain	Parents					Teachers				
	TOTAL	2 years	3 years	4 years	5 years	TOTAL	2 years	3 years	4 years	5 years
Inhibit	54 (50–62)	55	53	52	52	58 (48–68)**	55*	53	52	52
Shift	59 (49–68)	59	58	61	59	69 (50–78)	74**	70*	64	65
Emotional control	52 (44–59)	56	48	53	45	57 (45–70)	66	58*	58	55**
Working Memory	66 (59–72)	65	66	65	67	67 (59–75)	76**	67	63	65
Plan/Organize	59 (52–66)	59	59	57	59	66 (56–76)	71**	63	61	66
ISCI	53 (58–59)	57	52	54	50	59 (48–71)	67	58,5*	58	59*
FI	56 (49–63)	59	54	58	53	64 (51–75)	70,5*	65*	63	64**
EMI	65 (57–70)	64	65	62	66	66 (57–74)	74,5**	66	61	67
GEC	59 (56–65)	60	59	59	58	66 (56–77)	77,5**	68	63	67

Comparative analysis between parents and teachers median T scores by DA: *p < .05 Wilcoxon signed-rank test; **p < .005 Wilcoxon signed-rank test.

Flexibility Index. Finally, the Global Executive Composite, which combines all the EF subscale scores, showed clinical impairment in 58.7% of the children.

The bivariate analysis of abnormal composite indexes and demographic variables showed the following associations: low maternal education with Emergent Metacognition Index (OR = 2.95; 95% CI, 1.10–7.89) and with Global Executive Composite (OR = 21.91; 95% CI, 2.71–176.79), low paternal education with Global Executive Composite (OR = 6.30; 95% CI, 1.32–29.91) and with two or more brothers (OR = 2.95; 95% IC, 1.10–7.89). There were no differences in gender and socioeconomic status on any of the abnormal composite indexes.

5. Discussion

The results obtained in this study demonstrate that children and adolescents with DS effectively perform some EF tasks, but have impaired ability in other tasks. Children and adolescents of all age groups experienced the greatest difficulties on Working Memory tasks and showed better performance on emotional control and inhibition tasks.

The scores differed according to whether parents or teachers made the evaluation. Parental educational level showed that children whose parents that only completed primary school had a lower performance on different kinds of skills.

Considering the use of BRIEF-P as the preferred assessment tool for this study, as a standardized scale to evaluate EF in typically developed population, an initial DA was established for DS participants to reduce the existing gap between them and children and adolescents with typical development. Our findings (Figure 1) show that the variability of the DA in children with DS increases along with their chronological age in a pattern similar to that of children with typical development. Such variability explains why the performance of a 6-year-old child with DS was the same as that of a 2-year-old, according to DA, and how a 17-year-old with DS had a DA of 4 years. In addition, the broad age range demonstrated by each group can be explained in terms of the neurological phenotypic variability observed in the DS population; this is a result of genetic expression, associated pathologies, and environmental influences (Chapman et al., 2000; Letourneau and Antonarakis, 2012; Lott, 2012).

In evaluating EFs, we found a high variability and a low correlation between the ratings of parents and teachers on the BRIEF-P test, as evidenced by Global Executive Composite ratings. Parent ratings on this index showed that only 25% of children had difficulties, whereas teacher ratings indicated that 58% of children had difficulties. For this reason, the parent and teacher reports were analyzed separately.

There is compelling evidence from both laboratory and population rating-based tasks for a cognitive phenotype with characteristic areas of relative strength and weakness in EF. The results from this study identified a specific EF profile in children with DS that is consistent with findings from previous studies using rating-based measures, such as the BRIEF-P, as the preferred evaluation method. Regarding the BRIEF-P clinical scales, the present study showed that the most substantial deficits were on the Working Memory domain, according to both parent and teacher ratings (55% and 62.5% of the total evaluated population, respectively). This finding is in accord with previous studies indicating that more than half of evaluated children with DS have the greatest weakness on this domain (Baddeley and Jarrold, 2007; Daunhauer et al., 2014; Loveall et al., 2017).

Substantial deficits were also found on the Shift and Plan/Organize scales according to parent and teacher ratings; however, teacher ratings were higher for both domains. Whereas parents only identified a

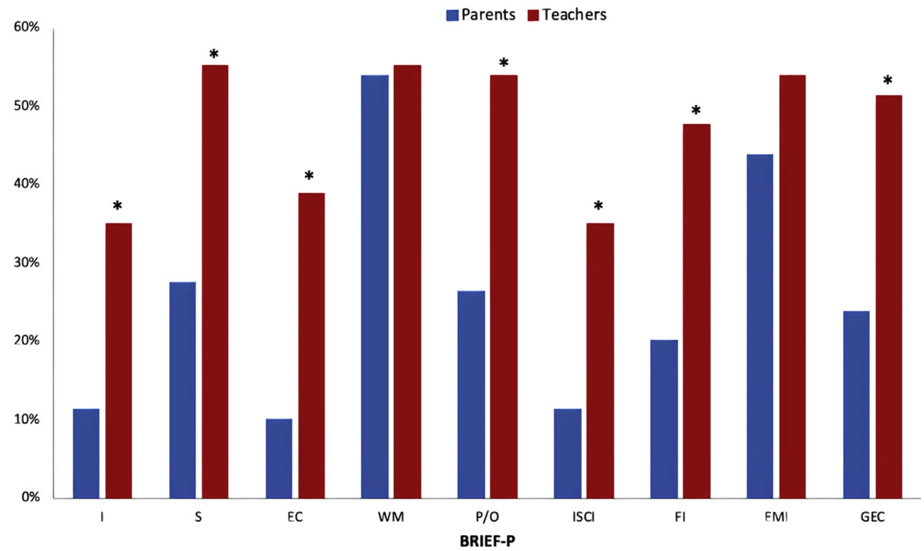

Figure 2. BRIEF-P teacher and parent comparative results – T-scores ≥65. BRIEF-P: Behavior Rating Inventory of Executive Function-Preschool Version. I: Inhibit. S: Shift. EC: Emotional Control. WM: Working Memory. P/O: Plan/Organize. ISCI: Inhibitory Self-Control Index. FI: Flexibility Index. EMI: Emergent Metacognition Index. GEC: Global Executive Composite. *: $p < .05$ (McNemmar Test).

substantial deficit in working memory, teachers reported difficulties in working memory, planning, and shifting, which are all classified as cool EFs (Hongwanishkul et al., 2005).

These findings are also consistent with those of researchers who have described planning as a domain with substantial EF impairment when profiling children with DS (Daunhauer et al., 2014; Lee et al., 2011; Loveall et al., 2017). Although previous studies have not identified shifting as an area of significant impairment, our results showed that teachers, but not parents, identified a relative weakness in shifting. This may be because different skills are required in the two environments, as argued by Esbensen et al. These findings also support the hypothesis of Sabat et al. that greater cognitive skills are required in school owing to the requirement of systematic and constant learning of new concepts and skills. This suggests the need for different EFs such as shifting, compared with more routine and adaptive homework (Esbensen et al., 2019; Sabat et al., 2020).

Consequently, the Emerging Metacognition Index, composed by both working memory and planning, was found to be the most clinically significant index for more than half of the participants, a finding consistent with those of previous investigations (Lee et al., 2011; Loveall et al., 2017).

The contrasting results between teacher and parent reports evidence a different set of adaptive skills needed for each scenario. For instance, children in school are introduced to new concepts with greater frequency than at home, which means EFs such as inhibition and flexibility are further developed in this setting in order to effectively adapt to a changing environment (Sabat et al., 2020). Furthermore, higher demands are expected for children in school regarding activities that involve planning, organizing and self- monitoring (Esbensen et al., 2019). On the other hand, children experience a more predictable and constant routine at home, which means that EFs like inhibition and flexibility are less needed and others like working memory become essential (Sabat et al., 2020). This can explain the differences between parent and teacher reports in EF weaknesses, especially those needed for the understanding of new concepts, as for parents these are far more difficult to perceive at home.

Despite the identified weaknesses in children with DS, our results are highly consistent with those of previous studies that indicate greater strengths in the emotional control domain (Daunhauer et al., 2014; Lee et al., 2011; Loveall et al., 2017). Indeed, although children with DS experience serious challenges in retaining information and anticipating future tasks, they excel at emotion modulation and corresponding behavioral responses, similar to their typically developing mental age-matched peers (Daunhauer et al., 2014).

The results showed that cool EFs were most affected; performance was better on hot EFs, including emotional control and inhibition. This suggests that the neurobiological pathways for cool functions may have greater clinical involvement, and the structures and regions that comprise part of this domain could provide an important research topic for future studies of children with DS (Hongwanishkul et al., 2005; Loveall et al., 2017).

There is currently no standardized test to evaluate EF in a DS population. Such a test is very much needed; however, the BRIEF and BRIEF-P have been used as appropriate psychometric tools to assess the cognitive components of EF in children with DS (Esbensen et al., 2019). Some new tools to measure EF have also been proposed, such as the NIH Toolbox cognitive battery for intellectual disability, which has an excellent feasibility and sensitivity to determine cognitive phenotypes in specific syndromes such as DS (Shields et al., 2020). Additional investigations are needed to develop a more accurate evaluation test for this population. Clinical trials are also needed to establish the utility of interventions for children with DS.

6. Limitations

The tests used in the current study have not been validated for the population of children with DS; thus, the test scores were compared with norms for children with typical development. However, the results are similar to previous studies that evaluated EF in children with DS. Another limitation is that the parent and teacher BRIEF-P ratings used to evaluate EF are subjective measures of children's skills, and therefore caregiver and teacher expectations may have led to response bias.

7. Conclusion

People with intellectual disabilities and DS experience a greater challenge in completing daily tasks and routines, owing to EF impairments that hinder the process of adaptability (Blair and Peters, 2003; Leonard et al., 2002). This study demonstrated the EF characteristics and profile of children with DS. The findings indicate the importance of monitoring the development of these abilities and their characteristics to establish early strategies to improve developmental outcomes. These findings could also inform strategies to allow children with DS to obtain an adequate level of independence, self-care, and social, academic, and cognitive skills (Tarazi et al., 2007).

Declarations

Author contribution statement

Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Julián Manrique-Niño, Andrés Díaz-Forero, Claudia Talero-Gutiérrez: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Alberto Velez-van Meerbeke: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Sofía Ramírez-Guerrero, Gabriela Florez-Esparza: Performed the experiments; Wrote the paper.

Funding statement

This work was supported by Universidad del Rosario.

Data availability statement

Data included in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

The authors thank all the participants and their families who made this research possible. We also thank the Down Syndrome Corporation, its director, and the rehabilitation staff who were trained to collaborate in this study. Finally, we thank the medical student Santiago Ramírez Rodríguez, member of the SemineURos neuroscience research seedbed of the Universidad del Rosario, for his collaboration with data collection. We thank Diane Williams, PhD, from Edanz Group (www.edanzediting.com/ac) for editing a draft of this manuscript.

References

Amado, A., Serrat, E., Valles-Majoral, E., 2016. The role of executive functions in social cognition among children with Down Syndrome: relationship patterns. Front. Psychol. 7, 1363.

Anderson, P., 2002. Assessment and development of executive function (EF) during childhood. Child Neuropsychol. 8 (2), 71–82.

Baddeley, A., Jarrold, C., 2007. Working memory and Down syndrome. J. Intellect. Disabil. Res. 51 (Pt 12), 925–931. JIR979 [pii].

Bausela-Herreras, E., Luque-Cuenca, T., 2017. Evaluación Conductual de la Función Ejecutiva-Versión Infantil (BRIEF-P, versión española): Fiabilidad y validez. Acta de Investigación Psicológica 7 (3), 2811–2822.

Blair, C., Peters, R., 2003. Physiological and neurocognitive correlates of adaptive behavior in preschool among children in Head Start. Dev. Neuropsychol. 24 (1), 479–497.

Test Reviews: Newborg, J. (2005) Bliss, S.L., 2007. Battelle developmental Inventory—Second edition. Itasca, IL: Riverside. J. Psychoeduc. Assess. 25 (4), 409–415.

Borella, E., Carretti, B., Lanfranchi, S., 2013. Inhibitory mechanisms in Down syndrome: is there a specific or general deficit? Res. Dev. Disabil. 34 (1), 65–71.

Brock, L.L., Rimm-Kaufman, S.E., Nathanson, L., Grimm, K.J., 2009. The contributions of 'hot' and 'cool' executive function to children's academic achievement, learning-related behaviors, and engagement in kindergarten. Early Child. Res. Q. 24 (3), 337–349.

Chapman, R.S., Hesketh, L.J., 2000. Behavioral phenotype of individuals with Down syndrome. Ment. Retard. Dev. Disabil. Res. Rev. 6 (2), 84–95.

Chapman, R.S., Seung, H.K., Schwartz, S.E., Bird, E.K., 2000. Predicting language production in children and adolescents with Down syndrome: the role of comprehension. J. Speech Lang. Hear. Res. 43 (2), 340–350.

Coster, W., Deeney, T., Haltiwanger, J., Haley, S., 1998. School Function Assessment (SFA). PsychCorp - Harcourt Assessment, Inc, San Antonio.

Daunhauer, L.A., Fidler, D.J., 2011. The Down syndrome behavioral phenotype: implications for practice and research in occupational therapy. Occup. Ther. Health Care 25 (1), 7–25.

Daunhauer, L.A., Fidler, D.J., Hahn, L., Will, E., Lee, N.R., Hepburn, S., 2014. Profiles of everyday executive functioning in young children with down syndrome. Am. J. Intellect. Dev. Disabil. 119 (4), 303–318.

Daunhauer, L.A., Gerlach-McDonald, B., Will, E., Fidler, D.J., 2017. Performance and ratings based measures of executive function in school-aged children with Down syndrome. Dev. Neuropsychol. 42 (6), 351–368.

Dieleman, L.M., De Pauw, S.S.W., Soenens, B., Van Hove, G., Prinzie, P., 2018. Behavioral problems and psychosocial strengths: unique factors contributing to the behavioral profile of youth with down syndrome. Am. J. Intellect. Dev. Disabil. 123 (3), 212–227.

Di Nuovo, S., Buono, S., 2011. Behavioral phenotypes of genetic syndromes with intellectual disability: comparison of adaptive profiles. Psychiatr. Res. 189 (3), 440–445.

Esbensen, A.J., Hoffman, E.K., Shaffer, R., Chen, E., Patel, L., Jacola, L., 2019. Reliability of informant-report measures of executive functioning in children with down syndrome. Am. J. Intellect. Dev. Disabil. 124 (3), 220–233.

Fidler, D.J., 2005. The emerging down syndrome behavioral phenotype in early childhood: implications for practice. Infants Young Child. 18 (2), 86–103.

Fuster, J.M., 2002. Frontal lobe and cognitive development. J. Neurocytol. 31 (3-5), 373–385.

Gioia, G.A., Espy, K.A., Isquith, P.K., 2003. The Behaviour Rating Inventory of Executive Function-Preschool Version (BRIEF-P). Psychology Assessment Resources, Odessa.

Gioia, G.A., Espy, K.A., Isquith, P.K., 2016. BRIEF-P. Evaluación Conductual de la Función Ejecutiva-Versión Infantil. In: Bausela, E., Luque, T. (Eds.). TEA Ediciones, S. A. U, Madrid.

Goldstein, S., Naglieri, J.A., Princiotta, D., Otero, T.M., 2014. Introduction: a history of executive functioning as a theoretical and clinical construct. In: Goldstein, S., Naglieri, J. (Eds.), Handbook of Executive Functioning. Springer, New York.

Haley, S.M., Coster, W.J., Ludlow, L.H., Haltiwanger, J.T., Andrellos, P., 1992. Pediatric Evaluation of Disability Inventory: Development, Standardization and Administration Manual. Trustees of Boston University, Boston MA.

Hongwanishkul, D., Happaney, K.R., Lee, W.S., Zelazo, P.D., 2005. Assessment of hot and cool executive function in young children: age-related changes and individual differences. Dev. Neuropsychol. 28 (2), 617–644.

Jiang, J., Jing, Y., Cost, G.J., Chiang, J.C., Kolpa, H.J., Cotton, A.M., Lawrence, J.B., 2013. Translating dosage compensation to trisomy 21. Nature 500 (7462), 296–300.

Lee, N.R., Anand, P., Will, E., Adeyemi, E.I., Clasen, L.S., Blumenthal, J.D., Edgin, J.O., 2015. Everyday executive functions in Down syndrome from early childhood to young adulthood: evidence for both unique and shared characteristics compared to youth with sex chromosome trisomy (XXX and XXY). Front. Behav. Neurosci. 9, 264.

Lee, N.R., Fidler, D.J., Blakeley-Smith, A., Daunhauer, L., Robinson, C., Hepburn, S.L., 2011. Caregiver report of executive functioning in a population-based sample of young children with Down syndrome. Am. J. Intellect. Dev. Disabil. 116 (4), 290–304.

Leonard, S., Msall, M., Bower, C., Tremont, M., Leonard, H., 2002. Functional status of school-aged children with Down syndrome. J. Paediatr. Child Health 38 (2), 160–165, 736 [pii].

Letourneau, A., Antonarakis, S.E., 2012. Genomic determinants in the phenotypic variability of Down syndrome. Prog. Brain Res. 197, 15–28.

Letourneau, A., Santoni, F.A., Bonilla, X., Sailani, M.R., Gonzalez, D., Kind, J., Antonarakis, S.E., 2014. Domains of genome-wide gene expression dysregulation in Down's syndrome. Nature 508 (7496), 345–350.

Liogier d'Ardhuy, X., Edgin, J., Bouis, C., de Sola, S., Goeldner, C., Kishnani, P., Khwaja, O., 2015. Assessment of cognitive scales to examine memory, executive function and language in individuals with Down Syndrome: implications of a 6-month observational study. Front. Behav. Neurosci. 9.

Lott, I.T., 2012. Neurological phenotypes for Down syndrome across the life span. Prog. Brain Res. 197, 101–121.

Lott, I.T., Dierssen, M., 2010. Cognitive deficits and associated neurological complications in individuals with Down's syndrome. Lancet Neurol. 9 (6), 623–633.

Loveall, S.J., Conners, F.A., Tungate, A.S., Hahn, L.J., Osso, T.D., 2017. A cross-sectional analysis of executive function in Down syndrome from 2 to 35 years. J. Intellect. Disabil. Res. 61 (9), 877–887.

Marchal, J.P., Maurice-Stam, H., Houtzager, B.A., Rozenburg-Marres Rutgers van, S.L., Oostrom, K.J., Grootenhuis, M., Van Trotsenburg, A.S.P., 2016. Growing up with down syndrome: development from 6 months to 10.7 years. Res. Dev. Disabil. 59, 437–450.

Matson, J.L., Hess, J.A., Sipes, M., Horovitz, M., 2010. Developmental profiles from the Battelle developmental inventory: a comparison of toddlers diagnosed with Down Syndrome, global developmental delay and premature birth. Dev. Neurorehabil. 13 (4), 234–238.

Metcalfe, J., Mischel, W., 1999. A hot/cool-system analysis of delay of gratification: dynamics of willpower. Psychol. Rev. 106 (1), 3–19.

Nadel, L., 2003. Down's syndrome: a genetic disorder in biobehavioral perspective. Gene Brain Behav. 2 (3), 156–166.

Parker, S.E., Mai, C.T., Canfield, M.A., Rickard, R., Wang, Y., Meyer, R.E., National Birth Defects Prevention Network, 2010. Updated National Birth Prevalence estimates for selected birth defects in the United States, 2004-2006. Birth Defects Res A Clin Mol Teratol 88 (12), 1008–1016.

Pritchard, A.E., Kalback, S., McCurdy, M., Capone, G.T., 2015. Executive functions among youth with Down Syndrome and co-existing neurobehavioural disorders. J. Intellect. Disabil. Res. 59 (12), 1130–1141.

Rabinovici, G.D., Stephens, M.L., Possin, K.L., 2015. Executive dysfunction. In: CONTINUUM Lifelong Learning in Neurology.

Roid, G.H., Miller, L.J., Lieter, L.G., 1997. Leiter international performance scale-revised: examiner's manual. In: Roid, G.H., Miller, L.J. (Eds.), Leiter International Performance Scale-Revised. Stoelting, Wood Dale, IL.

Sabat, C., Arango, P., Tassé, M.J., Tenorio, M., 2020. Different abilities needed at home and school: the relation between executive function and adaptive behaviour in adolescents with Down syndrome. Sci. Rep. 10 (1), 1–10.

Schmidt-Sidor, B., Wisniewski, K.E., Shepard, T.H., Sersen, E.A., 1990. Brain growth in Down syndrome subjects 15 to 22 weeks of gestational age and birth to 60 months. Clin. Neuropathol. 9 (4), 181–190.

Sherman, E.M.S., Brooks, B.L., 2010. Behavior rating inventory of executive function - preschool version (BRIEF-P): test review and clinical guidelines for use. Child Neuropsychol. 16 (5), 503–519.

Shields, R.H., Kaat, A.J., McKenzie, F.J., Drayton, A., Sansone, S.M., Coleman, J., Michalak, C., Riley, K., Berry-Kravis, E., Gershon, R.C., Widaman, K.F., Hessl, D., 2020. Validation of the NIH Toolbox cognitive battery in intellectual disability. Neurology 94 (12), e1229–e1240.

Shuai, L., Daley, D., Wang, Y.-F., Zhang, J.-S., Kong, Y.-T., Tan, X., Ji, N., 2017. Executive function training for children with attention deficit hyperactivity disorder. Chinese Med J 130 (5), 549–558.

Tamm, L., Peugh, J., 2019. Concordance of teacher-rated and performance-based measures of executive functioning in preschoolers. Child Neuropsychol. 25 (3), 410–424.

Tarazi, R.A., Mahone, E.M., Zabel, T.A., 2007. Self-care independence in children with neurological disorders: an interactional model of adaptive demands and executive dysfunction. Rehabil. Psychol. 5 (2), 196–205.

Unterrainer, J.M., Rahm, B., Loosli, S.V., Rauh, R., Schumacher, L.V., Biscaldi, M., Kaller, C.P., 2020. Psychometric analyses of the Tower of London planning task reveal high reliability and feasibility in typically developing children and child patients with ASD and ADHD. Child Neuropsychol. 26 (2), 257–273.

Wilde, L., Oliver, C., 2017. Brief report: contrasting profiles of everyday executive functioning in Smith-Magenis syndrome and Down syndrome. J. Autism Dev. Disord. 47 (8), 2602–2609.

Zelazo, P.D., Müller, U., 2002. Executive function in typical and atypical development. In: Goswami, U. (Ed.), Blackwell Handbook of Childhood Cognitive Development. Blackwell Publishing, pp. 445–469.