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The investigation of visuospatial memory and visual attention in children with intellectual disability and Down syndrome

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Abstract

Within cognitive domains, memory and attention are among the most studied processes in people with intellectual disabilities, and studies have documented difficulties or even heterogeneities in their functioning. This study investigates the differences and similarities in the development of visuospatial memory and visual attention between children with typical development and intellectual disabilities of various etiologies. The study involved 106 children: 42 with typical development, 41 with intellectual disabilities, and 23 with Down syndrome. The sex ratio was 1:1, and the mean chronological age across groups was 8.81 years. Tools used included the Visual Information Recall Scale and Scales for Sustained Visual Attention and Visual Attention Span. Findings revealed that children with typical development outperformed the others, with statistically significant differences between groups. Notably, children with intellectual disabilities and Down syndrome also showed significant differences, highlighting the cognitive heterogeneity in intellectual disabilities.

Keywords: visuospatial memory; visual attention; intellectual disability; Down syndrome

1. Introduction

Within cognitive domains, memory and attention are the most investigated processes in people with intellectual disability, and studies have documented severe difficulties in their functioning. For a long time, studies of cognitive development in intellectual disability were inspired by neuropsychological investigations of adults. Cognitive domains were treated as distinct variables, independent of each other, and considered as "impaired" or "intact" in the so-called "static" approach (Germine et al., 2011; Musolino et al., 2010; Vicari et al., 2016). However, research on neurodevelopmental disorders has shown that cognitive levels derive from multiple interactions between domains and that these interactions change over time in a more "dynamic" perspective (Hodapp & Fidler, 2016; Karmiloff-Smith, 2011; Vicari et al., 2016). Following this perspective, brain regions initially compete to process different types of inputs and then become progressively specialized across developmental ages (Karmiloff-Smith, 2012).

Indeed, the construct describing cognitive functioning in individuals with intellectual disability as a global delay shifted to a new understanding of the disability because of atypical development, with some cognitive abilities more proficient than others (Vicari et al., 2016).

Neurodevelopmental disorders with intellectual disability caused by genetic causes, such as Down syndrome, are considered a model to be examined in support of the dynamic cognitive developmental perspective versus the static one. Since gene mutations are expressed in different brain regions, the resulting difficulties affect different cognitive domains, rather than single functions, highlighting specific cognitive and behavioral profiles (Hodapp & Fidler, 2016; Karmiloff-Smith, 2012; Vicari et al., 2016).

Several researchers since the early 1960s (Vicari & Carlesimo, 2002) identified impairments and cognitive difficulties related to the use of memory strategies, working memory (Levorato et al., 2011), attention, and executive functions (Deutsch et al., 2008; Zagaria et al., 2021), multiple deficits (Detterman et al., 1992) or intrinsic motivation difficulties.

Therefore, as significant developments have taken place in these cognitive domains, the present research aimed to further explore the differences and similarities in the development of visuospatial memory and visual attention between children with typical development and intellectual disabilities of different etiologies.

1.1 Memory skills and people with intellectual disabilities

Research data show that memory difficulties are not homogeneous in all people with intellectual disability but are related to the specific etiology of the intellectual disability and do not follow universal and linear developmental patterns (Abbeduto et al., 2006). Specifically, about working memory in children with mild intellectual disability, contemporary research shows a developmental delay in this area, which aligns with their general cognitive ability (Levorato et al., 2011; Schuchardt et al., 2010). Consequently, their performance on the individual components of working memory is approximately at the level of younger children matched for mental age (Schuchardt et al., 2010; Van der Molen et al., 2009). It should be noted, of course, that children with mild intellectual disabilities show great heterogeneity in specific areas regarding their performance on working memory tasks (Oi et al., 2018; Van der Molen et al., 2007), which may be related to specific "structural" impairments that affect the storage of verbal and visuospatial information (Ferretti, 2019; Jarrold & Towse, 2006).

At the same time, visuospatial memory (memory of position in space) is a process that requires mental effort and not simply an automated encoding of information. Visuospatial memory is also affected by other parameters, such as experience and age (Alevriadou & Tsakiridou, 2010; Bray et al., 1994; Dulaney et al., 1996; Giaouri, 2010). It seems, then, that children's performance on visuospatial tasks is affected by processes (e.g., comparing positions in space, visual or verbal recall of each element separately) that require effective strategies, necessary for the encoding and recall of visuospatial information.

In everyday life, it seems that people with typical development make use of "external" mnemonic aids when the situation allows it (e.g., placing things in a certain place to remember where they are, writing notes to remember something, asking others for help to remember something, etc.). The use of these strategies may be the evolutionary precursor to "internal" (verbal) strategies. However, as typically developing children grow older, in addition to the "external" strategies, they also use verbal encoding, i.e., a symbolic verbal code, which puts them at an advantage over children with intellectual disability, who have difficulty using verbal strategies. Thus, whereas before age 7, typically developing children do not use verbal strategies to encode pictures, after this age, verbal encoding is used more frequently, supplementing rather than replacing analogical pictorial encoding in working memory (Cowan & Kail, 1996). In contrast, children with intellectual disability primarily encode pictures analogically, preserving the perceptual features of the physical stimuli.

Previously, it was found that children with intellectual disabilities have smaller and less organized knowledge bases than typically developing children, which affects memory function and the strategy that will ultimately be chosen (Ferretti, 1989). In contrast, in more recent research by Cherry (2002) with adults with and without intellectual disabilities, it appeared that both groups were superior in visual figurative encoding over visual verbal encoding, primarily in free recall and recognition tasks. Additionally, people with intellectual disabilities were able to use nonverbal encoding to enhance long-term retention of information as effectively as people with average normal intelligence (Henry et al., 2012; Poloczek et al., 2019).

However, other researchers (Agran et al., 2005; Dermitzaki et al., 2008) demonstrate that when instructions to solve a cognitive problem aim at self-regulation of the use of strategies by children with intellectual disability, then their performance and motivation improve (Alevriadou & Giaouri, 2009). The differences mainly in the memory profile described in people with intellectual disabilities reflect the differences in the rate of maturation of different brain networks, with some regions showing more typical development in structure and connectivity, while others are characterized by more maturational disturbances (Vicari et al., 2016). Nevertheless, the brain networks specifically involved in the memory of people with intellectual disabilities are still subject to further investigation, mainly studying neuroimaging memory functions in people with intellectual disabilities of genetic origin, such as Down syndrome. More specifically, genetic syndromes associated with intellectual disability present different memory capacities and weaknesses (Vicari et al., 2016). Thus, people with Down syndrome seem to show damage mainly in the phonological loop of working memory, while people with Williams's syndrome in the visuospatial sketchpad (Tungate & Conners, 2021).

According to their cognitive pattern, children with Down syndrome show potential in visual-perceptual ability and visual memory, as opposed to auditory processing and verbal short-term memory (Frenkel & Bourdin, 2009; Levy & Eilam, 2013; Lott, 2012). In this research, findings showed that children and adolescents with Down syndrome performed poorly on auditory-verbal memory tasks compared to children of typical development, matching their mental age. Typically developing children and adolescents with Down syndrome performed better on spatial sequential processing tasks compared to chronologically younger typically developing children and Down syndrome children, but no statistically significant differences emerged between them on visual memory tasks. People with Down syndrome also show a poor ability in terms of short-term phonological storage, which causes greater difficulties and delays, but no qualitative differences in the acquisition of vocabulary in these people than in people with an intellectual disability without Down syndrome (Laws, 2010).

These results support the theoretical view that individuals with Down syndrome do not simply show slower cognitive development compared to typically developing individuals, but that their development is qualitatively different, that is, presenting a unique pattern of cognitive strengths and weaknesses (Nichols et al., 2004).

People with Down syndrome do not seem to present significant difficulties in the perception of space. In previous research, on tasks of processing visual stimuli that require attention and vigilance, people with Down syndrome performed better, compared to other people with intellectual disability, but mental age appeared to affect their performance (Trezise et al., 2008). Also, children with Down syndrome have been found to retain the overall shape of drawings in visual works (Porter & Colthear, 2006), but fail to reproduce the internal type of drawings, appearing “weak” in composition and visual detail (Jones et al., 1995). It thus appears that, although they generally have difficulty concentrating (Pueschel et al., 1991), they nevertheless give weight only to basic information, ignoring details and individual events.

In more recent studies (Carretti et al., 2022; Doerr et al., 2021; Lanfranchi et al., 2015), individuals with Down syndrome were found to perform poorly on spatial simultaneous processing tasks, but not on corresponding sequential processing tasks. The fact that the speed of processing the projects was controlled did not appear to affect the performance of people with Down syndrome. Perhaps the observed difficulty in simultaneous spatial processing was due to the task’s demands for parallel processing of many stimuli at the same time, or to problems with the use and generalization of strategies (Doerr et al., 2021).

Furthermore, in their literature review, Yang et al. (2014) highlighted the presence of strengths and difficulties in spatial skills for people with Down syndrome, with challenges in some areas of visuospatial working memory, spatial visualization, and mental rotation.

1.2 Attention skills and people with intellectual disabilities

The importance of attention has also been investigated for many years in relation to intellectual disability (Deutsch et al., 2008; Djuric-Zdravkovic et al., 2010; Hronis et al., 2017; Zagaria et al., 2021). In particular, the contribution of visual attention has been studied mainly in the field of visual perception (Hollingworth & Henderson, 2002; Spence & Driver, 2004). Those functions of attention that involve the selective and sustained focus and selection of stimuli and properties, as well as the neglect of others, require the involvement of executive control functions (e.g., in blocking the intrusion of irrelevant stimuli and inhibiting inappropriate behaviors) while performing a cognitive task. Visual attention, as a dynamic process, is influenced by the visual recognition of stimuli and the motor demands of tasks and seems to be activated automatically in situations that are mainly meaningful.

Individuals with intellectual disabilities show difficulties in attention to the appropriate dimensions (e.g., color, shape, size, location, weight) of a particular stimulus or object (Westling, 1986). Unlike people without intellectual disabilities, they find it difficult to notice the correct dimensions of objects, which will provide them with the necessary information for a successful distinction between them. The lower their intelligence quotient (IQ) and mental age, the more difficult it is for them to learn to perform discrimination behaviors. And the greater the number of dimensions they must pay attention to, the longer it will take to learn this behavior (Giaouri, 2010).

One way to investigate attention difficulties in people with intellectual disabilities is to study their individual manifestations. Most of the research indicates that the use of selective attention (e.g., the ability to focus attention on a stimulus while intentionally ignoring irrelevant stimuli) differs between individuals with intellectual disabilities and typically developing individuals (Cha & Merrill, 1994). The specific research showed that irrelevant stimuli attract more attention of people with intellectual disabilities compared to the corresponding ones with typical development. Other researchers (Merrill, 2006; Merrill & Taube, 1996) have shown that people with mostly mild intellectual disability do not suppress the effect of distractors, resulting in their reaction to relevant information being slower and more difficult. Although people with intellectual disability and with typical development encode stimuli in a similar way, their differences are a result of the operation of selective attention mechanisms.

Another topic that researchers have dealt with is the distribution of attention and its relationship with intellectual disability. Individuals with intellectual disabilities either have fewer attentional resources than typically developing individuals, or the allocation of existing attentional resources is inefficient for processing information (Merrill & Peacock, 1994). According to the latter interpretation, the degree of task difficulty does not affect the allocation of attention of people with intellectual disabilities, as they show equal attention to both easy and difficult tasks. Conversely, typically developing individuals show greater attention to more difficult tasks (Tomporowski & Tinsley, 1997).

More recent research (Beck et al., 2005; Deutsch et al., 2008; Peltopuro et al., 2014; Simonoff et al., 2007) investigates the relationship of attention deficit hyperactivity disorder (ADHD) with intellectual disability. Interestingly, the finding showed that children with mild intellectual disability show an increased number of attention deficit and hyperactivity symptoms compared to the typical population (Burack et al., 2001; Celeste et al., 2019; Hastings et al., 2005).

2. METHOD

2.1 Participants

The present study involved two clinical groups of participants: 23 children with Down syndrome (DS) and 41 children with nonspecific intellectual disability (ID). The control group consisted of 42 typical development (TD) children. The sex ratio in these three groups was approximately 1:1 (Male:Female). The mean chronological age in DS group (M = 10.18 years, SD = .49) and the mean chronological age in non-specific intellectual disability group (M = 9.77 years, SD = .49) were significantly higher than in the typical development group (M = 6.49 years, SD = .33) ($F(2,103) = 812$, $p < .001$). The participants were matched on overall mental age as revealed by the Wechsler Intelligence Scale for Children (WISC-III-GR) (Georgas et al., 1997). The mean mental age did not differ among the intellectual disability groups (Down syndrome group: M = 6.60 years, SD = .38), intellectual disability group: M = 6.83 years, SD = .60) and the typical development group (M = 6.83 years, SD = .41) ($F(2,103) = 1.98$, $p = .14$, $p > .10$). All children with intellectual disability had mild IQ (IQ: 55-70) and were receiving special education support in inclusive general schools. Furthermore, none of the children in any of the groups had sensory impairments including hearing difficulties and decreased visual acuity. Finally, none of the children were on drugs.

Most studies of people with intellectual disabilities use mental rather than chronological age, as it is the best available option to investigate whether a particular ability is delayed compared to general cognitive ability (Giaouri et al., 2011).

2.2 Materials

A battery of neuropsychological tests was selected and administered, including tests assessing visuospatial memory and visual attention. The Attention and Concentration Detection and Investigation Tool (Simos et al., 2007) was administered to school-aged children (6-10 years old). The test items selected for the present study are the following: Sustained Visual Attention and Span of Visual Attention (positions in space). The total score for this test is equal to the sum of the scores in all movement sequences (maximum = 16).

From the Memory Disorders Screening and Investigation Tool (Bezevegis et al., 2007) the Visual Information Recall Scale and after discontinuance was used. The Visual Information Recall Scale is a visual memory scale that examines a child's ability to recall visuospatial information, without requiring a verbal response or reproduction of geometric designs. Standard scores have been expressed by the test makers on a common metric scale (on all scales the mean is 10 and the standard deviation is 3).

2.3 Procedure

All participants were tested at school. Total administration time varied from participant to participant, but required from 1.30 to 2 h, across two sessions for each participant (during 40–60 min according to the participant's attention). The WISC-III test was administered before the tasks. The session took place in a quiet room. Children's participation was completely voluntary, and their families approved the informed consent process for children's participation in this study.

3. Results

A factorial analysis of variance was used to test whether there were any differences in participants' overall performance on the visual memory test based on standard scores on the visual information recall scale and gender. The comparisons of the group of children with typical development to the groups of children with intellectual disability and Down syndrome, with gender as a secondary factor and as a dependent variable the typical scores on the visual information recall scale, showed that the effect of group was statistically significant [$F(5,100) = 20.75$, $p < .001$], but there was no effect of gender [$F(5,100) = 0.009$, $p = .92$, $p > .10$] and no interaction between group and gender [$F(5,100) = .057$, $p = .94$, $p > .10$].

In the Post Hoc Tests of multiple comparisons based on the LSD criterion of least significant difference, children with typical development performed better with a statistically significant difference ($p < .05$) than the other groups. There were no statistically significant differences between children with intellectual disability and Down syndrome ($p > .05$) (Table 1).

Table 1. Means and standard deviations on the visual information recall scale

	Means		Standard deviations	
Groups	Boys	Girls	Boys	Girls
TD	9.9	10.14	2.23	1.93
ID	7.05	7.09	2.79	2.36
SD	7.33	7.18	1.87	1.88
Total	8.24	8.32	2.71	2.54

To test whether there were differences in participants' overall performance on the visual attention test based on standard scores on the sustained visual attention scale and on the visual attention span scale and gender, two separate factorial analyses of variance were conducted. First, the comparisons of the group of children with typical development to the groups of children with intellectual disability and Down syndrome, with gender as the second factor and the scores of the sustained visual attention scale as the dependent variable, showed that the effect of group was statistically significant [$F(5,100) = 19.47$, $p < .001$], but there was no effect of gender [$F(5,100) = .10$, $p = .74$, $p > .10$] and no interaction between group and gender [$F(5,100) = .32$, $p = .72$, $p > .10$].

In the Post Hoc Tests of multiple comparisons based on the LSD criterion of least significant difference, children with typical development performed better with a statistically significant difference ($p < .05$) than the other groups. Children with intellectual disability performed better with a statistically significant difference ($p < .05$) than children with Down syndrome (Table 2).

Table 2. Means and standard deviations on the sustained visual attention scale

	Means		Standard deviations	
Groups	Boys	Girls	Boys	Girls
TD	42.38	45.71	23.64	22.48
ID	29	26.19	26.53	23.34
SD	10.83	5.9	18.68	2.02
Total	30.18	29.71	26.32	25.16

Also the comparisons of the group of children with typical development to the groups of children with intellectual disability and Down syndrome, with the second factor being gender and with the dependent variable the grades of the scale of visual attention span, showed that the effect of group was statistically significant [$F(5,100) = 28.12$, $p < .001$], but there was no effect of gender [$F(5,100) = .31$, $p = .57$, $p > .10$] and no interaction between group and gender [$F(5,100) = .97$, $p = .37$, $p > .10$].

In the Post Hoc Tests of multiple comparisons based on the LSD criterion of least significant difference, children with typical development performed better with a statistically significant difference ($p < .05$) than the other groups. Children with intellectual disability performed better with a statistically significant difference ($p < .05$) than children with Down syndrome (Table 3).

Table 3. Means and standard deviations on the visual attention span scale

	Means		Standard deviations	
Groups	Boys	Girls	Boys	Girls
TD	49.04	40.71	19.72	26.84
ID	17.75	21.9	18.81	23.53
SD	10	7.27	8.5	7.53
Total	28.39	26.32	24.25	25.87

4. Discussion

Memory and attention functions are particularly impaired in individuals with intellectual disability, and deficits are reported in different memory and attention components. The findings of the present study are consistent with developmental research (Celeste et al., 2019; Karmiloff-Smith, 2012; Vicari et al., 2016; Yang et al., 2014) highlighting the difference in performance between the two groups with intellectual disability of unknown etiology and Down syndrome. This difference in children's performance escapes the more general discussion of the cognitive difficulties of children with intellectual disability, as it highlights the contribution of the cognitive and behavioral phenotype of children with Down syndrome (Lorusso et al., 2007; Nadel, 2006).

Firstly, the results showed that children with typical development performed better than the other groups of intellectual disabilities on the visuospatial memory test. This finding is consistent with previous research (Ferretti, 1989), which found that children with intellectual disabilities have smaller and less organized knowledge bases than typically developing children, which affects memory function and the strategy that will ultimately be chosen. It seems, therefore, that children's performance in these tasks is affected by processes (e.g., comparing positions in space, visual or verbal recall of each item separately) that require more effective strategies necessary for encoding and recalling visuospatial information.

Secondary, the results showed that children with typical development performed better than the other groups of intellectual disabilities on visual attention tasks, but children with intellectual disability performed better than children with Down syndrome. A phenomenon also often observed in people with intellectual disabilities is that they "stare" more often off-task, which affects their performance on vigilance and object assembly tasks. In an earlier review of the literature, Dockrell & McShane (1992) emphasize that the performance of individuals with intellectual disabilities is reduced in complex, high-demand skills, particularly when distraction is present. This is because selective attention contains both facilitation processes towards the chosen target and matching suppression processes towards the inappropriate (distracting) target.

Also, people with Down syndrome show difficulties regarding the functioning of attention, which are found mainly in tasks of sustained attention, but also in complex tasks of selective attention (Grieco et al., 2015). These difficulties persist into adulthood (Kittler et al., 2004).

Therefore, as it emerged from the research, children with Down syndrome show greater difficulties in more complex visuospatial tasks of simultaneous processing and in focusing their attention (Carretti et al., 2022; Caycho et al., 1991; Lanfranchi et al., 2009), than in visual memory abilities in general and because of the involvement of executive functions in which people with Down syndrome show generalized difficulties (Tungate & Conners, 2021).These difficulties are mainly related to the ability to perceive and process the details of visuospatial stimuli (Carretti et al., 2013). Executive and memory functions and especially visuospatial and verbal working memory are particularly impaired in people with intellectual disabilities and seem to be at the "core" of the learning difficulties they face (Alevriadou et al., 2018; Godfrey & Lee, 2018; Jarrold & Brock, 2012; Oi et al., 2018; Spaniol & Danielsson, 2021).

Further studies in groups of people with intellectual disability of different etiologies would be a promising avenue to define the possible neural circuits of atypical development of memory and attention linked to genes. Attempting to decipher the path from genes to the brain and from there to phenotype expression and behavior may be the key to understanding what accounts for the diversity in Down syndrome symptoms. These studies could give us additional useful information for more effective and educational strategies for different groups of people with intellectual disabilities.

A properly organized and structured multi-sensory teaching environment using new technologies will provide the best opportunities for the learning process. Teachers can assist students with intellectual disabilities in developing memory and attention strategies and help them in various ways to compensate for their deficits in this area. For example, children can learn to make picture books as mnemonic aids, showing the sequence of steps in a task to be performed, the elements of a task to be done, or a checklist of prerequisite actions. Further adaptations are required, i.e., modifications that reduce the size or change the content of tasks, changes in terms of time, format of material, response, and alternative forms of assessment (e.g., tasks with photographs, pictures, symbols).

5. Conclusion

Limitations of the present study could include the small sample of children with intellectual disability of different etiologies. The data collection of the study was synchronic rather than longitudinal. However, the longitudinal method allows for multiple assessments of children during the developmental period, which could provide more reliable conclusions regarding the development of cognitive skills of children with intellectual disability. In addition, further study of children with intellectual disability of different etiologies could be done by equating children in groups of lower and higher mental age, with the aim of investigating whether increasing mental age increases the probability of significant differences in favor of typically developing children in other cognitive abilities (executive functions, mental imagery, self-regulation, etc.). This will provide a more complete picture of the developmental rates and the trajectory of the strengths and weaknesses of children with intellectual disability of different etiologies. Indeed, genetic intellectual disability is not presented in a homogeneous way.

A better understanding, therefore, of the needs, strengths and weaknesses of memory and attention in people with intellectual disabilities is necessary to create focused interventions that reduce their learning difficulties and improve their quality of life. Capitalizing on the idea that educational interventions might "play to the child's strengths", we borrow those educational techniques that teachers have begun to use with children who show simultaneous over sequential processing, or visual over auditory processing, or linguistic over visuospatial processing. Additional research is needed to confirm the findings of the present study.

Data Availability

The data and materials used in this research are available upon request from the corresponding author.

Ethic Statement

Children's participation was completely voluntary, and their families approved the informed consent process for children's participation in this study. The study was conducted according to the Declaration of Helsinki with written informed consent obtained from the legal representatives of all participants.

Conflict of Interest

I have no conflicts of interest to declare. In addition, I have not been granted APC funds from my institution.

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