



The contribution of ICTs to the Down Syndrome Children's Language and Cognitive Development

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Abstract: Down syndrome is considered to be one of the most prevalent genetic causes of intellectual disability, derived from chromosomal disorder, which accounts for dysfunctions in many organs and has a characteristic phenotype, which consists of physical and behavioral features. Many studies have shown that language is one of the most impaired areas of function in Down syndrome and perhaps, the highest barrier for their substantial inclusion into formal education and community. The aim of this paper is to investigate the specific features of this linguistic phenotype, presenting the strengths and weaknesses of their language, as well as the factors that contribute to their formation, compared to normally developing children. In addition, it scopes to highlight the role of educational mobile apps, as innovative and interactive tools for the developmental learning of Down syndrome children. The results of the research indicate that their language goes through the same, with typical development sequences, but progressively erases a slowing trajectory and results in lower performance. However, the use of ICT tools can, significantly, improve language, literacy and short-term memory skills, but also stimulate their cognitive and fine motor functioning, in order to upgrade their quality of life.

Keywords: Down syndrome, language phenotype, factors, ICT tools

1. Introduction

Down syndrome is the most common chromosomal disorder with a frequency of about 1/800 births and affects 25-30% of people with intellectual disabilities [1]. It is also called trisomy 21, as 95% of this population has a third copy of all or part of chromosome 21, instead of the normal two copies, while the less common types of the syndrome are translocated 21 and mosaicism [2]

The mental retardation of the syndrome ranges from mild to severe, with an observed impairment of cognitive functions, along with increasing chronological age. At the same time, the pathogenic function of the genes of the extra chromosome 21 contributes to the formation of a specific phenotype of characteristics, related to health problems, cognitive and language deficits, neuromotor dysfunction and early aging [3].

With regard to language impairment, they show a number of selective deficits in expressive vocabulary, syntax, and speech comprehension and production skills, in relation to typical developmental children [4]. However, there is considerable individual variation, as each area of their language system is affected to a different degree, while their expressive language has greater deficits than the language of comprehension [5], which is influenced by chronological age, non-verbal cognitive ability and the state of hearing.

Thus, Down syndrome children, due to their neurological dysfunction, have significant deficits that extend from their language skills to the performance of practical activities of daily life [6]. For this reason, they need personalized teaching strategies that respond to their learning style, with continuous support and innovative educational tools that will contribute to the full development of their intellectual potential. In addition, due to their reduced attention span, they need attractive educational tools that can increase, to a higher degree, their incentives, active involvement and commitment in the learning process, compared to traditional teaching methodology [7].

ICT provides digital alternative education tools, through a variety of devices and software, with creative and enjoyable activities, structured according to their learning pace, to develop language skills, literacy and short-term memory mechanisms. At the same time, their use stimulates their fine motor skills and promotes their cognitive flexibility, as their design incorporates the main cognitive theories of behaviorism, social learning, dual coding and constructivism, while several apps provide the



possibility of recording and evaluating the emotional reactions of children during their interaction with them.

The present literature research aims to investigate to what extent and how the developmental language learning sequence of Down syndrome children is different from typical development and therefore, it examines the evolutionary process of the various areas of their language, compared to typically developed children, and how the particular features of the syndrome, as well as other factors, contribute to impairments in specific areas of their language system. Moreover, it examines the effectiveness of learning and practice through the integration of technology in the educational processes, emphasizing the continuous interactions with their environment and the connection of the provided knowledge with familiar elements and experiences of their daily life [6, 8].

2. Clarification of concepts

2.1. Definition - Types of Down syndrome

Down syndrome was named by the British doctor Down (1828-1896), replacing the term “Mongolism”, which was used to describe mental disorders, considering that the Mongols were more prone to them, compared to other ethnic groups [9]. He contributed significantly to the epidemiology of the syndrome, continuing the epidemiological studies that began in the mid-1800s, in which several doctors described the special characteristics of this group of patients with mental disability, among which the fact that they were short and prominent and they had flat nasal bridge, hypotension and a protruding tongue [10].

Down syndrome or trisomy 21 is a chromosomal disorder, characterized by mild to severe mental retardation and a range of physical and medical impairments due to the presence of an extra chromosome 21, which can be attributed to three possible causes.

In “trisomy 21” (92-95%), the egg or sperm develops with an extra chromosome, resulting from the fertilized egg obtained, having three chromosomes 21 instead of two. Separation failure, during the reduction of one of the chromosome pairs, usually occurs in women, while the frequency is higher in older ones. Thus, as the embryo develops, the extra chromosome is repeated in each new cell. In “mosaic trisomy” (2-4%), the probability of the extra chromosome results, due to the above condition, some cells having 46 and others 47 chromosomes. In “translocated trisomy” (3-4%), material from one chromosome 21 sticks or shifts to another chromosome, before or during conception. Therefore, the individual cells have two normal chromosomes 21, but also an additional chromosome material on the translocated chromosome [11].

2.2. Neurological profile in Down syndrome

The area of the brain of a Down syndrome child that is mainly affected is the cortex, both in neuronal density and in weaker neural synapses. Thus, as the child grows older, s/he will develop microcephaly with reduced brain volume, frontal and temporal lobes, cerebellum, myelination process and other areas of the brain with differentiated development. Particularly, the head of these infants has a larger third ventricle than normal developing infants, which is associated with the abnormal development of a wider area of the brain, such as the chamber, hypothalamus, or white substance of the brain, areas associated with cognitive processing and responsible for their cognitive deficits [3]. Moreover, they have abnormal neural interactions between the frontal and parietal lobes, which also affect the Broca area, while the abnormal development of the cerebellum creates problems of dysarthria, balance, synchronization and coordination of movements, as it is associated with executive function, reading, the sequence of learning, movement and language [11]. Also, due to the neurological development of the syndrome, from the age of about 35, they have the effects of the neuropathology of Alzheimer’s disease.

3. Language development in Down syndrome

3.1. The pattern of the language deficit

What constitutes the language phenotype of Down syndrome children is a series of selective deficits, from the early stages of their development, to expressive vocabulary, syntax, speech comprehension and

speech production, compared to typically developing children, of similar developmental age [4]. However, vocabulary development, as opposed to syntax, is clearly superior to Down syndrome children, as when they are called upon to recognize, identify or produce vocabulary, they perform at almost the same level as children of similar mental age, with or without mental disability. Furthermore, the delay in grammar in relation to vocabulary, which is larger in them than in other populations with intellectual disabilities, increases in parallel with the chronological and mental age and remains in the production and comprehension of syntactic structures, finding that chronological age is important for the development of syntax, while mental age is important for the development of vocabulary. Finally, Down syndrome adolescents perform better in vocabulary comprehension, less in comprehension of syntax, and face difficulty in producing syntax, as reflected in their Mean Length of Utterance (MLU) [12].

3.2. Theories of the language deficit

The language delay in Down syndrome children, usually, coexists with a generalized cognitive retardation and manifests as a linguistic deficiency in expressive or even receptive language, although comprehension skills appear more advanced.

Regarding the factors that slow down their language development, the role of auditory short-term memory is important in the first place, as 60% of these people present mild to moderate hearing loss, which also affects comprehension skills [12].

Another view focuses on the neurological structures, which are subject to language and dysfunction in Down syndrome children, since they have anatomical and neurochemical abnormalities in their brain, which are attributed either to abnormal rates of glucose metabolism in their brain, in areas related to the language function at either slower motor response rates and abnormal cerebral laterality [13]. Additionally, linguistic differences appear to be related to the lack of a dominant language hemisphere, as they do not have the advantage of the right ear, unlike typically developing children, which indicates the existence of a severe disability in language area.

Another possible explanation, for the large variation between their language and cognitive level, is provided by Lenneberg's "Critical Period" hypothesis (1967), which argued that maximum language development takes place before adolescence, while Newport (1982) added that the specific language learning skills are not available beyond the age of 7, according typical language development. Next, Fowler (1984) reported that their language development may be consistent with the general developmental course of maturation, but it will stop or differ from the typical course due to their reduced brain function [4].

An important factor is the quality of the linguistic registration of their environment, as the speech addressed to them consists of short and simple sentences with limited vocabulary, thus not allowing them to acquire the necessary language structures. This, in turn, indicates the reduced maternal expectations for their children's language ability [14], which reproduces the telegraphic speech they receive [15].

The hypothesis that children with intellectual disabilities have reduced motivation in information processing tasks [16], compared to typically developing children of similar mental age, needs further study on the role of motivation or lack of appropriate strategies for their language development [17-18].

Finally, one position that does not receive enough support is the institutionalization of their language, as it is argued that it has a negative effect in many areas of development, including their vocabulary and fluency. However, in a number of syntactic measurements, no significant differences were found with those growing up in a family environment [4].

3.3. Phonology

Down syndrome children have a high rate of phonological errors, similar to those of younger children with typical growth rates. However, the inconsistency of these errors is a special feature of the phonological disorder in Down syndrome. Thus, they use phonological procedures, such as simplifying patterns and systematic sound errors - such as reducing clusters and deleting final consonants - for much longer than their typical peers. Additionally, their poor intelligibility of speech affects the linguistic skill

of production and, to a certain extent, it interprets the difference between the level of their receptive and expressive language [19].

3.4. Semantics and expressive language

Although, there is a significant individual variation in the degree of language dysfunction, which depends on the field of language, which is assessed and the age of Down syndrome children, the deficits in semantic processing and especially in their expressive language are greater and even in relation to their general cognitive development [20]. Thus, their expressive language, presents much greater deficits, apparent from childhood, compared to the language of comprehension and non-verbal cognitive ability [21], as evidenced by deficits in phonology and early non-verbal requests, which lead to a slower and limited expressive vocabulary [22], which even in adolescents, rarely exceeds 3-5 years of typical development [23]. In contrast, receptive language and comprehension appear more developed than expressive language, during all age stages until the onset of adolescence [24].

The appearance of the first words and utterances, consisting of two words, takes place at a similar developmental age to the control group, while their verbal vocabulary and especially the expressive one is constantly delayed over time. At the same time, they perform lower in a number of semantic activities such as receptive vocabulary, correlated vocabulary, word-image matching and verbal (expressive) vocabulary due to semantic deficits [20].

Laws (2004) [5] states that individuals, with good phonological memory, imitate and successfully reproduce the syntactic structures of adults and based on these standards have higher performance in expressive language. However, Down syndrome children have a deficit in verbal short-term memory, due to their low level of language skills and not to a specific inherent deficiency in a system of verbal short-term memory. Moreover, their difficulty in verbal versus non-verbal skills is linked to their reduced verbal versus visual-spatial memory function. Furthermore, it has been shown that, in Down syndrome adolescents, comprehension rather than cognitive function or chronological age is a predictor of speech production ability [25].

On the other hand, when evaluated in vocabulary production, using language samples from real communication situations and not from standardized measurements, they show a delay in their expressive vocabulary, in relation to their non-verbal cognitive ability. In particular, their expressive ability is measured by the MLU of their sentences, i.e., by the number of words and / or morphemes they use, in conversation or narrative samples, and this has been found to be less than typically developing children, equated to non-verbal ability [26] or similar developmental age, with other mental health problems. Thus, while Down syndrome children tend to use more complex utterances, with more words, at a similar mental age to their typical peers, the MLU of their verbal phrases increases more slowly, despite its direct relationship to chronological age, resulting in deficits in measurements of syntactic complexity, word frequency, diversity of a fixed number of utterances and word production rate, in language samples of narration and conversation [27]. However, some Down syndrome adolescents show a modest syntactic development in late adolescence, indicating that the development of expressive language, as reflected in the MLU of verbal phrases, in sample narratives - longer phrases, vocabulary diversity - continues into the years of adolescence, at a fairly high rate in the development of expressive language, contrary to the "critical period" hypothesis [28].

3.5. Vocabulary

A high percentage of Down syndrome children (80%) start talking in the 2nd year of their life and only a small percentage (10%) in the 1st year. So, some of them will say their first words, at about the same mental age with children growing at a typical pace and specifically at 8-45 months. However, quite often they do not acquire words until the 2nd year, nor the skill of combining them until the 3rd or 4th year of their age, while they inconsistently use the newly acquired vocabulary, sticking to what characterizes much younger children [29]. Therefore, they produce their first words, usually at a much older age than typically developed children [30], with an average of 21 months and then, their progress slows down, compared to the typical sequence [22]. On the other hand, the deficits of their productive



vocabulary -although with significant individual variations- are due to their hearing condition (8%), chronological age (35%) and their non-verbal cognitive ability (13%) [27], while there is more variation between typical and non-typical children in the developmental sequence to acquire their first 50 words.

It is also interesting that they find it difficult to understand words that express emotions, due to their difficulty in assessing the perspective of other people in general. In typically developed children, the first words of internal situations start from the 2nd year and after the 3rd year, show a large increase. Down syndrome children will follow the same path, but due to the general deficits in their expressive language, they produce a more limited vocabulary [31]. In addition, they use, to the same extent as their typical peers, words to express physiological states and sensory perceptions and much less words that refer to their will or cognitive ability, because they are unable to understand abstract thinking.

However, in late childhood and adolescence, vocabulary comprehension is an area of potential for Down syndrome adolescents that is compatible with or higher than their nonverbal cognitive ability, unlike other areas of language, such as syntax. Thus, older Down syndrome children and adolescents show typical or accelerated vocabulary development, compared with normal developing children of appropriate developmental age due to intervention programs, which they have accepted to enrich their vocabulary or to the richest, stimuli, learning environment, due to their vocational training [12]. Additionally, they understand better high-frequency vocabulary with specific content, rather than the unusual and conceptually complex vocabulary. Therefore, they need more contact with a word to understand its meaning and benefit from their experience with familiar words, compared to younger children of typical development [2].

3.6. Syntax

In contrast to the development of their vocabulary, the development of syntax is disproportionately delayed and mainly in the production of language, in relation to their non-verbal cognitive ability. In particular, comprehension of the structure is characterized by developmental retardation in late adolescence and early adulthood, which may result mainly from a lack of articular loop exercise, which increases in parallel with the age and it is associated with impairments in their expressive language. Consequently, the gap between vocabulary comprehension and syntax skills increases with chronological age, while still being associated with mean mental age and inadequate auditory short-term memory, which impedes syntactic learning, because it does not allow them to retain memory and process large word sequences. Thus, compared to typically evolving children of developmental age, they have a more homogeneous pattern of syntactic use with shorter and simpler syntactic structures in their oral speech, as reflected in the MLU of their utterances and the omission of grammatical functional words and forms -as they lag behind in grammar morphology skills- [19] minimizing the risk of making grammatical errors through the use of new syntactic structures [26].

Particularly, a comparison of the language structure of Down syndrome children, mild to moderate retarded, with children of typical developmental stage, shows that they initially use two-word formation, in which they encode the same thematic concepts. In the next language stage, children with the syndrome use more words that indicate place and condition, while they find it difficult, similarly to the control group, to form hypothetical sentences and refer to past or future events [4]. At the same time, the beginning of the combination of the two words appears between the 1st and the 6th year, while the formation of the first sentences from the 1st-17th year of their age, producing simple noun and verb phrases and simple questions and negations, in which grammatical morphemes are omitted and in particular, the tense morphemes [19]. Therefore, syntactic deficiencies and not vocabulary place limitations on the narrative production [3]. However, as they use more complex word combinations, at the same mental age as typical developmental children, they gradually show slower growth rates, complexity and length of utterances and inconsistency even in already acquired grammars, indicating that they will never reach a complete knowledge of syntax.

In the past, their difficulty in achieving more complex morphological and syntactic development was attributed to chronological age, referring to “a critical period” defined by the onset of adolescence, with alternating language stages of “fast growth” and “plateau”, when development it slowed down or stopped altogether and was limited to the simple syntax ceiling [4]. However, more recently, it has been



found that older Down syndrome adolescents (16-20 years old) showed an improvement in their narrative language, compared to younger adolescents, using complex utterances, similar to those of a typical preschool child matched to MLU [22]. Furthermore, it has been found that the occurrence of delay in their syntactic development depends, in part, on the nature of the sample examined.

On the other hand, the fact that utterance length continues to develop, in some adolescents, until the age of 20, does not imply syntactic development, as longer sentences result from the improvement of all language skills, lexical, morphological and syntactic. It was also found that the MLU, in the context of narration and conversation, increases in parallel with the age and mainly in narration, after the age of 16 years. Thus, it seems that the narrative production, which is closely related to expressive language and syntax, is influenced to a lesser extent. Therefore, it seems that the developmental sequence in these children with atypical development is similar to that of children of typical development, compared to MLU, but the syntax develops more slowly than the vocabulary and this deviation widens over time. Otherwise, in terms of comprehension of syntax, the MLU and complexity of syntax continue to increase until late adolescence and early adulthood, rejecting the claim that Down syndrome adolescents have entered the stage of a plateau in syntax or remain at the ceiling of simple syntax and at the same time, making expressive syntax a fertile field of intervention [24]. However, even when they can produce complex utterances, they tend to shorten their sentences, using a lower percentage of long complex sentences, compared to the control group [28].

3.7. Pragmatics

Down syndrome children display a complex profile with strengths and weaknesses in the pragmatic aspects of language, similar to those seen in younger children with typical developmental interactions with their parents or other adults. Thus, from the pre-linguistic stage of development, they have many difficulties in trying to respond to non-verbal requests and therefore their interlocutors have to use verbal and non-verbal modes of communication [32].

Their potential includes the ability to stay focused on their subject, such as children with normal growth rates, of similar mental age and much more than younger children, matched to MLU. Additionally, they respond to requests for clarification in order to restore communication interruption. Another feature is adequate storytelling, with visual support, as they are able to retrieve more plot elements and references to the subject than normally developing children of a corresponding MLU or expressive language level. Also, by extending the content of their narratives with data from other sources and using a larger number of simpler linguistic utterances, they compensate, to some extent, for their deficits in expressive syntax.

On the other hand, some areas of pragmatics may benefit from the intervention, as they, usually, begin issues less frequently, than younger children of a similar developmental level. In addition, they find it difficult to construct utterances, in order to express their intention effectively and yet, they will not be the first to state that they did not understand the message of their interlocutor, during their communication, asking for clarifications or additional information [19]. However, these problems are not due to deficits in vocabulary or syntax, but to the very slow processing of information [33]. Finally, they show a low percentage of verbal obsession, off-topic language, stereotyped language in the conversation, due to the cognitive rigidity [17-18], and at the same time, impairments in the coherence of the conversation and the ability to use contextual information.

4. ICTs for Down syndrome children

The incorporation of digital technologies in the education domain is very productive, successful, facilitates and improves the assessment, the intervention and the educational procedures via Mobiles [34-47], various ICTs applications [48-84], AI & STEM [85-95], and games [96-105]. Additionally, various strategies and techniques can be incorporated in educational approaches via IoT. The combination of ICTs with theories and models of metacognition, mindfulness, meditation and emotional intelligence cultivation [106-148] as well as with environmental factors and nutrition [149-152], accelerates and improves more over the educational practices and results, especially the gifted students with ADHD.

However, educational processes should not focus on the use of technology, but on the potential for interaction and the provision of multisensory stimuli, which allow the active learning and development of Down syndrome children, exploring the environment through their senses. The design of technological interfaces and the use of electronic devices for their training should take into account their particular physical and learning characteristics, but also their strong individual variation. Moreover, it is noted that the majority of educational software is intended to improve literacy, language and communication skills and their socio-emotional development is overlooked to some extent. Similarly, the choice of the suitable educational approach, but also of the appropriate social environments, is considered crucial, so as to provide a holistic orientation of their education, both towards their cognitive maturation and the adaptability of their behavior.

Particularly, their cognitive limitations relate to working memory dysfunction, which hinders the development of memorization strategies to consolidate and maintain new knowledge and therefore learning. Additionally, they do not understand abstract thinking, show a slow rate of processing mainly auditory information, a low level of motivation and difficulties in concentrating and maintaining their attention (mainly in the mechanisms of releasing their attention from the previous stimulus and directing it to the next stimulus). The difficulties in adapting their behavior concern deficits in socialization, communication, in matters of daily living -time and money management, safe movement-, their dependence on other people, the acquisition of digital skills to operate computers and other electronic devices and the manifestation of inappropriate behavior, due to poor emotional tolerance for failure. Therefore, adequate training of teachers is required for the use of ICT, as an educational tool of alternative learning for this population, that multiplies equal educational opportunities and their access to the job market, the prospects for independent living and active participation in the community [6, 153, 154].

Recent research provides evidence that their first interactions with technology take place between 3-5 years of age, while their use, in the school environment, is also quite frequent. The most commonly used applications are the web, digital games and educational software (at a rate of 80%). Experts point out that an educational software program with a variety of creative and enjoyable activities, which takes into account their mental age, significantly, increases their motivation and self-esteem, while the multiple opportunities for systematic practice, observation and visualization of the educational material and tasks on the computer screen have a beneficial effect on increasing the plasticity of their brain [153, 155].

However, access to ICT and the use of computers requires a number of adaptations, in order to make hardware and software accessible to Down syndrome children similarly to their peers, so as to enhance their prospects of inclusion in mainstream school.

Furthermore, the creation of an ICT-based activity for home or school education should meet certain conditions. The software should be designed to easily adapt to each child's learning profile and follow their changing needs, while maintaining their interest and learning incentives. It is also pointed out that technology can be an important educational tool for children, when computer-based learning is integrated into a meaningful context, within which they work independently or with the support of the parent or teacher, who choose the most suitable software for them and discreetly monitor their progress, guiding their thinking, enhancing their understanding, supporting their learning and motivating them to solve problems, while allowing them room for experimentation and exploration, so that they experience a sense of achievement. At the same time, it is considered necessary that they are encouraged to learn to use a software, that the instructions provided to them are simple and understandable, that their every effort is immediately praised and reinforced, in order to acquire duration. Children should be seated comfortably so that they can move freely and have effortless access to the screen, keyboard, mouse or other input devices. For young Down syndrome children, software that can be accessed with one or two switches is considered more suitable, while devices with a mouse or keyboard are suitable for older ages. They can also use custom keyboards, small mice, touch screens, trackballs, joysticks, depending on their capabilities [156]. Thus, the use of ICT provides innovative, engaging and interactive personalized learning tools for Down syndrome children, designed on the basis of their strengths and to compensate for their weaknesses, providing them with the necessary encouragement, stimulation and support, due to their intellectual disability, limitations in expressive language and reduced attention span [157].

Supporting their learning through ICT has the following advantages:



- Computer software and other ICT tools enhance their learning with visual stimuli, at the same time, as hearing aids by leveraging their visual advantage.
- Provides the ability of a non-verbal response with the press of a key, a click of the mouse or a touch of the screen, compensating for deficits in expressive vocabulary and unintelligibility of their speech.
- The computer environment meets their desire for a controlled and autonomous way of learning, as it allows them to practice systematically, strengthening their self-esteem and their incentives. In any case, before to interact effectively with an ICT device, they need some time to practice and learn the operation of an application. Additionally, the familiarity with using technology (apparatus, software) inhibits the manifestation of inappropriate behaviors that, sometimes, cause their frustration with their limitations.
- Repetition and practice opportunities lead to a gradual improvement, accompanied by positive feedback and reflected by sound effects, moving images and music, which even in case of failure, takes the form of a prompt to try again.
- Most educational software is carefully designed with activities, structured in small steps and adapted to the learning readiness of each child, in order to experience positive learning experiences and success, without the stress of error, which often leads them to avoid behaviors of more challenging activities or even, to giving up the effort.
- In addition, quality educational software offers a well-structured learning environment, without complex stimuli and distractions, meeting their need for predictable and organized learning environments.
- Moreover, a software can be programmed to provide the appropriate learning stimuli to the child and adapt the presentation of a sequence of activities.
- The use of multimedia material - videos, images, sounds, animations - stimulates their interest in active learning and increases, significantly, their attention span (which, usually, ranges from 3-15 minutes).
- They offer the possibility of self-regulated learning, so that each child proceeds with the activities according to his/her individual pace and having the necessary time to process the information, which are prerequisites for a correct answer [153, 156, 158, 159].

Finally, it must be made clear that the main goal of Down syndrome children's contact with ICTs is to acquire early digital skills and to realize that their interaction with them is subject to a "cause and effect" relationship, since they control the sounds, they hear and the images, they see through a switch, a mouse click, a keyboard key, or a touch of a screen. This awareness will be the basis for the construction of their learning [156].

4.1. ICT tools for the acquisition of language and literacy skills

Although Down syndrome children show selective deficits in some areas of short-term working memory with appropriate training, with the use of alternative technological tools, responding their learning profile and with the guidance of parents or teachers, they can acquire literacy skills, starting with the knowledge of letters, as improving their expressive language allows them to communicate effectively, promoting their autonomy, education and social inclusion [160-162].

A. "Screening Literacy Phonological Awareness for Preschool" (PALS-Pre-K), with the use of an iPad and the appropriate software, that can be adapted according to the needs of each child, contributes to the acquisition of phonological awareness, with the guidance of the parent, in order to develop early literacy skills, through the knowledge of each letter and its sound [160].

B. "Sound Beginnings 2" is a specially designed program to improve vocalization skills in Down syndrome children. The parent or instructor introduces interesting images, which gradually appear accompanied by sound stimuli, giving the child the opportunity to experiment, through enjoyable activities, with sounds, voices and words. The correct pronunciation of a word, which sets the foundations of his/her language development, is rewarded by the system, which makes it possible to monitor his/her progress [163].

C. “Clicker 4” has been, widely, used in the UK, enabling the creation of a variety of educational activities for differentiated curriculum instruction, with the use of ICTs. It consists of “Clicker Writer” and “Clicker Grids”.

“Clicker Writer” is a word processor that reads the text and represents keywords or key- phrases with images, that appear above the text. “Clicker Grids” consist of grids with words, phrases, pictures and with one click, the computer shows the word or plays a movie clip or sound effect or even moves the user to another grid or sends its content to the “Clicker Writer”. Thus, the teacher or parent with this program creates writing grids and children can construct sentences, by selecting words or phrases with one click.

D. The “Cloze Pro” program is based on the same vein, including “fill-in-the-blank” or “closed-answer” activities. The text is entered at the top of the screen and the teacher selects some words or phrases to be replaced with spaces. Then, these are sent below in a grid, from which the student is asked to select them to fill in the blanks.

E. “Switch It Maker” and “Choose It Maker” are tools for creating personalized speech and language activities, that assess receptive vocabulary comprehension at the phoneme, word, and sentence levels. In “Switch It Maker” the child clicks on a series of pictures accompanied by sound and text. In “Choose It Maker” chooses a picture to answer a question [156].

F. “Clicker 5” - the improved and easier to understand version of this program - features a new speech system, that creates human-like voices. It includes word practice activities, structured around the whole word recognition technique and other ones making sentences, either by filling in the missing words or by understanding the process of making sentences using words. The skill of comprehension is cultivated through activities based on pictures and words, according to the context story and checking to what extent the child has understood the text [163].

G. A software to improve language and reading skills, using a smartphone was implemented in Peru, with Down syndrome children, aged 7-9 years. It consists of two programs (for the instructor and for the child), focusing on word recognition by children. Words, corresponding to images, stored on the device. Cards are displayed on the device screen and their pronunciation is heard. The child must associate each picture with the corresponding word. The successful answer is indicated by an animation with sound effects, while a different sound indicates the wrong choice.

The advantages of this tool, that contributed to their vocabulary increase, were the possibility to practice before the game, the provision for the necessary response time and the instructor’s guid. [7].

H. “HATLE” is based on cognitive processing theory, through multisensory learning, with the assistance of portable technology devices and therapist input, to support reading and writing skills in the Spanish language. It was developed in Mexico, with the participation of Down syndrome children, aged 6-15 and consists of a touch screen, personalized user access to track their individual progress and graphics with animated characters, that have the physical characteristics of the syndrome, to create a sense of familiar environment and member of a cooperative group.

It includes 10 fun activities to teach, practice, assess and self-correct phoneme association and letter recognition exercises. In particular, the speaking activities are based on a combined strategy of phonics and reading, to learn a specific vocabulary with words from their daily life, in order to form phrases and simple sentences, acquiring the ability to generalize their knowledge to other contexts. Design activities, provided through fun educational games and controlled visual/ auditory/ tactile stimuli, forming with the fingers on the screen straight and curved lines, letters, geometric shapes, in order to understand their arrangement in space and improve the alignment of the written text, but also to stimulate their fine motor skills.

The application, to evaluate their performance, uses an artificial neural network for automated recognition of users’ speech and writing. This innovative tool, along with improvements in reading, spelling and writing quality, was found to compensate for deficits in working memory attention and abstract thinking, producing improvements in phonological/ verbal and visuospatial memory, as well as, in spatial perception [157].

I. An interactive and intuitive tool, in the form of a battery-operated “smart glove”, developed as part of the AlfaDown project, to improve literacy skills and assess the attention and engagement levels of Down syndrome children, through the AffDex software.



The device consists of a microcontroller, a Bluetooth module, an array of LEDs and a laser emitter on the glove's index finger, which allows interactive environments to be configured. The Gobetwino software connects the reading glove to a Windows platform to launch a slideshow software, displaying the letters in various colors and corresponding images, stimulating the user's visual perception. Another software sends the command to Gobetwino to read first, the number of letters and then, each letter and its color. The Bluetooth module exchanges data with the computer, making the glove reconfigurable and allowing interaction with a multimedia projector.

It was observed that the integration into the learning environment and the educational material of technological devices, which offer opportunities for interactive and motivational activities, promote the active learning of Down syndrome children, through the exploration of their environment. The system achieved high levels of attention of its users, by providing the ability to adjust the display of letters according to children's preferences [164].

J. A customized hard disk-based software, assisted by assistive technology and applying the interactive learning model (ILM), to enhance spelling and reading skills, was developed in Pakistan and implemented exploratively in the setting of an inclusive mainstream school classroom, where Down syndrome children, aged 6-16, studied.

The teacher's laptop connects wirelessly to students' tablets and the classroom's interactive whiteboard, where the lecture is displayed for all students. This connection facilitates Down syndrome students by giving them the time they need to send their questions and comments to the teacher, removing reading and writing limitations and supporting their understanding with visual stimuli, while, at the same time, practicing their motor skills. Using another alternative and augmentative communication software, the Microsoft Windows operating system, text is converted to speech compensating for reading difficulties [161-162].

K. As part of the AlfaDown project at the University of Goiás, in Brazil, an application was developed, with virtual reality activities, enhanced with a wealth of visuospatial elements. The software features a biofeedback algorithm that uses the device's web camera as a sensor to record, either in real time or save to video, in connection with Google Drive, data of users' behavioral reactions and focus on attention, during performance of the activities.

The Android operating system was chosen as the platform for the application, due to its low cost and compatibility with a large number of devices. It includes four very interesting activities, adapted to the learning readiness level of Down syndrome children, with pronunciation, letter recognition, reading and writing exercises. Children's interactions with the device are done by touching or dragging and moving items on the device screen, thereby improving their fine motor skills.

In the first three literacy skills activities, children have to make the correct combinations of letters to form words. Pictures and sounds make the activities interactive, while the visual stimuli, provided for the auditory amplification, come from the children's everyday life. The fourth activity assesses their sensory perception, with pictures that they have to match with words, while even sounds are part of their familiar everyday life. Emphasis was placed on vivid colors and large fonts, that allow text to be visualized. With appropriate settings from the screen, activities are repeated, and after each success, positive reinforcement is provided immediately.

After the end of each activity, the "Attention Meter" (biofeedback algorithm) creates a report on the performance of each user, with data on the performance, but also on their emotional state, during its execution [6].

L. By adapting the traditional "DSRW" (Down Syndrome Reading Writing) teaching methodology to the interactive technology of tangible interfaces (TUI), a prototype was built for the prompt and more efficient development of the reading ability of Down Syndrome children.

The advantage of the DSRW method is that the graphic representation of a verbal word allows it to be retained in memory longer and ultimately consolidated, due to its simultaneous delivery through two channels, the auditory and the visual.

TUIs use ordinary objects of daily life to naturally represent digital information, promoting children's active engagement, free expression and inquiry, and maintaining high levels of attention and completion of activities without additional instruction or encouragement.

As a user interface, the transparent surface of a table and a set of digital tools were used, containing the “DSRW” educational material (word cards and picture cards) and bearing augmented reality labels to be read by the software, through a web camera located under the table. A mirror is also placed there to project images onto the desktop.

Tangible interfaces are the physical objects that depict the images and words shown to children and have augmented reality tags on the bottom, which are read by the web camera. The camera transmits the data to a computer software to verify that the game tag matches the word or picture card displayed on the tabletop.

The user has to perform three activities: a. read the four-word cards displayed on the tabletop b. relate them to games (tangible interfaces) and c. match the word cards with the picture cards projected on the tabletop.

The software then provides feedback on the children’s correct answers, who with a touch or a movement can select cards and activities. The instructor has the ability to save data and cards, create or customize cards, or even, determine the order of cards for a particular session [165].

M. “MEL-SindD” software, designed in Malaysia, to develop Down Syndrome children’s early reading skills, based on the principles of multi-sensory learning, using multimedia, the ARCS (Attention-Relevance-Confidence-Satisfaction) motivational model and three educational approaches: a. learning without error b. scaffolding and c. the mnemonic strategy.

According to them, the software provides more time for children, so that they do not give up trying to learn, as well as, systematic support in new tasks and the possibility of gradually exploring the screen and software modules, compensating for their cognitive limitations and fear of failure. Furthermore, using pictures, graphics, animations that represent the words aims to enhance their memory and acquire the ability to encode and memorize the information.

However, these should fit into the context of an entertaining narrative and be specific to their experiences and learning readiness. The integration, in the educational design of “MEL-SindD”, of the ARCS motivation model, aims to motivate students to maximize the time and intensity of the effort, in order to acquire targeted knowledge and skills, through techniques of attracting interest, maintaining attention them, enhancing their self-confidence and the relevance of the educational material to their experiences, so that they experience a satisfaction that emerges from positive learning experiences. At the same time, it uses the theory of double coding, by processing of information intake through two sensory channels, the auditory and the visual, and of active learning, by providing opportunities for high interactions of children with the educational material [158, 166].

N. A Tangible User Interface (TUI) system based on radio frequency identification technology (RFID) for early literacy acquisition, by incorporating RFID tangs into 3D printed objects and reduced-cost toys. It is based on the “whole word” reading method and involves words and pictures that are, repeatedly, shown to children.

TUI, one of the most modern technological tools, contributes to improving their cognitive and motor skills, by interacting with objects of different texture, size, color and shape, increasing their motivation for active involvement and commitment in the learning process.

The research was conducted in a special education institution, in Costa Rica, with 12 Down Syndrome children and 5 special educators, who in the first model, chose simple concepts to study and classified them into four categories. Then they designed and printed for each category six cards with the corresponding words in red color. The second prototype is a Graphical User Interface (GUI) for a web browser, accessible from PC or mobile devices, and includes the icons in red of the physical objects. The third TUI-based prototype involves the fabrication and printing of 3D objects and simple toys and the integration of RFID technology.

The system consists of three modules: a. an object recognition tool that has two RFID readers, connected to the processing unit. This, by reading the object’s RFID tang, sends a signal to display the corresponding word and sound reproduction of its pronunciation b. a set of 24 objects to be recognized by the system through the RFID tag and c. the graphical environment of the user, who by selecting a device and connecting to the internet, comes into contact with the pictograms, words and their pronunciation, which depict the physical objects.

It is pointed out that both words and objects are familiar and understandable to children, facilitating the vocabulary acquisition process. Thus, technology provides children with the possibility of developing social interactions, abstract thinking and learning, through the representation and association of physical objects and abstract concepts [167].

O. The same tool, incorporating RFID technology, to support the development of early literacy skills, was studied with 6 Down Syndrome students, in a special education school in Costa Rica, using innovative teaching and learning strategies that achieve high levels of children's motivation and interaction, enhancing attention, perception, memory and, at the same time, improving their language and motor skills.

The devices used were a tablet and an iPad. The system consists of three interfaces: a. the one based on traditional cardboard cards b. the Graphical User Interface (GUI), using digital cards and c. the Tangible User Interface (TUI), where 3D letters and common toys are used with RFID tags.

The process included: a. children's ten-minute sessions with each of the three interfaces b. individualized treatment by a teacher, where a vowel is selected and some words are pronounced and c. independent learning tasks.

It was found that the guided learning style and the TUI were more effective in achieving the determined interaction and learning objectives [8].

4.2. ICT tools for visuospatial short-term memory skills improvement

Working memory (WM), temporarily, stores and maintains the information that a person receives, through a variety of mental activities, playing a catalytic role in their learning.

Assistive computer technology can contribute to the training of visuospatial short-term memory in the school environment, by a trained teaching staff.

As mentioned above, Down Syndrome children show greater deficits in the verbal short-term memory (STM) system, which are reflected in limitations in their expressive language and understanding of morphosyntax [168].

A. An effective developmental age-appropriate intervention program is the "Junior Cogmed Memory Training" (JCWMT), which is the preschool version of the "CWMT" program, designed for typically developing children.

The program includes seven visuospatial memory training tasks, which require the temporary storage and management of visuospatial sequences. Then, the children are asked to recall them in serial order, by clicking with the computer mouse. The four tasks ask, only, the storage of visual information, the next two, the management and storage of visual information as well, and the last one, the storage of auditory along with visual information. The child must complete, in each session (total of 25 sessions), three training activities, while receiving continuous positive verbal feedback, as well as, exchangeable rewards.

The selective improvement observed in visuospatial memory led to the hypothesis that verbal short-term memory deficits may be related to a more pervasive difficulty in their verbal skills and not only to their limitations in processing verbal information. At the same time, minor improvements were found in the verbal short-term memory system. Furthermore, it was found that the progress in visuospatial memory was, also, transferred to some executive functions and, mainly, to the issue of shifting the attention between individual units of the same activity or during the transition from the previous to the next activity. Lower behavioral improvements were found in the ability to concentrate for longer, in reducing their frustration levels, in case of an error, and in better cooperation in the school environment [168].

B. As part of the EU's Horizon 2020 (H2020) research and innovation program, three different game applications were designed for Down Syndrome children, for use on tablets: a. "Bubbles", to improve selective attention b. "Pairs and Learn" to train visuospatial short-term memory and c. "Tangram" to enhance visuospatial processing ability, which refers to understanding the structure of general and specific information from one's environment and being able to generalize it to other contexts.

In the past, it was thought that Down Syndrome people, because of their holistic way of processing information, have difficulty focusing on more detailed information. However, recent research has



revealed that visuospatial processing is related to visuospatial short-term memory function and possible dysfunctions in selective attention mechanisms, as well as, the type of stimulus or task presented.

After the three-month period, where 26 Down Syndrome children aged 7-17 worked, under supervision in the school environment, but autonomously choosing the sequence and type of application, significant improvements were found in the areas of visuospatial processing and visuospatial memory. Lesser improvement was seen on the “Bubbles” tasks, due to their nature of requiring selective attention and competent response time, relative to the speed of stimulus presentation. However, it was found that the training of basic cognitive schemas could be transferred to more complex tasks [169].

4.3. ICT tools for emotional evaluation and social adjustment

Various software and games offer alternative educational techniques with physical activities, to improve Down Syndrome people’s mobility and body awareness in space, enhancing mental well-being, self-confidence and facilitating their social adaptation.

A. An intervention methodology was developed in Spain and Ecuador, for Down Syndrome children, mental age 7-12 years, in order to evaluate their emotions, during educational and rehabilitation activities.

It consists of three tools: a. the “TANGO:H” physical and cognitive rehabilitation platform, using personalized exercises and action games, multiplies children’s interactions with the system, through their body movements and gestures b. “EMODIANA”, a tool for structured observation and subjective assessment of users’ verbal and non-verbal language and social interactions, during video-recorded movement and gaming activities, and c. the “HER” tool, which automatically analyzes and evaluates children’s emotions, through video observation of training and rehabilitation sessions [170].

B. The various sensory and language deficits presented by Down Syndrome children hinder their learning achievements and make it difficult for them to communicate effectively. For this reason, an online platform was developed, based on cutting edge technologies, with learning modules that include interactive activities to promote language, math, motor and social skills, as well as, hygiene habits.

The platform provides the potential of analytically monitoring the performance and progress of each child and has a function to detect the user’s face and capture their emotions. Thus, the application suggests activities with quizzes, music, videos and other multimedia elements for each child, based on their emotions, while the negative emotional state of the user activates the possibility to change the content of the activities.

It was implemented in three research centers in Sri Lanka and a significant improvement was found in the learning skills and cognitive ability of the participating children [171].

5. Discussion & Conclusions

Language development is the area of Down syndrome children that presents the greatest impairment, which is exacerbated over time, with the main feature of inconsistencies in the development of different language areas and processes and with higher performance in language comprehension and greater difficulty in the syntax production. At the same time, the cumulative effect of a set of factors - cognitive, linguistic and maturation - contributes to the manifestation of individual differences, displaying different linguistic patterns of strengths and weaknesses, given that children’s growth and development is not the same in any person. Moreover, despite their observed delayed onset, their linguistic structures follow the typical order of occurrence, but at a progressively slowing pace - possibly due to their cognitive deficits - starting from the early years of their life and performing at the lowest level of formal variation. These findings, for slow but typical development, are reinforced by the Developmental Approach, which points out that all children cross similar developmental sequences (Hypothesis of the Same Developmental Sequence) and much more from an enlarged developmental perspective, that even individuals with organic etiology mental disabilities, such as Down syndrome children, follow the established principles of development and maturation, but at different rates (Different Rate Assumption) and with a lower final achievement level.

Therefore, all this is in line with what our research has shown, as the language development of Down syndrome children -mainly with mild retardation- was found to be qualitatively similar to younger children of typical development, equated to mental age (cognitive-developmental level). That confirms



Lenneberg's (1967) view that "language development, in Down syndrome children, is a slow-moving copy of typical acquisition, similar in all respects, which differs only at the rate of acquisition" [4]. However, in information processing tasks, they differ qualitatively from the formally developing children, as these reflect the pace of cognitive achievement. Nevertheless, according to the hypothesis of "the physical variation" of the developmental model, some forms of intellectual disability are part of the individual variation of typical cognitive development. This finding is consistent with Fischer's words (1980), as saying that "dissimilarity is the rule of development" [172].

On the other hand, given the great heterogeneity of the Down syndrome population, more in-depth research is required of their cognitive and language skills, but also of the results of the provided education, based on the differentiated diagnosis of their linguistic profile. In addition, these findings suggest that, in order for early intervention language programs for Down syndrome children to be effective, they need to integrate the developmental sequence applicable to children with formal language acquisition, due to the similar trajectory in language acquisition. Furthermore, these programs, taking into account the high variability in their cognitive and language skills, should integrate ICTs that, with the appropriate device, flexible educational software and suitable learning theories, can become alternative educational tools for early intervention and effective rehabilitation, enhancing their language, literacy, cognitive, memory, social and mobile skills and abilities, promoting their autonomy and facilitating their inclusion to formal education and their active integration into the job market and the community life.

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