A pilot study of the use of emerging computer technologies to improve the effectiveness of reading and writing therapies in children with Down syndrome

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Abstract

Despite the potential benefits that computer approaches could provide for children with cognitive disabilities, research and implementation of emerging approaches to learning supported by computing technology has not received adequate attention. We conducted a pilot study to assess the effectiveness of a computer-assisted learning tool, named “HATLE,” for children with Down syndrome. The tool helps to improve reading and writing abilities in Spanish, through mobile computing, multimedia design, and computer speech-recognition techniques. An experimental design with nonequivalent groups was used to assess the effectiveness of HATLE. The treatment group was taught using HATLE; the control group received typical instructions with the same material. Individual literacy achievement was assessed for both groups, before and after therapy sessions. The dependent variables in all analyses were posttest scores, adjusted via Analysis of Covariance (ANCOVA) for pretest variance. Differences between treatment and control groups were statistically significant in favor of the HATLE group on measures of Single-Word Reading (p = 0.048) and Handwriting-Form (p = 0.046) with large effect sizes (d > 0.8). Results indicate that HATLE might be effective in supporting computer-aided learning for children with intellectual disabilities. The results are discussed in terms of limitations and implications.

Introduction

Down syndrome (DS), or trisomy 21, is a genetic disorder caused by the presence of an extra copy in some or all the cells of the body, of chromosome 21, due to nondisjunction during cell division (Jacobs, Court Brown, Baikie & Strong, 1959). DS, which is correlated with advanced maternal age (Yoon et al, 1996), is the most common chromosomal abnormality in humans and the leading cause of mild to moderate learning difficulties. The estimated incidence of DS is 1 in 1000 live births, worldwide (Weijsman & De Winter, 2010), and around 220 000 babies are born with the condition annually (Burgoyne, Duff, Clarke, Smith et al, 2012). Incidence in Mexico is estimated to be 1 in 650 newborns, and according to a non-official estimate, 250 000 Mexicans have DS (Garduño, Giammatteo, Kofman & Cervantes, 2013). Still, many children...
with DS do not attend school, and their main opportunity for academic instruction is through nongovernmental organizations (Katz, Rangel, Allen & Lazcano, 2008), although mainstream or special education schools (van Wouwe, van Gameren, Verkerk, van Dommelen & Fekkes, 2014) and home bound education (Ricci, 2011) also provide important opportunities, which vary among countries. The use of emerging technologies to support teachers, therapists and parents could be a valuable option in the difficult task of equipping children with DS to lead independent adult lives.

Despite the potential of new technologies for helping children with DS communicate with others, to improve their academic performance and motivation, there are not enough applications tailored to their specific needs. A child with DS presents specific learning abilities and patterns that determine the individual way in which he or she assimilates educational content. Therefore, the present study is an interdisciplinary effort to develop a computer-assisted learning tool for children with DS. “HATLE,” a complementary learning strategy that uses mobile computing, multimedia design and computer speech recognition, aimed at improving reading and writing abilities in Spanish, through speech and drawing activities.

**Practitioner Notes**

What is already known about this topic

- The majority of children with Down syndrome can learn to read and write.
- Computer-assisted learning has the potential to help children with Down syndrome in their education.
- Multisensory teaching techniques are frequently used for children with learning disabilities.

What this paper adds

- Test of effectiveness of emerging computing technologies to support reading and writing therapies for children with Down syndrome.
- Implementation of computer speech-recognition technology in reading therapies for children with Down syndrome.
- Implementation of computer touch-screen technology in writing therapies for children with Down syndrome.

Implications for practice and/or policy

- The study provides a computer technology tool to support reading and writing therapies in children with Down syndrome.
- Further investigation is required of the impact of computer technology tools for children with learning disabilities.

**Background**

*Education for children with DS*

Children with DS have different capacities and skills for understanding and learning (Daunhauer, Fidler & Will, 2014). Due to their intellectual disabilities, they need more support and stimulation than unaffected children to function independently. However, their learning potential depends on their educational environment, and on the encouragement and support received from birth. Specific skills or abilities are learned through exposure to various situations, experiences and learning opportunities. Therefore, it is necessary to create settings that facilitate optimal achievement. For example, it has been suggested that, for children with DS to learn new skills, activities need to be broken down into smaller steps, and that more repetition and structure are required.
for retention (Hulme & Mackenzie, 1992). Conversely, each child with DS demonstrates individual abilities, strengths and weaknesses, and has their own learning profile. These personal patterns of learning can be used to develop teaching strategies and therapies that are particularly effective for that individual (Rodriguez, 2012).

Reading and writing skills
The majority of individuals with DS can develop some literacy, when explicit instruction is provided (Fowler, Doherty & Boynton, 1995; Kay, Cleave & McConnell, 2000). In fact, some children with DS learn to read earlier than would be expected based on their language and cognitive development (S. Buckley, 2003). A important number of studies have examined reading development in children with DS through cross-sectional analyses (Boudreau, 2002; Burgoyne, Duff, Clarke, Buckley et al, 2012; Byrne, Buckley, MacDonald & Gillian, 1995; Fletcher & Buckley, 2002; Gombert, 2002; Kennedy & Flynn, 2003; O’Brien, Wallot, Haussmann & Kloos, 2013; Snowling, Hulme & Mercer, 2002; Verucci, Menghini & Vicari, 2006), or longitudinal analyses (Baylis & Snowling, 2012; Byrne, MacDonald & Buckley, 2002; Cupples & Iaconao, 2000; Hulme et al, 2012; Kay et al, 2000; Laws & Gunn, 2002; Roeh & Jarrold, 2012). Although fewer studies have focused on written language development, recent research has taken more interest (Bird, Cleave, White, Pike & Helmkay, 2008; Buckley & Johnson-Glenberg 2008; Kay & Chapman, 2011; Prest, Mirenda & Mercier, 2010).

In general, word identification appears to be an area of particular strength within reading development in children with DS (Byrne et al, 1995; Cologon, Cupples & Wyver, 2011; Cupples & Iaconao, 2000; Kay et al, 2000; Næss, Melby-Lervåg, Hulme & Lyster, 2012). Word recognition has been positively associated with strength in visual processing (Fidler, Most & Guiberson 2005), so that some studies have recommended visual reading approaches (Buckley & Bird, 2002; Roch & Jarrold, 2008). Writing skills depend more on physical abilities, and children with DS often show delayed acquisition of independent walking and other skills that require motor coordination and balance (Bruni, 2006; Mauerberg & Angulo, 2000; Whitt, O’Neill & Stettler, 2006). In the early stages, low muscle tone is a common cause of motor difficulties affecting manual dexterity and, therefore, the ability to write (Feng, Lazar, Kumin & Ozok, 2010; Kumin, 2006; Volman, Visser & Lensvelt, 2007). Nevertheless, with maturation and appropriate progressive interventions, improvements during the second childhood stage and adolescence, their writing becomes clear and legible. The use of computers, either through the keyboard or touchscreens, might remedy some of the early writing difficulties in many cases.

Computer-assisted learning for children with DS
A set of educational characteristics have been highlighted from the learning profiles of children with DS to examine the potential use of emerging computer technologies as teaching tools (Black & Wood, 2003; F. Buckley, 2000; Feng et al, 2010; Moni & Jobling, 2000; Murray & Gamradt, 1999; Ortega & Gómez, 2006; Schery & O’Connor, 1995; Tanenhaus, 1995). These new technologies have features that are ideally suited to the learning style of children with DS.

Children with DS often have attention problems that make clear, detailed instructions imperative (Macias, 1999), to ensure that each child understands what they are being asked to do. Difficulties in processing visual and auditory information further support this need (Roizen, 1997; Shott, 2000). Children with DS often have pronounced hearing impairment and prefer to receive information visually (Broadley, MacDonald & Buckley, 1995). Use of a computer can facilitate their perception using a multimedia approach (Ortega & Gómez, 2006).

Computer-assisted teaching can counteract difficulties in motivation and fatigue that often occur in children with DS. Creative and playful activities using computer technology can increase their confidence and motivation (Ortega & Gómez, 2006; Wuang, Chiang, Su & Wang, 2011). Several
studies have found that students with learning disabilities have greater enthusiasm for computer-assisted instruction than for traditional paper and pen methods (Ahmad, Muddin & Shafie, 2014; Chen & Bernard, 1993; Ortega & Gómez, 2006).

The use of computers promotes individualized teaching, allowing adaptation of the work to the skill level of each student. Computer technology enables repetition, errorless learning, self-correction and immediate feedback. Software can be designed to provide support at each step, allowing the child to learn a sequence of steps to achieve success. A computer can be a patient and repetitive teacher, providing students with multiple opportunities for learning and assessment, and ultimately decreasing anxiety and expectation of failure (Black & Wood, 2003).

Computers offer students the possibility of increasing their autonomy and personal independence, to be able to learn alone and need less help from others. Children can accomplish tasks with less effort, greater speed, and higher quality, reducing work avoidance, frustration, and inappropriate behavior (Meyers, 1988). The computer can also store achievement data for each child, providing an objective record of their progress.

However, computer technology cannot be considered as a panacea for educating children with DS, because the actual benefits of computer-assisted learning depend greatly on the quality and adequacy of the software (Lloyd, Moni & Jobling, 2006). To effectively reach educational goals promoting motivational and independent learning, software must be developed through interdisciplinary collaboration of special education professionals and software developers, and emerging technologies should be used to develop innovative learning strategies.

Application of emerging technologies

Although emerging technologies have affected and continue to affect our entire society, in activities related to work, education, health and entertainment, those dedicated to support learning for people with disabilities have not received adequate attention (Istenic & Bagon, 2014). This is partly because the new technologies must benefit people with special educational needs both in a general framework and as tools for specific functions (Cabero, Barroso & Fernández, 2000). The new technologies must also address diverse learning styles and be adaptable to various teaching approaches.

Nevertheless, recent developments in emerging technology have produced tools to assist children with disabilities in inventive ways, improving their sensorimotor functions and increasing meaningful learning. For example, Wii gaming technology has demonstrated benefits in improving motor proficiency, visual-integrative abilities, sensory integrative functioning, limits of stability and postural stability in children with DS (Berg, Becker, Martian, Danielle & Wingen, 2012; Wuang et al, 2011). Other technologies address specific deficiencies, such as hearing impairment. These new approaches include practice opportunities for identifying single notes through a music-learning system (Yang, Lay, Liou, Tsao & Lin, 2007); extra-curricular support via smart phone (Liu & Hong, 2007); and recognition of appropriate Chinese ideographs related to graphic symbols, which gradually fade out (Lin, Chen, Wu & Yeh, 2008). Saz et al (2009) developed a semiautomated system to facilitate the acquisition of language for children with neuromuscular disorders, through automatic speech recognition and pronunciation verification techniques. Other software facilitates speech production by providing feedback from audio visualizations that represent basic audio features and coherent parts of speech, tracked by a hidden Markov model (Jain, 2013).

Emerging computer technologies offer an increasing range of methods, such as touchscreens, to assist children with learning disabilities. Multitouch gestures require only direct pointing, and are easier for children with poor fine-motor skills to use than a mouse or touchpad (Shah, 2011), because less cognitive processing is needed (Greenstein & Arnaut, 1988). Touchscreens also
usually only require use of one finger, versus the multiple fingers that are typically used for holding and guiding a mouse (Forlines, Wigdor, Shen & Balakrishnan, 2007). Ahmad et al (2014) reported that a new touchscreen application for teaching basic numbers to DS children is effective for those with a moderate IQ. Recently developed approaches to improving literacy and handwriting skills in special-needs children promote reading through animation and repetition (Lin & Nzai, 2014).

Methods
Software design
The design of HATLE was supported by therapists at “Casa Down Mazatlan” a Private Assistance Institution of Education for children with DS, located in Mazatlan, Mexico. HATLE is a computer-aided tool on an Android platform. HATLE provides a multimedia playful learning environment, integrating 10 play activities that incorporate education, exercise, assessment and automated correction of phonetic associations and character recognition (Figure 1). All play activities follow the same scheme (Figure 2): the application shows visual information to the user while playing an audio recording about the purpose and steps to perform activities. Speech training exercises show pictographic information while playing a related audio, which the user must pronounce adequately to successfully complete each play activity. Drawing activities involve correct drawing of words, letters, lines and geometrical shapes. HATLE implemented automated handwriting and speech recognition using an artificial neural network (Graves, Mohamed & Hinton, 2013; Jiao, Liu, Yuan & Bai, 2012) to assess the performance of users. Neural network output was designed with three recognition thresholds (0.5, 0.6 or 0.7) to enable the selection of different accuracy levels for successful completion one activity. Threshold equal to 0.5 was the minimum required

Figure 1: HATLE graphical user interface. Speech activities consist in touch pictographic information to listen audio and pronounce adequately the corresponding word. Drawing activities consist in make the correct charted of letters, lines and geometrical figures
to recognize correct utterance or charted. HATLE design also included touchscreen technology, personalized access only with username to monitor individual progress and a Graphical User Interface that includes animated characters with features of people with DS (Figure 1).

**Pedagogical aspects**

Cognitive theorists of multimedia approaches believe that presenting information using mixed modes (modality principle) and providing some prior knowledge of what is going to be taught before the instruction (pretraining principle) is one of the ways to minimize cognitive overload (Mayer, 2005). The pacing principle asserts that students learn better if the pace of the intervention is individualized based on their performance (Sorden, 2005). According to the self-modification principle of information processing theory, children are active learners, and learning happens when they use knowledge and strategies to modify their previous answers and can make more sophisticated responses (Parke & Gauvain, 2009). Finally, guided by the multisensory principle, it is believed that memory is reinforced when learning occurs simultaneously through
multiple senses, such as visual, auditory, tactile-kinesthetic and articulatory-motor (Moats & Farrell, 2005).

In this regard, the priority in the pedagogical design of HATLE was that the student understands what he or she has read and written, did it fluently, that was motivated, and is able to sustain his/her interest in the activities. To achieve this understanding, fluency and motivation, we designed an intervention to facilitate individualized teaching, adapting activities to the skill level of each student according to their own pace and allowing a more objective monitoring on validity and progress of learning. The playful component aims to reduce anxiety and ensure motivation to favor a more attractive learning for the student. The incorporation of animated characters with DS was an emotional type of strategy that pursues to help lose the fear to participate or to make mistakes, to feel in a friendly environment and become part of a group of mutual aid and cooperation.

The speech strand was based on a combined approach that teaches reading and phonics together aimed to present a small vocabulary “to view” or global, choosing words that children use daily in their speech and encouraging them to build their own phrases and sentences (e.g. family members, body parts and home areas), for each acquisition remains consolidated and the student is able to transfer what they learn and generalize to other contexts.

The drawing strand was centered on the multiple contexts approach making use of visual, auditory and touchscreen supports to develop visuospatial, perceptual motor and cognitive skills using simple games to reinforce learning. Drawing activities included elementary strokes (e.g. letters, curves and straight lines and geometrical shapes) to improve manual dexterity, and familiar words that can perform functional tasks such as writing shopping lists (e.g. fruits and vegetables). Based on the hypothesis that finger drawing on a tablet screen enhances the quality of writing production because it bypasses the difficulties involved in handling a pen (Picard, Martin & Tsao, 2014).

Participants
Twelve children with moderate intellectual disability were selected from 18 students based on the school’s determination of intellectual level and that they would remain in the Institution for the duration of the study. Participants were aged between 6 and 15 years at the start of the exploratory study. All participants were native Spanish speakers, recruited from Casa Down Mazatlan. The average age of children was 10.4 years and 41.6% were girls (n = 5). We relied on each school’s determination; IQ scores were not available for any of the participants. Informed consent was obtained from parents of each child. The Ethical Review Board of Casa Down Mazatlan reviewed and approved all protocols.

Assessments
Literacy skills were assessed using tests designed by Casa Down Mazatlan, including letter identification (upper and lowercase), reading, spelling, and handwriting quality (legibility and form) of single words (nouns). None of the tests had time constraints. Reading test scores were quantified on the basis of correct responses, and write tests required subjective judgment. The possible final score of all assessments ranged from 0 to 10.

Letter Identification: uppercase and lowercase letters of the Spanish alphabet were shown to be uttered. Single-Word Reading: children were asked to read the names of 20 one-word pictures. Spelling: 10 words were presented as pictures to be named and spelled. Handwriting Quality: the test consisted in provide the sound of 20 individual words to be written. The evaluation was based on therapist judgement of the legibility of words and appropriate size of letters (form).
Procedure
A nonequivalent groups design was used to assess literacy skills progress. Two groups of six children were randomly allocated to the treatment or control group, and trained during 16 weeks in daily 60-minute sessions in classroom. After training with HATLE on Android tablet computers, two therapists of Casa Down Mazatlan participated in this pilot study. In all sessions, children worked with assistance of any of those therapists. If any student pointed to the correct response, he/she received descriptive social praise from computer (treatment) or therapist (control) like “¡Felicitaciones! (Congratulations!)”, “¡Muy bien! (Very good!)” and “¡Buen trabajo! (Good job!).” Literacy abilities of individual participants in both groups were assessed before and after therapy sessions. During the study, researchers conducted weekly visits to check the application of therapies five times per week.

The treatment group was taught using HATLE on Android tablet computers. Therapist worked with one student at a time in each session, selecting and adapting HATLE activities to the particular learning profile of each child. At the beginning of the intervention, therapist taught the participants how to enter their usernames. Within 2 to 3 weeks, students were observed to inputting username independently. The initial recognition threshold for successful completion of each HATLE activity was set at 0.5, and gradually increased the level of accuracy through of more demanding thresholds in steps of 0.1.

The control group received individual instruction on the same material but for pencil and paper-based tasks. The dynamics was similar as HATLE group, but only with the mediation of the therapist. Children using approaches as color printed cards, repetition, no time constraints, multiple chances and prior knowledge before instruction.

Data analysis
ANCOVA was used to analyze the data, because univariate analysis indicated that pretest scores were significantly higher for the treatment group than for the control group on the Single-Word Reading ($t(10) = 2.26$, $p = 0.047$) and Handwriting Legibility measures ($t(10) = 2.29$, $p = 0.045$). ANCOVA minimizes the effect of such preexisting differences (Huck, 2000). The dependent variables in all analyses were posttest scores, adjusted via ANCOVA for pretest variance. Levine’s test of equality of variance was applied prior to each ANCOVA, to test that the assumption of homogeneity of covariates was not violated. Statistical significance was accepted at the $p < 0.05$ level to testing the hypothesis that the learning attainment was larger in the treatment versus control (one tailed). Cohen’s $d$ effect sizes that have general utility for most intellectual and developmental disability research studies (Dunst & Hamby, 2012), were used for judging the magnitude of the influences of HATLE on children’s literacy outcomes. Effect sizes were calculated by difference in raw score gains divided by pooled standard deviation (SD) at pretest, which allowed estimation of the effect of the treatment, controlled for pretest score. The $d$ indices were interpreted using Cohen’s benchmarks for insignificant ($0.00 \leq d \leq 0.19$), small ($0.20 \leq d \leq 0.49$), medium ($0.50 \leq d \leq 0.79$) and large ($d \geq 0.80$) effect sizes (Dunst & Hamby, 2012).

Results
Table 1 presents the mean and SD of pretest and posttest scores for each group for all outcome measures, as well as results of ANCOVA and effect size estimations. The differences between adjusted posttest scores for the treatment and control groups were statistically significant in favor of the HATLE group on Single-Word Reading ($p = 0.048$) and Handwriting Form ($p = 0.046$) measures, with large effect sizes ($d > 0.8$). The other outcome measures showed medium (Letter Identification, $d = 0.56$), small (Handwriting Legibility, $d = 0.28$) and insignificant (Spelling, $d = 0.14$) effect sizes.
By the end of the study, all participants in the treatment group completed the HATLE activities with recognition thresholds of at least 0.5. The average of final thresholds for all speech and drawing activities was 0.65 (SD = 0.02). Eighty-three percent of the participants (n = 5) successfully performed the Family, Vowels, Cloud and Maze activities at the most demanding threshold (0.7); only one participant (17%) successfully completed the Blackboard activity at that threshold. Data collection is available at www.upsin.edu.mx/assets/archivos/lmena/HATLE_DATA.xlsx.

**Discussion**

This study aimed to (1) develop a computer-assisted learning tool (HATLE) based on emerging technologies for children with DS, and (2) determine the effectiveness of HATLE by comparing literacy progress in Spanish, using measures of letter identification, reading, spelling and handwriting quality, by children who received HATLE intervention and children receiving typical instruction.

Recent meta-analysis found a significant positive additional effect of emerging multimedia technologies on literacy development for different groups of disadvantaged children (Takacs, Swart & Bus, 2015). Findings were discussed from the perspective of cognitive processing theories of multimedia learning that consisted of different principles.

Current studies support the hypothesis that through appropriate tablet computer applications, special learners with disabilities or learning difficulties are able to enrich their English literacy skills (Chai, Vail & Ayres, 2015; Lin & Nzai, 2014). Nevertheless, this pilot study is one of the first efforts to assess the effectiveness of an emerging intervention software for children with DS to improve literacy abilities in Spanish; and expands the literature by embedding adjustable neural network recognition procedures in a tablet application.

**Findings**

After controlling for differences in initial literacy achievement, the HATLE group, on average, made significantly more progress on Single-Word Reading and Handwriting-Form measures than the control group, suggesting a strong effect of the intervention. The HATLE group also had improvement in Letter Identification. The intervention had a positive, but insignificant, impact on

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**Table 1: Posttest outcome measures for experimental and control groups, controlling for pre-test differences**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Experimental group (n = 6)</th>
<th></th>
<th>Control group (n = 6)</th>
<th></th>
<th>F</th>
<th>p</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretest</td>
<td>Posttest</td>
<td>Pretest</td>
<td>Posttest</td>
<td>Pretest</td>
<td>Posttest</td>
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<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td></td>
</tr>
<tr>
<td>Letter Identification</td>
<td>5.83</td>
<td>0.54</td>
<td>6.52</td>
<td>0.49</td>
<td>5.85</td>
<td>0.33</td>
<td>6.27</td>
</tr>
<tr>
<td>Single-Word Reading*</td>
<td>5.87</td>
<td>0.25</td>
<td>7.28</td>
<td>0.52</td>
<td>5.13</td>
<td>0.76</td>
<td>6.08</td>
</tr>
<tr>
<td>Spelling</td>
<td>5.60</td>
<td>0.63</td>
<td>6.85</td>
<td>0.45</td>
<td>5.22</td>
<td>0.80</td>
<td>6.37</td>
</tr>
<tr>
<td>Handwriting Legibility*</td>
<td>4.87</td>
<td>0.45</td>
<td>6.12</td>
<td>0.52</td>
<td>4.17</td>
<td>0.60</td>
<td>5.27</td>
</tr>
<tr>
<td>Handwriting Form</td>
<td>5.08</td>
<td>0.37</td>
<td>6.42</td>
<td>0.49</td>
<td>4.40</td>
<td>0.66</td>
<td>5.28</td>
</tr>
</tbody>
</table>

*a*Significant pretest differences between groups.

\(d\) = Effect size calculated by difference in raw score gains divided by pooled SD at pretest.

*\(p < 0.05\).*
Handwriting Legibility and Spelling outcomes. Thus, the computer-assisted intervention proved beneficial in assisting children with learning disabilities.

The effectiveness of HATLE is possibly attributable to principles of multimedia instructional design, and its ability to present very tightly controlled stimuli in an entertaining game-like format, which provides enough repetitions for learning and helps to avoid frustration and stress. HATLE allows integration of speech and touchscreen input, personalized task sequences that help to address attention deficit and working memory limitations, adjustable recognition thresholds that help to make adaptations in progress to facilitate teaching according to learning profile of each student, and the presentation of animated objects that helps overcome deficits in abstract thinking.

Conversely, feedback and repetition by computer-based activities seem to increase focus of attention and facilitate learning process of students more than solely by interaction educator (Ortega & Gómez, 2006).

The children in the HATLE group practiced reading aloud with visual-speech output and touchscreen-speech recognition input, encouraging the development of their auditory-verbal and visual-spatial working memory through sound symbol relationships of words, and ultimately resulting in improvements on Single-Word Reading test. Because individuals with DS preferentially use information from the eyes and muscles to control and plan movements involved in producing the shapes of letters (Zesiger, 1995), drawing activities on the computer screen might have enhanced the quality of size, spatial arrangement and alignment of letters in the written text, accounting for improvement in Handwriting Form outcomes.

Limitations
The main limitation of this study was the small sample size. Although it is a pilot study of small reach this could result in an underpowered design. Another limitation was student participation based on school assignment, which represents a risk of sample selection bias. Although differences in pretest scores of the treatment and control groups were addressed statistically, unidentified group differences might have influenced the outcomes. A final limitation is the lack of standardized tests for assessing Spanish literacy skills in individuals with learning disabilities. Clearly, research on the effectiveness of computer-assisted learning should be conducted with larger samples \((n \geq 30)\) and stratification, which would allow analysis of learning outcomes in relation to the specific intellectual disabilities of each participant. However, due to the low percentage (3%) of the population with DS who receives special education in Mexico (Maldonado Salazar & Muñoz Cano, 2012), next studies should nest students from different schools. HATLE was developed and tested in a Spanish-speaking population residing in Mexico, further research is required to assess its utility among children of Hispanic descent residing in other Spanish-speaking countries, or among individuals whose mother tongue is Spanish but reside in other countries whose main language is not Spanish. Transferability of HATLE framework to other languages is also required to assess how the performance of the individuals is related to environment, language and culture.

Implications
Despite the potential benefit that computer-assisted learning tools could provide for children with cognitive disabilities, development of such tools is not currently recognized as important for children with DS (Feng et al, 2010), largely due to the physical limitations of DS children in manipulating computer input devices, to a lack of appropriate design for educational software, and to a dearth of teachers trained to teach computer skills to children with DS. Nevertheless, the continued development and use of emerging technologies, such as mobile computing, touchscreen design, speech recognition and multichannel input, have provided teaching methods that are more accurate, easy to use and less expensive than other forms of assistive technology.
Specifically designed educational software, such as HATLE, can pave a fresh path to learning for children with DS, with a more personal and responsive interface, offering instant gratification to students with limited patience. Ultimately, such tools could result in more successful social integration, as well as greater appreciation of emerging technical innovations by children with learning disabilities.

**Statements on open data, ethics and conflict of interest**

Data collection is available at www.upsin.edu.mx/assets/archivos/lmena/HATLE_DATA.xlsx. Informed consent was obtained from parents of each child. The Ethical Review Board of Casa Down Mazatlan reviewed and approved all protocols. The authors declared no conflict of interest.

**References**


Jain, P. (2013). Visualizing speech production with a hidden Markov model tracker to aid speech therapy and communication (Thesis for the degree of Master of Science in Computer Science, Graduate College, University of Illinois, Urbana-Champaign).


