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LONG PAPER

Gestural interaction and reading skills: a case study of people with Down syndrome

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Abstract

People with Down syndrome present cognitive difficulties that affect their reading skills. In this study, we present results about using gestural interaction with the Kinect sensor to improve the reading skills of students with Down syndrome. We found improvements in the visual association, visual comprehension, sequential memory, and visual integration after this stimulation in the experimental group compared to the control group. We also found that the number of errors and delay time in the interaction decreased between sessions in the experimental group.

Keywords Down syndrome · Kinect sensor · Reading skills

1 Introduction

People with Down Syndrome (DS) can benefit from learning to read at an early age as opposed to not having this early stimulation. Such benefits include improvements in their spoken language and memory skills. Learners with DS learn to read in the same way as typically developing children, although they can present difficulties related to hearing, which can affect their behavior, performance, and language learning [1].

Further, students with DS also present difficulties in working memory, which can contribute to their speech and language delays [2]. Reading provides opportunities for improving these problems. Research has shown that learners with DS perform better in tests of visual memory than verbal memory [2–5]. This deficit in verbal memory can be explained by (a) hearing loss, (b) speech production problems, (c) poor language knowledge [6]. Some training strategies can help to address each problem, such as (a) providing visual support, (b) reducing/removing the need for speech support, and (c) matching receptive vocabulary [7, 8]. Also, research shows clear evidence for the benefits of effective, sustainable memory training programs adapted for students with DS [1, 2, 5, 7]. Usually, students with DS have better language comprehension (understanding) than language production (talking/signing), due to their problems with word retrieval, sentence structuring, and speech-motor control [7]. It is crucial to start with vocabulary that they can understand and simple sentence structures, and to increment the vocabulary and grammar according to their progress. Some strategies for teaching reading include typical activities such as picture matching, picture naming or picture selecting [7]. In addition, students with DS can learn about the sounds associated with each letter and carry out phonetic learning activities. Students with DS can also benefit from Educational games typical of pre-school and school-age for developing reading skills (e.g., PBSkids[1]) or for working memory training (e.g., Cogmed[2]).

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[1] Web: https://pbskids.org/games/reading/

[2] Web: https://www.cogmed.com/

There are various specialties related to teaching reading, such as speech therapy and psycholinguistics, a discipline which has consistently made significant contributions to the field [9]. According to de Zubiria's *Theory of the Six Readings* [10], there are six levels of reading: phonetics, primary, secondary and tertiary decoding, categorical, and "metatextual," the first four levels considered elementary and the latter two a higher level. Following this theory, we focus on secondary decoding as it is the standard reading level among the DS population.

Reading comprehension is a cognitive process that constructs meaning from a text by integrating the relevant ideas with prior knowledge. The executive processes in working memory play a crucial role. The efficiency of these processes can be assessed through brief stimuli called 'memory reconsolidation.' The relationship between response time (velocity) and various identified items aims to measure how well information is retained in the limited capacity of short term memory [11]. Memory reconsolidation allows the reactivation and modification of memories by stimuli [12]. Its strength is inversely proportional to the age of the memory [13]. In the context of this study, the variables of time and cognitive errors were selected as a methodological basis to measure the variation of learning between periodic lessons.

The assessment allows teachers and educational systems to undertake the best methodological and didactic strategies [14–16]. In students with DS, the assessment does not vary from the rest of the students to measure their achievement, measuring variables such as response time, successes, and errors. However, it is essential to consider the student's degree of error [17, 18] or the continuous feedback to the process, motivating the student's effort, not only the achievement [15]. In this work, the assessment process has been designed and supported by technical designers and teachers taking DS students' special characteristics. One of the most critical dimensions in assessing the teaching–learning process is probably academic performance [19]. Teachers can assess academic performance according to skills and competencies proposed in curriculum planning [15, 20].

Additionally, motivation is the key to the educational process because it initiates and directs behavior toward achieving a goal [19]. It promotes continuous interest in learning, reaching a level of metacognition (knowledge about knowledge). In this sense, gamification can be used as a methodological strategy for academic motivation, keeping students' attention on achieving short-term goals, and passing learning milestones in a fun way [20, 21]. These areas are the transversal axis in this work, and they have been promoted through the gestural interaction and specific methodological strategies [22].

Related to the above, the dialogue between special education professionals and designers in technology shows a growing interest in Natural Interaction (NI) and its uses in education and health [23–25]. This research presents a shared vision between designers of technological applications and users (teachers, students, etc.) in the context of providing specific training for people with DS. The integration of NI devices and applications into the teaching–learning process for people with disabilities requires the design of specific methodological resources and the adaptation of curricular activities and content. Such efforts for pedagogical inclusion allows those with disabilities to develop their potential and skills by focusing on their zone of proximal development [26]. Moreover, in combination with NI platforms, gamification in education can be very useful for people with some degree of motor difficulties [27, 28]. For this reason, in this work, we propose TANGO:H [28], a gamified platform which has been tested in previous studies with people with motor difficulties, among others, as a means to support motivational therapies in hospital classrooms.

This paper is organized as follows: first, we review related literatures on using gestural interfaces to stimulate reading skills in people with DS. We then briefly describe how the TANGO:H platform works, and how its contents and activities (exercises) can be personalized. The experimental study is then described, including methodology, research questions, hypothesis, variables and indicators, sample, and educational resources adapted to TANGO:H. The results are then presented and the hypothesis and research questions are answered. Finally, we present a discussion of the results and draw conclusions.

2 Literature review and background

2.1 Reading skills of Down Syndrome students and gestural interfaces

Reading is a process that involves deciphering written signs and understanding their meaning, using different neurophysiological processes that can be developed at different speeds. In people with DS, this variability is more visible—their reading comprehension progress is much slower than reading mechanics [29], limiting their reading to the secondary decoding level. However, there are cases called "exceptional" in which a higher level of reading (comprehension) has been registered. These cases also showed a significant development of phonological skills, visual and verbal working memory, on par with (and in some cases higher than) the reading comprehension of people of their age without this pathology [30]. In such cases, parents played a vital role with respect to their approach to developing reading, with studies showing that most were very optimistic and continuously stimulated these skills at home with extra-curricular activities [31].

People with DS typically find sign language a better mode than verbal response for indicating word comprehension, and show a remarkable ability to read by visual analogy, which facilitates the learning of the lexical elements [32]. Vocabulary and its continuous stimulation is a good predictor of reading skills [33, 34], allowing learners to achieve the level of secondary discrimination in reading. A related study indicates that technologies improved reading therapies [35]. Taking into consideration previous work, we designed methodological strategies with gestural resources to stimulate visual-motor memory in people with DS, and studied the stimulation of reading abilities using gestural interaction.

Previously published research results show aspects such as reading strategies [36] language and verbal memory skills (short-term memory), and predictions on language production from their understanding. It has been shown that poor phonological discrimination is not directly related to poor visual working memory in people with DS [37]. A case study showed that stimulation of the visual memory in a boy with DS compensates the deficit of verbal working memory (short-term) required for reading comprehension [38]. In this background, our methodological proposal is based on the use of a technological gamified platform, TANGO:H, with exercises that use visual stimulus (text and figures) and gestural interaction [39]. The following section gives a brief description of the technological platform TANGO: H.

2.2 TANGO:H

TANgible GOal: Health (TANGO: H) is a platform for playing active games, using gestural interaction with the Kinect sensor (compatible with both version 1 and 2). The power of TANGO:H lies in its capacity to tailor exercises to meet specific needs. It is not a static platform in which exercises or games are fully defined and integrated, rather it allows these to be modified through an editor that makes this task simple. The system interprets and executes the exercises previously created by professionals in the editor TANGO: H Designer. The end-user interface is an active videogame, in which students perform the pre-loaded exercises in a game format, interacting with the system through body movements and gestures. The combination of editor and game modules allows various exercises to be created, personalized and adapted to the characteristics of the users.

The exercises consist of a set of objectives (resources) that are grouped on the screen; the user must select the objectives according to different guidelines depending on the type of exercise:

- Physical: oriented toward motor rehabilitation.
- Cognitive: aimed at developing cognitive stimulation.
- Classification: requiring the selection of specific objectives for a particular group.
- Matching: setting goals involving finding paired items.
- Sequence: involving selection in a specific logical sequence.
- Free: no specific function is set.

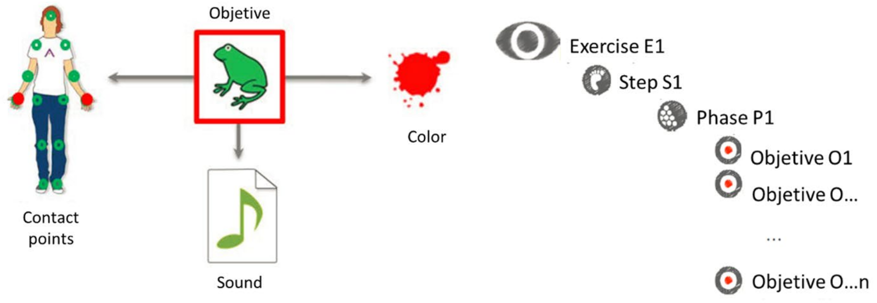
It can be played individually—as in our case—or collaborative/competitively with another user. Based on a gestural interface using Kinect, interaction is achieved through a virtual skeleton, which in version 1.0 consists of 13 points enabled for the limbs and head. As can be seen in Fig. 1, the basic design for the TANGO:H platform is made up of a target—contact point—which is composed of an image, color, and sound. Likewise, the interface is composed of (1) a menu bar, (2) an exercise panel, (3) an objective panel, (4) an available lenses panel, and (5) a design panel. The design is simple, and version 2 is available to perform the exercises from the web. The exercises are recorded in a*.tica* extension file that is imported into the TANGO:H client application (from XML structure).

The platform has several personalization functions. The user profile includes student information such as identification (full name, user name, and picture), date of birth (used for age), and gender. Other customization options relate to exercises, like timing and action range (Fig. 2). Timing and action range allow the level of exercise difficulty to be graded according to the ability of the user. Both parameters are included in the XML definition of the exercise. It is also possible to specify this range with a factor assigned by the user. All the settings for the range of action, both in the performance and in the user profile, are visible in TANGO:H. When the user touches within the range (not necessarily in order), the timer is activated. This functionality can also create difficulty levels for exercises and users and enables the designer to create groups of exercises that require different skills from simple to more complex. The level can be adjusted depending on the user's progress and within her/his possibilities and needs.

It is also possible to group users with similar capabilities and interaction needs. Each user or group can be assigned to the exercises with which they can interact. Exercises can be customized to the user capabilities at the moment the interaction starts, assigning scores according to the time required to complete each of the exercises.

At the end of each exercise sequence, the student provides an indication of their emotional state by selecting from one of three emotional emoticons (smiley, sad, and neutral). A star rating (from zero to five) is also given according to the time taken to complete the exercises. The student can exchange prizes, extra score, or other resources according to his/her level of exercise. All this information is stored in a.log file for later analysis if required.

Fig. 1 TANGO H. characteristics

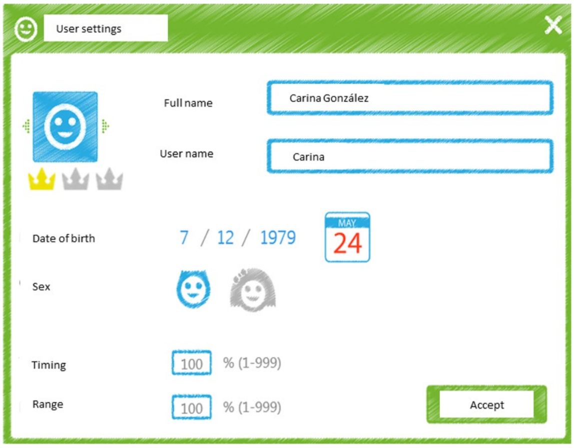


a Objective and properties

b Structure of an exercise

c Matching exercised

d Main Design Window



Full name: Carina González

User name: Carina

Date of birth: 7 / 12 / 1979 MAY 24

Sex

Timing: 100 % (1-999)

Range: 100 % (1-999)

Fig. 2 The user profile example includes the username (real and username), date of birth, gender, and personalization options (timing and range of action)

2.3 Personalization and adaptation

Regarding the personalization of technologies, specifically those applied to education, the NMC Horizon report 2017 K-12 Edition [40] proposes adapting content and exercises associated with student profile and learning style, including multi-user collaborative digital environments. In this field, we found contributions oriented toward personalization and adaptation for users with cognitive and/or motor disabilities [41]. Personalization of methodological resources is thus fundamental for education oriented toward people with special cognitive needs [42]. This means that the design of educational resources take into account users' academic level and characteristics. Understanding individuality, both in personal contexts and those of interaction throughout life (family, school, friends, etc.), is the key to appropriate design. Personalization of the learning and teaching process for students with DS needs to consider not only the motor difficulties, but also various aspects of their cognitive, auditory, visual and emotional characteristics [43]. Research has shown that videogame applications using the Kinect sensor have improved global motor, balance, body schema, and spatial organization of a group of twenty children with DS [44]. Equally, tactile interfaces have been used with students with DS to develop essential skills in computer use, to teach addition and subtraction with digital displays [45], and to achieve considerable advances in reading and writing skills [46]. Despite existing research into tactile and NI interfaces with people with DS, reading comprehension has been less investigated with people with cognitive disabilities, and for this reason it was selected as the central theme for this study.

3 The case study

3.1 Method

Following the recommendations of Lazar (2017) [47] regarding research methods for human–computer interaction (HCI) in the case of people with disabilities, we selected the method of "in-depth case study", focusing on a small number of instances within a specific real-life context (from three to ten participants). According to Lazar, a world renowned expert in HCI and disabilities, for research focusing on users with disabilities, it is generally acceptable to have 5–10 users with a specific disability take part in a study. Thus, this case study compared six participants divided into two groups [experimental (EG) and control (CG)]. Three individual cases from the experimental group were then analyzed to build a deeper understanding, generate a hypothesis, provide evidence of behaviors, and other insights into the variables studied, in order to be able to generalize to other cases. This in-depth study's primary goal was to assess the development in reading by students with DS as a result of specialized training using a computer-based natural interaction environment. Although not the primary goal, we also took the opportunity to subject the hypothesis to statistical analysis. The research question that this study aimed to address is: *Does stimulation through personalized educational resources from a computer-based gestural interaction environment improve the reading skills in students with Down Syndrome?*

The educational exercises were designed and developed using an educational gamified platform TANGO:H, personalized for each student with DS. For the validation, the following hypotheses were proposed:

> *hA* Errors by students with DS concerning specific knowledge about stimuli with learning objects in a gestural interaction environment show no variation between lessons.
> *hB* Response times by students with DS to stimuli with learning objects in a gestural interaction environment show no variation between lessons.

The hypotheses were validated by quantifying the variations in correct answers/errors and the response times for completing each task between one lesson the next, taking into account the theoretical basis of cognitive learning.

3.2 Participants

Recruitment was carried out from the 56 members of the Down Tenerife Association in the Canary Islands, Spain. A special authorization was signed by the legal representatives of each student and the approval of the Ethical Board of the institution. The researchers selected the sample according to the following inclusion criteria:

> *Disability*: students diagnosed with Down syndrome (Trisomy 21) and with a cognitive age above 5.
> *Technology*: students who had already worked with the TANGO:H platform for physiotherapy (for the experimental group).
> *Education*: students with basic reading skills.
> *Communication:* students able to communicate orally.

According to Lazar [47], the optimum cohort size for research focusing on users with disabilities is 5–10 users. This case study was composed of six subjects with DS (2 females and 4 males), three of whom had already worked with the TANGO:H platform for physiotherapy, and three who had not (Table 1).

Table.1 Participant characteristics

Participant ID	Natural age (years)	Level of education	Cognitive age (years)	Sex
Experimental Group (GE)				
E1	18	2nd yr (Secondary)	12–14	M
E2	29	2nd yr (Elementary)	6–8	M
E3	28	6th yr (Primary)	10–12	F
Control Group (CG)				
C1	17	6th yr (Primary)	10–12	M
C2	23	Inclusive classroom (Secondary)	12–14	M
C3	13	2nd yr (Primary)	6–8	F

Table.2 Procedure Details

Phase	Instrument	Variables	Groups
Pre-test	ITPA test	Cognitive Visuomotor Skills	GC and GE
Experiment	Semi-structured observation Platform TANGO:H	time number of errors	GE
Pos-test	ITPA Test	Cognitive Visuomotor Skills	GC and GE

3.3 Variables and indicators

The following variables were measured during the experimentation and in a post-test in both groups (EG and CG): visual association, visual comprehension, sequential

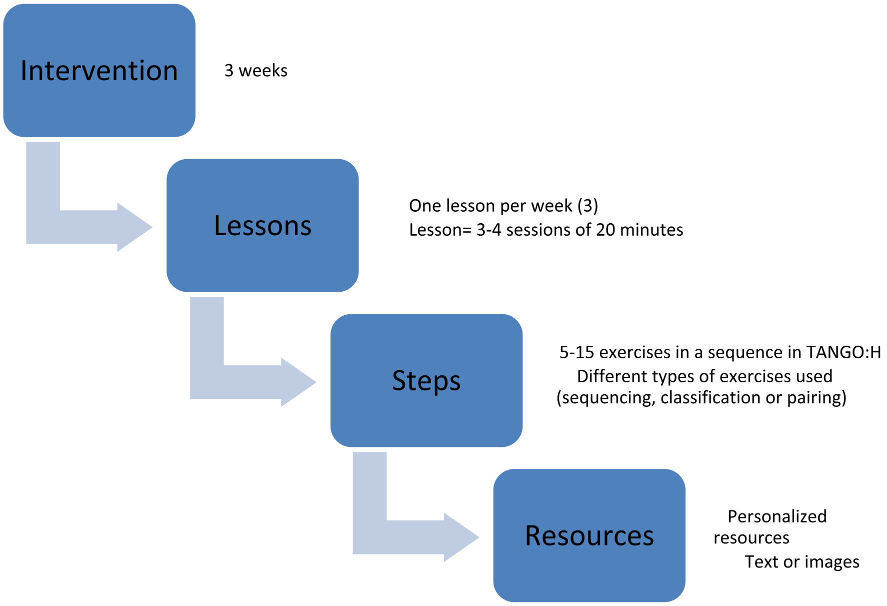


Fig. 3 Structure of the intervention

memory, and visual integration using the Illinois Test of Psycholinguistic Abilities (ITPA) [48] (Table 2).

Further, in the EG we measured the variation in time Δt that each student required to complete each task and the variation in the number of errors Δe. The latter were analyzed in terms of an overview, and separating images and text, to find out which of these resources produced better learning.

$\Delta t_{L1-L2} = t_1 - t_2$	Between L1 (week 1) and L2 (week 2)	$\Delta e_{L1-L2} = e_1 - e_2$
$\Delta t_{L2-L3} = t_2 - t_3$	Between L2 (week 2) and L3 (week 3)	$\Delta e_{L2-L3} = e_2 - e_3$
$\underset{-}{\Delta} t_L = \frac{\Delta t_{L1-L2}+\Delta t_{L2-L3}}{2}$	Average of inter-weekly variations	$\underset{-}{\Delta} e_L = \frac{\Delta e_{L1-L2}+\Delta e_{L2-L3}}{2}$
$\Delta t = t_1 - t_3$	General variation from L1 (first lesson) and L3 (final lesson)	$\Delta e = e_1 - e_3$

The above formulas (1–4) were applied as appropriate to obtain the following indicators:

- Response time (Δt)
- Effective interaction time. This was measured from a video recording so that the times obtained were exact.
- Delay time caused by device error or another external factor. This variable allowed us to obtain a precise measure of the actual interaction time that the user needed to meet the task objectives in each step and session.
- Cognitive error during interaction (Δe)
- The number of errors during each lesson (calculated as the total number of errors in exercises in each step and session).

3.4 Procedure

The intervention took the form of three lessons, one per week. Each lesson comprised 3 or 4 sessions, and included from 5 to 15 exercises (sequencing, classification, and/or pairing) (Fig. 3). The exercises were designed and programmed according to the capabilities and skills of each participant. The personalization, carried out in TANGO:H designer, made reference to the participants' individual workbooks compiled by the teachers, and incorporated the learning objectives and competencies foreseen for each lesson within the overall plan for the academic cycle. The lessons were organized around the students' established daily activities at the Down Tenerife Association in order to keep disruption to a minimum.

The role of mediator was carried out by the teacher with the researcher's support. The resources were used iteratively, that is, each student used the same resources in each consecutive lesson, according to the availability of time and each student's progress. The researcher and classroom teacher both conducted structured observation of the lesson in order to provide a subjective experiential account of the learning for the purposes of comparison. A video recording was also made of the entire intervention, using two digital cameras, located behind and in front of each individual, in order to validate interaction times.

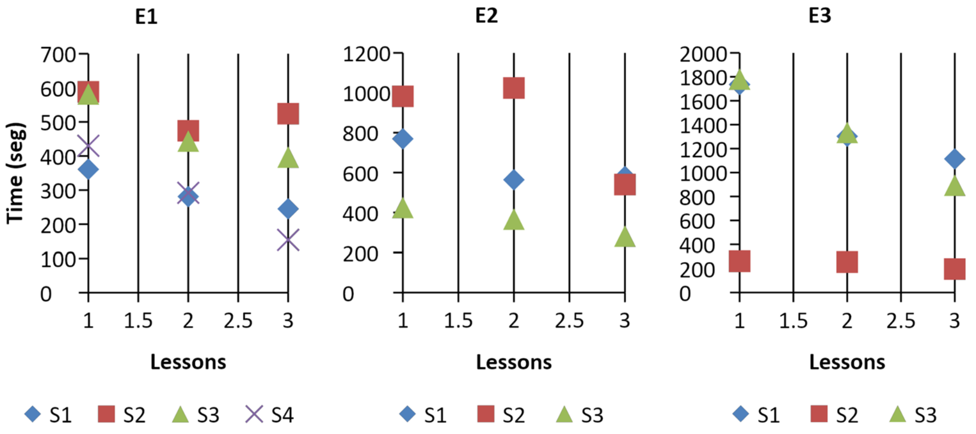
3.5 Resources designed and adapted in TANGO:H

The methodological resources were personalized according to the information shared by the teachers in the ATT21 in a workshop. As the objectives within the TANGO:H platform are image files, both graphics and text were saved in image

Table.3 Example of an exercise in TANGO:H

Exercise E1_S1: Relate direct syllabic groups k	
Exercise 1 The user must match two-letter syllables with three-letter counterparts (5 steps). They then identify the pictures which correspond to the sound of the syllable (5 steps). Finally, the user must match the syllable with the written form of the word in the previous image (5 steps)	Title: E1_S1 Exercise Type: Cognitive Matching Game Mode: Single Guided Number of steps: 15 Number of achievable goals: 30 Number of distractors: 45 The duration for maximum score: 90 s Maximum points: 150 Minimum points: 30 Special rules: The player is first given a demo, and further guidance is available if player frustration is considered an issue

Fig. 4 Variations in the response times for each participant



Response times per participant, lesson, and session.

format, following workbook parameters. Various exercises were prepared and repeated in the weekly lessons. The lessons were planned according to each student's motor and cognitive abilities, as shown in Table 3.

3.6 Results

This section presents the results of the controlled experiment regarding the variables response time and number of errors per session and activity, along with the variable visuomotor skills, by which the hypotheses of the in-depth case study were tested.

The first of the two hypotheses to be considered is hA: "Errors by students with DS concerning specific knowledge about stimuli with learning objects in a gestural interaction environment show no variation between lessons."

With respect to the EG, response times and matching errors made during the entire interaction were analyzed separately. Data from each step and session over the three lessons was compared (Fig. 3). In order to avoid distortion of the data, all errors in the observed time caused by the Kinect sensor have been eliminated from the analysis. The time taken to find the correct response has been maintained, omitting specific cases, as in E1-Lesson 3-Sessions 1 and 2, where a slight increase in response times can be seen (Fig. 4).

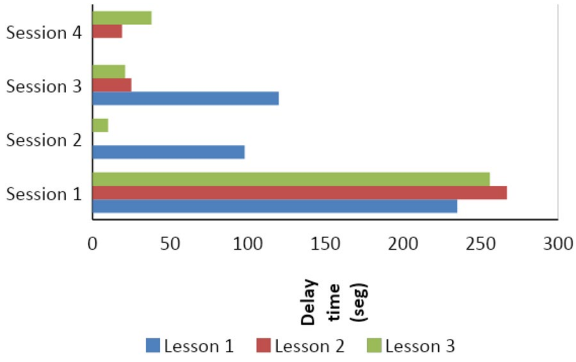


Fig. 5 Total delay time in interaction ordered by resources and lessons of sessions

Response times were affected by errors in the Kinect sensor, or by not following the instructions for each activity correctly. As shown in Figs. 5 and 6, these errors are more significant in session 1 of each lesson. They then decrease continuously over the sessions in each lesson (Table 4).

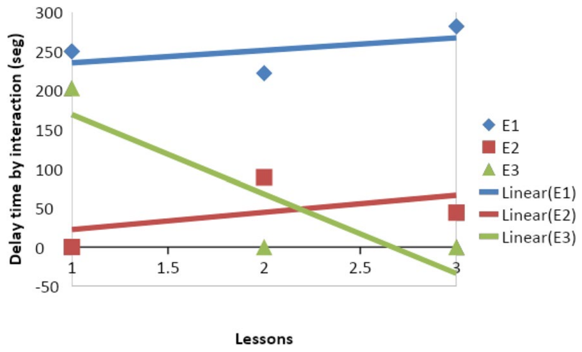


Fig. 6 Delay time in seconds caused by interaction according to user and lessons

These errors have a direct relationship with the user and their abilities for gestural interaction with Kinect. Each participant learnt to control the Kinect at a different pace, without any relation between one user and another. Consequently, user experience and interaction skills directly influenced the performance if the measurement of this was sustained in the time required to comply with a learning activity.

Applying the *t*-Student statistic, we found that time variation is significant in the first two sessions as in the intersession media. Only the difference between session 2 and 3 was not significant (see Table 5).

The second hypothesis, hB, was: “Response times by students with DS to stimuli with learning objects in a gestural interaction environment show no variation between lessons”.

Table.4 Time in sessions and lessons for EG

		L1	L2	L3	dif 1	dif 2	dif media	dif t
E1	S1	361	281	245	80.0	36.0	58.0	116.0
	S2	588	474	524	114.0	-50.0	32.0	64.0
	S3	582	444	397	138.0	47.0	92.5	185.0
	S4	430	292	154	138.0	138.0	138.0	276.0
E2	S1	769	564	580	205.0	-16.0	94.5	189.0
	S2	982	1024	540	-42.0	484.0	221.0	442.0
	S3	425	367	282	58.0	85.0	71.5	143.0
E3	S1	1735	1303	1114	432.0	189.0	310.5	621.0
	S2	261	254	196	7.0	58.0	32.5	65.0
	S3	1781	1335	894	446.0	441.0	443.5	887.0

Table.5 Time variation between lessons and sessions for participants

	Media in seconds	Standard deviation	Typical error Media	t-Student	t (0,01; 9)
Δt_{L1-2}	157.6000	163.9269	51.8383	3.0402	2.8214
Δt_{L2-3}	141.2000	182.8714	57.8290	2.4417	2.8214
Δt_L	149.4000	135.7395	42.9246	3.4805	2.8214
Δt	298.8000	271.4790	85.8492	3.4805	2.8214

Table.6 Number of errors by session and lesson during EG interaction

		L1	L2	L3	dif 1 (L1-L2)	dif 2 (L2-L3)	dif media	dif t (L1-L3)
E1	S1	14	8	12	6	-4	1	2
	S2	24	11	1	13	10	11.5	23
	S3	17	7	1	10	6	8	16
	S4	5	3	1	2	2	2	4
E2	S1	19	8	7	11	1	6	12
	S2	34	18	7	16	11	13.5	27
	S3	25	10	4	15	6	10.5	21
E3	S1	9	5	3	4	2	3	6
	S2	0	0	0	0	0	0	0
	S3	14	6	1	8	5	6.5	13

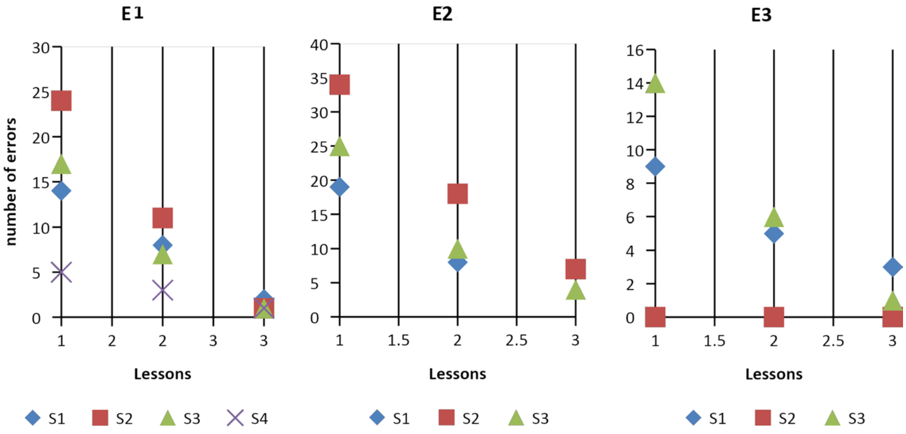


Fig. 7 Errors in the interaction (sessions and lessons) according to participant

Table.7 t-Student statistic of variation in matching (comprehension) errors between lessons and session

	Media in seconds	Standard deviation	Typical error Media	*t*-Student	*T* (0,01; 9)
Δe_{L1}	8.5000	5.4620	1.7272	**4.9212**	2.8214
Δe_{L2}	3.9000	4.6056	1.4564	2.6778	2.8214
Δe_{L}	6.2000	4.6738	1.4780	**4.1949**	2.8214
Δe	12.4000	9.3476	2.9560	**4.1949**	2.8214

Table.8 Comparison of the paired differences of variables by groups (experimental and control) in the post-test

Variable	Groups	*N*	Mean	SD	Std. error mean
Visual Comprehension Post	Experimental	3	**22.00**	3.000	1.732
	Control	3	21.00	0.000	0.000
	Experimental	3	**13.67**	4.726	2.728
Sequential Memory Visuomotor Post	Control	3	8.67	2.309	1.333
Visual Association Post	Experimental	3	**27.67**	3.512	2.028
	Control	3	17.67	2.517	1.453
Visual Integration Post	Experimental	3	**19.00**	4.359	2.517
	Control	3	13.33	1.528	0.882

We also totaled the errors that each student made during each session and lesson (Table 6) (Fig. 7). The results show a significant difference in results between sessions, with a confidence level of 99% (Table 7). Only between the second and third session, does the variation not exceed this degree of confidence.

The final variable to consider is that of "visuomotor skills" of the control group in the study.

Descriptive analysis was carried out based on central tendency (mean and standard deviation) about the variables (visual association, visual comprehension, sequential memory, and visual integration), comparing the experimental and the control group. Table 8 presents the results obtained in SPSS.

4 Discussion

The results show that the variables visual association (EG = 22.00; CG = 21.00), visual comprehension (EG = 13.67; CG = 8.67), sequential memory (EG = 27.67; CG = 17.67), and visual integration (EG = 19.00; CG = 13.33) in students with Down Syndrome improved after stimulation with game-based teaching strategies in an environment of gestural interaction with a computer. The results also show a significant change in the time variables Δt and cognitive errors Δe, on the basis of which the null hypotheses hA_0 and hB_0 can be rejected. Response times, such as the number of errors that students made in the first lesson, and over consecutive lessons, were reduced by significant percentages, according to the visible t-Student (n = 9, confidence level 0.01) as can be seen in Tables 4 and 5. In the case of Δt, the difference is greater between the first two lessons (3.0402 > 2.8214), and decreases between the second and third. However, at the beginning and the end of the intervention, the statistically significant difference (3.4805 > 2.8247) is maintained. For Δe, the trend is similar, decreasing greatly between the first and second lessons (4.9212 > 2.8214), after which the difference between the second and third lessons decreases, but is still significant between the first and last lessons (4.1949, 2.8214). This difference would be even greater if we directly discarded Session 2 of E3, since it denotes a domain of the topic from the first session having a margin of error = 0.

With these results, it is possible to answer the research question Q1 with the affirmation that gestural interaction does improve reading skills in people with Down Syndrome. The answer is supported by the significant statistical variation (99%) in the variables Δe and Δt, with a progressive reduction in delay between continuous lessons, which indicates significant improvements in the measured variables. The periodic stimulation (weekly in our case) and the results are consistent with the theoretical representation of Morgado [12], which explains the reconsolidation of memory by reactivation and stimuli modification. Hence, the variables related to reading skills (visual association, visual comprehension, sequential memory, and visual integration) in the EG showed an improvement compared to the CG.

The methodological strategies devised for an environment of natural interaction through gestures are emerging pedagogical tools, appropriate not only for people with cognitive and motor disabilities; they can be extended to a general context of application in all educational institutions, complemented by augmented and virtual reality technology. It should also be noted that the above in no way diminishes other strategies highly valued by teaching professionals, but on the contrary, complements and strengthens them. The tools also foreground the need to consider the particular characteristics of the user through personalized exercises. Results are also corroborated, which, from reading through visual analogy, improves knowledge of lexical element', a predictor of reading skills. Reading comprehension in people with DS is slower than reading mechanics.

The experiment was carried out over the course of three lessons (one per week). It allowed us to measure each individual's variation between lessons and, more generally between the first and last lesson in order to learn the actual variation after the experimentation. The longitudinal method is standard in small research projects featuring case-centered groups in which a specific behavior is monitored, or the variation in a stimulus on a timeline. It promotes a process of non-disruptive interaction, with minimal variation in the daily schedule, requiring only a few lessons of the students' time. The collaboration of the authorities, legal representatives, and professionals of the Tenerife Down Association allowed the adaptation of the spaces for interaction according to the Kinect requirements. TANGO:H Designer facilitated the development of interactive teaching resources from the conventional workbooks, personalized for each student. The resources designed and the methodological strategies were based on a gestural interaction with image and text resources, which stimulate visual-spatial working memory. Better learning has been achieved in people with Down syndrome. According to the results, the visual stimulation applied enabled significant learning to take place.

The particular form of interaction presented during lesson 3 with E1 and E2 is worth mentioning as an additional point. The participants' behavior was also assessed qualitatively through descriptive observation. It was notable that the students had fun during the interaction and mastery of the subject. This behavior corresponds to metalinguistic abilities, like thinking, playing, expressing oneself, analyzing the components, and making judgments (phonology, axis, semantics, pragmatics). Thinking metalinguistically is present in the act of making verbal jokes, extracting meaning from what is said.

Finally, we believe and recommend promoting pedagogical work in the classroom using interactive gestural environments as a complementary strategy to achieve reading comprehension skills. Since it is not an inferential study and is an emerging research area, it is necessary to continue the study with a broader population and consider other variables related to other aspects of learning and various areas of science.

5 Conclusions

In this paper, we have described a study into improving visuomotor memory in students with DS using gestural interaction and personalized educational resources. The following main findings can be highlighted:

1. Interaction times in learning spaces based on gesture interaction devices and personalized resources for students with DS decreased between lessons on the same thematic content; this implies improved reading skills.
2. Stimulating visuomotor memory in interactive gestural environments and personalized resources is a methodological strategy that significantly improves the reading skills of students with DS.
3. Students with DS exhibit higher-order learning characteristics reflected in metalinguistic skills, not obtained in previous studies with periodic stimulation over such a

short time. Students joked about the answers by deliberately ignoring the correct ones and selecting the errors.

4. Users quickly learnt to interact with teaching resources in the gestural interaction platform, evidenced by the continuous decrease in non-cognitive errors presented in the initial sessions. These also tended to disappear as the process of experimentation progressed, with improvements in their gestural interaction skills.

With regard to the limitations of the study, we found it would have been beneficial to have a specific academic reading history for each of the study participants. This would have allowed us to make a linear comparison between traditional learning advances concerning the achievements in this experimental period. It would be of great interest to have other physiological and sensorial variables to know the variation that the individual experienced during the stimulation processes with the TANGO:H gestural interaction. However, during the intervention, some errors with the gestural platform caused by environmental or limiting situations of the sensors directly affected the students' behavior in the specific session. Another factor to consider is that the experimental process is not part of the Tenerife Down Association's general curricular planning. Thus, it was proposed to consider maintaining a continuous stimulation laboratory as part of the annual academic planning. So, all institution staff can be an integral part of this process, and students can have more learning spaces. With respect to further studies, we aim to add to the interaction platform the function for automatically customizing learning resources based on the interaction skills that each student, and the emotional state that they show during the interaction.

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Declarations

Conflicts of interest The authors declare no conflict of interest.

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