

EVALUATION OF THE EFFECTS OF A VIRTUAL INTERVENTION PROGRAMME ON COGNITIVE FLEXIBILITY, INHIBITORY CONTROL AND BASIC MATH SKILLS IN CHILDHOOD EDUCATION

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Abstract

The main objective of this study was to analyse how the use of digital resources contributes to improving cognitive flexibility, inhibitory control and basic math skills in early childhood education.

Ninety children, aged 5 to 6 years, were divided into three groups. One group received the intervention in paper and pencil format, another group received the same intervention in digital format, and a third was a non-treatment group. Executive functions were evaluated using the Eriksen flanker task, while basic mathematical skills were evaluated using the Test for Diagnosis Assessment of Mathematical Disabilities (TEDI-MATH).

The results showed significant improvements in the two groups that received the intervention. However, there were no differences between the two modalities of intervention, except in the total reaction time for the tasks of inhibitory control. The group that received the intervention in digital format obtained shorter total reaction times.

The data obtained support the idea that it is possible to improve executive functioning and basic math skills in early childhood education. However, it was the content and not the format of the tasks used that determined the observed changes.

Keywords

Early childhood education, Games, Simulations

1. Introduction

This paper analyses the effectiveness of educational intervention programs, and the specific potential of technology based on gesture-controlled games for improving cognitive flexibility (CF), inhibitory control (IC) and basic mathematical skills (BMSs) in early childhood education.

There is abundant scientific literature that shows the role that ICTs play in the development of programs for the improvement of specific processes and skills. However, it is rare to find studies comparing how traditional and digital learning methods affect learning outcomes (Beavis, 2017; Hendriks, 2014)

This study responds to the need to distinguish the effects of the use of digital convergence and virtual environments from those derived from the task content.

1.1. Executive functions and mathematical skills

Executive functions (EFs) are constituted by higher mental processes that regulate, coordinate and control the cognitive processes of human beings during the performance of tasks and during the performance of behaviours that have as an objective the achievement of a pre-established goal (Miyake et al., 2000). These are skills involved in the initiation, supervision, regulation, implementation and readjustment of behaviours to achieve complex objectives, especially those that require a novel and creative intervention (Verdejo-García & Bechara, 2010; Baggetta & Alexander, 2016). Miyake et al. (2000) described three components: working memory (WM), CF and IC. This point of view is also maintained by authors such as Diamond (2013) and Thorell et al., (2009).

We agree with the arguments of Welsh et al. (2010) who raised the possibility that the relations between EF and mathematics skills could be reciprocal, as stronger conceptual and procedural knowledge may free up EF resources that can then be devoted to mathematical tasks.

BMSs refer to the mental operations necessary for the elaboration and use of mathematical concepts and properties, for example, BMSs for simple memorization, BMSs for the elaboration and use of algorithmic procedures, BMSs for the elaboration and use of concepts and properties, and BMSs for analysis and problem solving (Brown & Borko, 1992). Research has shown that the relationship between EFs and BMSs is essential during the early stages of development (Clark et al., 2013; Clements et al., 2016).

In a recent study on the predictive value of EFs with respect to performance in language and mathematics in early childhood education, Rosas et al., (2017) found that EFs, together, predicted between 15% and 23% of the general academic performance, between 10% and 14% of the reading performance and between 9% and 19% the mathematics performance of boys and girls. Considered separately, only WM and IC had predictive capacity, but not CF.

Below, we present the most relevant conclusions with respect to three EFs that, at early ages, are related to BMSs performance: WM, IC and CF.

WM is responsible for storing and mentally managing information (i.e., when information is no longer being perceived). For researchers in this area, WM is a system that maintains, temporarily and actively, a limited amount of information to achieve immediate or short-term goals (Baddeley, 2000; Diamond, 2013).

The most relevant research results regarding the relationship between WM and mathematical performance revealed that the relationship is evidenced in both children and adults (Bull & Lee, 2014; Raghubar et al., 2010) and is more important during early development in childhood. Solving any mathematical problem, however simple or complex, involves simultaneous operations of storage and processing operations. That is, keeping information, operating with its elements and storing the results to continue processing (Clark et al., 2013; Clements et al., 2016; Thorell et al., 2013).

The importance of each component of WM is not the same for all the BMSs. Thus, verbal work memory is related to processing numerical words and coding tasks, and visuospatial WM is related to mental representation and problem solving (Li & Geary, 2013; Peng et al., 2015).

Finally, WM can act as a predictor of performance in mathematics (Alloway & Alloway, 2010; Alloway et al., 2014), with its predictive value being much more powerful than that of other EFs (Friso et al., 2013).

IC is considered a primary component of executive functioning, given that it is one of the first EFs to develop (Carlson & Moses, 2001). This component of executive functioning allows us to consciously direct our attention to stimuli that will enable us to conduct a task. This cognitive function permits us to avoid thoughts, behaviours, or emotions unsuited to the demands of a given situation (Friedman & Miyake, 2004; Diamond, 2013). Examples of IC in kindergarten would be: waiting to go outside for recess after the bell sounds, a game of musical chairs, raising one's hand to participate, etc.

The majority of studies show that the relationship between IC and WM is very strong at early ages, to the extent that IC would prevent saturation of WM. The fact that boys and girls with various difficulties in mathematics are not able to eliminate the information present in WM causes overload and, therefore, causes children to fail at effectively satisfying the demands of the tasks. In short, difficulties in IC could be related to difficulties in WM (D'Amico & Passolunghi, 2009; Nigg, 2000; Passolunghi & Siegel, 2001; Szűcs et al., 2013). However, a small number of studies have found no differences in IC between children without and with difficulties in mathematics (Censabella & Noël, 2005; Censabella & Noël, 2008). These results could be due to variables such as the age of the subjects or the evaluation tests used.

After reviewing the literature, it can be concluded that the predictive value of IC with respect to mathematics difficulties is greater than that of WM during the first years of schooling (Aragón et al., 2015; Bull & Lee, 2014; Lan et al., 2011) and can extend to the first primary education courses (Ng et al., 2014).

Finally, CF is the ability to adapt thoughts and behaviours according to changing task demands (FitzGibbon et al., 2014). It allows us to adjust to the demands posed by the environment in an efficient manner (Miller & Cohen, 2001) by creating alternative ways of solving problems from multiple perspectives (Diamond, 2012), shifting our attention, or changing our strategies according to stimuli (McGowan et al., 2018). Examples of cognitive flexibility in kindergarten would be: in the area of Maths, doing series with a changing given criterion that; in the area of Language, producing different words with

the same letters; in the area of psychomotricity, playing games while changing the rules; in the area of autonomy and personal initiative during the assembly encouraging them to put themselves in other people's place and to understand different points of view.

Since CF develops later, it is difficult to find early childhood education data that demonstrate the relationship between CF and performance in mathematics (Bull & Lee, 2014). For this reason, it cannot be considered a predictive variable of mathematical performance during childhood education.

Therefore, the components of executive functioning begin to develop at an early age, although with different trajectories. Best and Miller (2010) pointed out that IC develops significantly between 3 and 5 years, after which it slows considerably and finally stabilizes at 12. While WM develops gradually between 4 and 14 years. In the case of CF, development is also gradual until reaching stability at 15 years.

The preschool stage plays an important role in the development of FE between 3 and 6 years. Much of the curricular activity is aimed at mastering the planning, supervision and control skills that define FE and are expressed through tasks and games that involve WM, IC and CF in isolation or in combination. This type of process always appears contextualized in tasks of a verbal, mathematical, socio-emotional nature, etc. that give educational meaning to its realization. Kindergarten contributes to learning curricular content as well as metacognitive development. Both essential for later learning.

The development of the components of executive functioning allow the individual to respond to changing task demands, maintain context or problem-specific information active in WM and inhibit distracting information (Diamond, 2013, 2016; Baggetta & Alexander, 2016).

1.2. Digital game-based learning and gesture-based learning (GBL)

Digital game-based learning (DGBL) is defined as a type of video game that includes learning models and educational content whose main objective is to improve learning (Prensky, 2003). One of the main challenges of current education is to increase the motivation of students towards learning and maintaining attention in class. Given that students present a high level of interest in computer games when compared to traditional classes (Whitton, 2014; Prestridge, 2017; Liao, 2010), some researchers and teachers incorporate digital/video games in the learning experience.

In the last decade, based on new technologies, companies have developed a series of games that are based on interactivity. For example, the WiiMote and motion controllers for PlayStation, Kinect V1 and V2 for Xbox, and PCs (Han et al., 2017) are instruments that allow recognition of the hands of players, as well as specific movements of the body. In this way, with these devices, the player can enjoy a more natural and fun experience that increases motivation and physical activity. This technology not only tracks the movements of the joints but also recognizes head, face, hand, arm, and/or body movements. Thus, the recognition of gestures allows the establishment of natural communication with the computer without the need to use mechanical devices.

Therefore, it is important to develop games that include gesture recognition. Applications are currently emerging that focus on GBL (Hostetter & Alibali, 2008; Tellier, 2008). These applications are particularly relevant because they imply an increase in physical activity, which is fundamental in the face of current sedentarism. In recent years, several experiences have been developed based on this learning paradigm, such as software promote students' reasoning skills in engineering and technology which includes Scratch, Puzzle, Simulation, Video Game, Kahoot and Brain Blast (Abdul et al., 2019), geography courses (Tüzün et al., 2009), language learning, such as Chinese (Hao et al., 2010) and English (Liu & Chu, 2010), and mathematics (Alzubi et al., 2018; Hung et al., 2012; Hung et al., 2014). In addition, research has shown the positive impact of DGBL on the acceptance and efficiency of teachers (Ketelhut & Schifter, 2011; Prestridge, 2017); the self-efficacy of children (Chen, 2017; Hung et al., 2014); collaboration or interaction between equals (Baek & Touati, 2020; Beavis et al., 2017); and the content to be evaluated (Nelson et al., 2011).

Given this relationship between EF and BMSs, how can we improve them through clinical or educational intervention, and what can instructional technology contribute to the design of educational programs?

In a previous study, Fernández, et al. (2019), using two experimental groups and a control group of children in early childhood education, compared the application of a virtual programme based on interactive learning through games using gestures with the application of the same programme in paper and pencil format. The results showed improvements in both WM and in BMSs in the two groups to which the programme was applied, regardless of the format in which it was presented.

The aims of this study are the following: 1) analyze the way in which intervention formats (technological or not) affect the improvement of MBSs and executive functioning, 2) Check if the performance of tasks involving IC or CF affect the level of competence in MBSs.

2. Method

2.1. Design

To carry out the present study, a 3×2 factorial design with repeated measures was used, with an intergroup factor (group that received the intervention in digital format, group that received the intervention in paper and pencil format, and control group without intervention) and an intragroup factor as a function of the moment of measurement (pre-test and post-test evaluation). The dependent variables were EFs, CF and IC, as well as BMSs.

2.2. Participants

The sample was selected from boys and girls in the third year of the second cycle (children 3 to 6 years old) of early childhood education at a school for early childhood and primary education in A Coruña (Spain). The selection of the educational centre was intentional due to the interest of teachers in the use of information and communication technologies (ICTs).

The total sample consisted of 41 boys (45.55%) and 49 girls (54.44%) between the ages of 5 and 6 years old ($M = 5.6$). To recruit the participants, the recommendations of the Ethics Committee of the University of A Coruña were followed; permission was requested from the school management, an informed consent forms were signed by the parents. A meeting was held with the teachers; they were informed of the objectives of the study as well as the inclusion and exclusion criteria.

The inclusion criteria were education level (3rd year of the 2nd cycle of early childhood education) and age between 5 and 6 years. The exclusion criteria were children with specific educational support needs or special educational needs, educational reinforcement or curricular adaptation plans, or a relaxed educational path and, therefore, an age greater than 6 years.

The 90 participants were divided randomly into three homogenous groups of 30 subjects each: one group received the educational intervention programme in digital format, another group received the same intervention in paper and pencil format, and a third group received no intervention and served as the control group.

2.3. Instruments

First, the instruments used for the evaluation before and after the training are described. The instruments were identical for both evaluation phases and were used with all participants regardless of the group.

The *Test for Diagnosis Assessment of Mathematical Disabilities (TEDI-MATH)* was used to evaluate BMSs (Grégoire et al., 2001). It is an individual application test, with a duration of approximately 30 minutes. It allows obtaining data about the main mathematics competences in children between the ages of 4 and 8 through 5 areas: logical operations with numbers, verbal number sequences, numerical quantification processes, number systems, and arithmetic. It consists of six tests: counting, numbering, comprehension number system, logical operations, operations and estimation of size.

Counting is made up of four subtests: counting up to the highest number, having an upper limit, having a lower limit and having lower and upper limits. Numbering consists numbering linear sets, numbering random sets and abstraction of counted objects. Comprehension number system is made up of two subtests, Arabic number system and the oral number system. Logical operations covers numerical series, numerical classification, numerical conservation and numerical inclusion. Operations includes operations with image support, operations with arithmetic statement and operations with verbal statement. Finally, size estimation consists of comparing scattered point models. The direct score for each test is obtained as a result of the number of correct answers, which is transformed into typical scores using an age scale.

The reliability of all indices measured through Cronbach's α exceeds .90 in the majority of cases. The calculation of Cronbach's α with the data from the sample that participated in this study revealed a reliability of .86 for the pre-training scores and .90 after the end of training.

CF and IC were evaluated using the *Eriksen flanker task* (Diamond et al. 2007). It is a computerized test that has been typified for children 5 years of age and older. This task

is organized in three blocks in which there are fish with arrows inside: a block in which only blue fish are present, a second block in which only pink fish are present and a third block in which fish of both colours are present. Each block has the same number of congruent stimuli (all the arrows in the fish point in the same direction) and incongruent stimuli (when the arrows in the fish on the sides and the fish in the middle point in different directions). If the fish are blue, the indication is to look at the fish in the middle, and if the fish are pink, the indication is to look at the fish on the sides.

Following Röthlisberger et al. (2012), overall precision, overall reaction time in milliseconds (mean response time), and the conflict score in milliseconds (average response times by subtracting the incongruent assays from the congruent assays) were considered indices of IC. All data were extracted from the responses in block 2 (pink fish).

With respect to CF, the variables that were taken into account were the overall precision in the congruent tests and the reaction time in milliseconds. The data were obtained from the responses in block 3 (mixture of blue and pink fish).

Regarding the intervention phase, the *Virtual Intervention Programme to Improve Executive Functions and Basic Mathematical Skills in Early Childhood Education* was used (Alzubi et al., 2018; Fernández, et al., 2019), as well as a similar version in paper and pencil format. The programme includes nine tasks: three to train visuospatial memory, three for CF, and three for IC. Table 1 and Table 2 provide a brief description of the activities in the virtual intervention programme that improve CF and IC, as these are the focus of this work. Appendix A and Appendix B show the instructions and illustrations for each of the tasks

Table 1

Description of Activities to Improve CF

Activity	Description
We go up and down!	Four numbers and a ladder are shown, and the numbers on each rung must be arranged from least to greatest and then from greatest to least. Throughout the test, participants have to change their approach to satisfactorily complete the activity.
Fish of colours!	Different coloured fish and a colour circle appear, which varies, indicating the colour of the fish to catch.
Is it from inside or from outside?	First, ten objects inside and outside the classroom are shown for a few seconds. Then, an avatar appears, and the child decides, raising the right hand, if the object is from inside the

	classroom; if the object is outside the classroom (variable instruction during the test), the child does nothing. Finally, participants indicate the number of objects inside the classroom and outside the classroom by adding or subtracting on a counter.
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Table 2

Description of Activities to Improve IC

Activity	Description
We play with the numbers!	A row of numbers is shown for one minute. They appear again with a blank space, which is filled in by the child.
We play musical chairs!	This game is similar to musical chairs, but instead of placing five classmates, they only change two and have to move only the changed classmates, controlling the initial impulse to move several.
The statues!	Two avatars appear with two balls at the top. Participants must reproduce the movement of the avatars when the balls are green and remain still if the balls are red.

In addition to the virtual version, the programme was also applied in a paper and pencil format, for which materials similar to those for the digital version were designed. The tasks were identical to those of the digital intervention.

For the application of the virtual programme, a computer (Kinect VI or similar apparatus to capture the movements of the body and the extremities) and a projection screen.

2.4. Procedure

The work was carried out in the math schedule through three phases: an evaluation phase prior to the intervention, the training phase in which the programme was applied in digital format and paper and pencil format, and finally an evaluation phase at the end of the study to determine if the set objectives had been achieved.

Prior to beginning the study, permission was granted by the school management and informed consent forms were signed by the parents. Subsequently, a meeting was scheduled with early childhood education classroom tutors to inform them about the work and to request their collaboration in the selection of participants based on the inclusion and exclusion criteria.

Once the participants were selected, they were distributed into three homogeneous groups according to the training they would receive (digital, paper and pencil, or control). All of the participants underwent a pre-training evaluation during which measures of BMSs, CF and IC were obtained. Each individual implementation had a maximum duration of 45 minutes. This phase took place over a period of three weeks.

Next, the educational intervention was applied to the two groups that received the training, while the control group only completed the second evaluation. To carry out training in the school, an ICT corner was created for the digital group, and a corner without ICT was created for the paper and pencil group. In the ICT corner, the material used was a computer, a screen, a Kinect VI, and the *Digital programme to improve EF and BMS in Early Childhood Education*. The corner without ICT was provided with the necessary materials to be applied in paper and pencil format. In both cases, the educational intervention was carried out in 20 30-minutes sessions during a seven week period, at a rate of three sessions per week that were performed with different types of grouping (as individuals, in pairs and in groups of five) depending on the type of task

After the training period, all children (including those in the control group) underwent a second evaluation phase, using the same instruments as that used for the pre-intervention evaluation. The duration of this phase and the implementation times were the same as those of the pre-training evaluation phase.

2.4. Data analysis

Data analysis was performed using the statistical programme Statistical Package for Social Sciences (SPSS) version 23. A multivariate analysis of variance of repeated measures with a intergroup factor with three levels (Control, Paper and Pencil and Digital) and an intragroup factor (pre-posttest) with post hoc analysis was performed.

As dependent variables were introduced:

For IC (Eriksen Flanker Task): overall precision, overall reaction times, conflict score, extracted from block 2.

For CF (Eriksen Flanker Task): the overall precision in the congruent tests was analysed, as well as the reaction time in milliseconds, extracted from block 3.

For BMS (TEDI-MATH): the total score obtained in the test, which takes into account the total correct answers provided by the participants.

The data for participants who committed three or more errors in block 1 were discarded (four participants), leaving a total sample of 86 (27 in the digital group, 30 in the paper and pencil group, and 29 in the control group).

3. Results

The multivariate analysis of repeated measures carried out shows the existence of a significant effect due to the two main factors. For the intergroup factor: $F(12,158) = 2,885$, $p < .001$, $\eta^2 p^2 = .180$, $1-\beta = .986$. For the intra-group factor (pre-post-test): $F(6,78) = 93.47$, $p < .001$, $\eta^2 p^2 = .878$, $1-\beta = 1,000$. Additionally, the analysis reveals the existence of a significant interaction between the group factor and the pre-post-test factor: $F(12,158) = 4.10$, $p < .001$, $\eta^2 p^2 = .298$, $1-\beta = 1,000$.

3.1. Executive functions

As specified above, the data obtained in the Eriksen flanker task with respect to IC were analysed as a function of the variables overall precision, overall reaction times, conflict score, obtaining data from block 2. For CF, the overall precision in the congruent tests was analysed, as well as the reaction time in milliseconds, extracted from block 3. Below, the results obtained for each of these variables are presented.

3.1.1. Inhibitory Control

First, a descriptive analysis of the data obtained for the variable *overall precision* was performed (see Table 3). The analysis shows an increase in the mean percentage of correct answers in the post-training evaluation phase for all groups, being more pronounced in the two groups that received the intervention.

Table 3
Percentage of Correct Pre- Post-Test Responses in Block 2 of the Eriksen Flanker Task

Groups	Pre-training evaluation	Post-training evaluation
	M (DT)	M (DT)
Control	93.39% (7.49%)	96.10% (3.60%)
Paper and pencil	93.50% (7.49%)	99.20% (1.04%)
Digital	93.80% (7.60%)	99.50% (1.11%)

Levene's test of equality of variances showed that the groups were homogeneous before starting training ($F(2, 83) = .21, p = .80$) but not at the end of the training ($F(2, 83) = 31.26, p < .001$).

The analysis revealed statistically significant intragroup differences between the two evaluation phases ($F(1,83) = 38.13, p < .001, \eta_p^2 = .31, 1-\beta = 1.00$), with no interaction between group and time of evaluation ($F(2,83) = 1.66, p = 0.196, \eta_p^2 = 0.38, 1-\beta = 0.341$).

Regarding the intergroup effects, the data indicated the absence of statistically significant differences among the three groups ($F(2,83) = 1.58, p = .211, \eta_p^2 = .037, 1-\beta = 0.327$). In this sense, the Bronferroni test showed that there were no statistically significant differences between the digital group and the paper and pencil group, between the digital group and the control group, and between the paper and pencil group and the control group.

A second variable analysed was the *overall reaction time*, that is, the mean response times. Table 4 shows the results of the descriptive analysis for each of the groups. The reaction times were shorter in the evaluation performed after training.

Table 4
Pre- and Post-Test Response Times in Block 2 of the Eriksen Flanker Task

Groups	Pre-training evaluation	Post-training evaluation
	M (DT)	M (DT)
Control	21070 (4402)	15798 (3080)
Paper and pencil	21820 (3578)	13762 (3002)
Digital	19005 (3232)	12658 (2178)

Levene's test of equality of variances revealed that the groups were homogeneous both before beginning training ($F(2,83) = 1.32, p = .271$) and at the end of training ($F(2,83) = 2.06, p = .133$).

Regarding the intragroup effect, the analysis showed the existence of statistically significant differences between the two measurement timepoints ($F(1,83) = 242.19, p < .001, \eta_p^2 = .74, 1-\beta = 1.00$), with no interaction between group and time of evaluation ($F(2,83) = 3.82, p = .026, \eta_p^2 = .084, 1-\beta = .68$).

In addition, it was possible to verify the existence of statistically significant differences among the three groups ($F(2,83) = 7.03, p = .002, \eta_p^2 = .14, 1-\beta =$

.920). Post hoc analyses using the Bronferroni test revealed differences between the digital group and the control group ($p = .002$) and between the digital group and the paper and pencil group ($p = .002$), but not between the paper and pencil group and the control group ($p = 1.00$). Therefore, regarding overall reaction times, there are differences depending on the resources used, specifically in favour of the group that received the educational intervention in digital format followed of the paper and pencil group.

Finally, the last variable related to IC that was analysed was *conflict score*, that is, the average response time obtained after subtracting the incongruent trials from the congruent trials. The data from the descriptive analysis shown in Table 5 indicate that there was only an increase in the scores obtained for this variable in the group that received training in digital format.

Table 5
Pre- and Post-Test Score in Block 2 of the Eriksen Flanker Task

Groups	Pre-training evaluation	Post-training evaluation
	M (DT)	M (DT)
Control	-735 (1531)	165 (996)
Paper and pencil	-1057 (1363)	229 (1726)
Digital	-518 (1253)	807 (1600)

Levene's test of equality of variances indicated that the groups were homogeneous both in the pre-training evaluation ($F(2, 83) = 1.25, p = .28$) as in the post-training evaluation ($F(2, 83) = .74, p = .47$).

The results of the analysis showed the existence of statistically significant intragroup differences between the pre-training evaluation phase and the post-training evaluation phase ($F(1,83) = 33.11, p < .001, \eta_p^2 = .285, 1-\beta = 1.00$), with no interaction between group and time of evaluation ($F(2,83) = .446, p = .642, \eta_p^2 = .01, 1-\beta = .120$).

The results also indicated that there were no statistically significant differences between the groups ($F(2,83) = 2.05, p = .13, \eta_p^2 = .04, 1-\beta = .41$). The Bronferroni test indicated the absence of statistically significant differences between each of the groups.

3.1.2. Cognitive flexibility

As indicated above, for CF, overall precision was analysed in the congruent tests, as well as the reaction time in milliseconds, extracted from block 3.

Table 6 shows the results of the descriptive analysis for *overall precision in the congruent tests*. As seen, there is a decrease in errors in the two groups that underwent training (digital and paper and pencil).

Table 6

Overall Precision in the Congruent Tests in Block 3 of the Eriksen Flanker Task

Groups	Pre-training evaluation	Post-training evaluation
	M (DT)	M (DT)
Control	1.25 (1.99)	1.20 (1.56)
Paper and pencil	2.03 (2.34)	0.27 (0.45)
Digital	0.88 (1.18)	0.26 (0.45)

Levene's test of equality of variances indicated that the groups were not homogeneous neither before starting training ($F(2,83) = 4.43, p = .015$) nor at the end of training ($F(2,83) = 9.02, p < .001$).

Repeated measures ANOVA results showed the existence of statistically significant intragroup differences between the pre-training evaluation phase and the post-training evaluation phase ($F(1,83) = 12.72, p = .001, \eta_p^2 = .13, 1-\beta = .94$) as well as an interaction between group and time of evaluation ($F(2,83) = 5.01, p = .009, \eta_p^2 = .11, 1-\beta = .801$).

Regarding the intergroup effects, ANOVA revealed the absence of statistically significant differences among the groups ($F(1,83) = 2.96, p = .06, \eta_p^2 = .07, 1-\beta = .56$).

The results of the descriptive analysis of *reaction time* in block 3 are shown in Table 7.

Table 7

Pre- and Post-Test Response Times in Block 3 of the Eriksen Flanker Task

Groups	Pre-training evaluation	Post-training evaluation
	M (DT)	M (DT)
Control	3624.29 (950.74)	3012.03 (866.81)
Paper and pencil	4068.62 (953.15)	2783.89 (1401.85)
Digital	3330.56 (695.67)	2466.51 (551.37)

Levene's test showed that the groups were homogeneous with respect to reaction time both before ($F(2,83) = 1.71, p = .18$) and after ($F(2,83) = 1.21, p = .30$) training.

Repeated measures ANOVA showed the existence of statistically significant differences between the two measurement timepoints ($F(1,83) = 45.97, p < .001, \eta_p^2 = .35, 1-\beta =$

1.00), with no interaction between group and time of evaluation ($F(2,83) = 2.15, p = .12, \eta_p^2 = .05, 1-\beta = .43$).

However, significant differences were found among the groups ($F(2,83) = 4.26, p = .01, \eta_p^2 = .09, 1-\beta = .73$). Post hoc analyses revealed differences only between the digital group and the paper and pencil group ($p = .020$). The digital group obtained better scores than did the other two groups.

3.2. Basic Mathematical Skills

BMSs were evaluated using the TEDI-MATH (Grégoire, et al., 2001), analysing the total score obtained in the test, which takes into account the total correct answers provided by the participants.

From the descriptive analyses, the total TEDI-MATH score increased in all groups with respect to the pre-treatment evaluation, especially in the two groups that received the training, regardless of the format (Table 8).

Table 8
Total BMSs Scores in the Two Phases of Evaluation

Groups	Pre-training evaluation	Post-training evaluation
	M (DT)	M (DT)
Control	1061 (252)	1178 (235)
Paper and pencil	1046(263)	1536 (131)
Digital	1105 (286)	1573 (128)

Levene's test indicated that the groups were homogeneous before starting the training ($F(2, 83) = .479, p = .621$) but not post-training ($F(2, 83) = 10.08, p < .001$).

ANOVA revealed the existence of differences between the two evaluation phases ($F(1,83) = 310.6, p < .001, \eta_p^2 = .789, 1-\beta = 1.00$), showing an interaction between group and time of evaluation ($F(2,83) = 35.75, p < .001, \eta_p^2 = .463, 1-\beta = 1.00$).

The data indicated the existence of statistically significant differences among the digital group, the paper and pencil group and the control group ($F(2,83) = 9.04, p < .001, \eta_p^2 = .179, 1-\beta = .97$).

The Bronferroni test indicated statistically significant differences between the digital group and the control group ($p < .001$) and between the paper and pencil group and the control group ($p = .006$) but not between the digital group and the paper and pencil group ($p = 1.00$). Therefore, there were differences in terms of receiving or not educational intervention, in favour of the educational intervention, but not in terms of the resources used in that educational intervention.

4. Discussion and conclusions

In the present study, the effectiveness of a virtual programme based on gesture-controlled games for improving CF, IC and BMSs in early childhood education was analysed. The results obtained after application of the programme were compared with those obtained after application in paper and pencil format and with no intervention. Previous research found that the tasks, not the format in which they were presented, produced considerable improvements in WM (Fernández, et al., 2019).

First, with respect to IC and CF, the descriptive analyses showed higher scores for the post-treatment evaluation of the variables that were evaluated in all groups when compared with the scores for the pre-treatment evaluation.

However, the overall reaction times in IC were different only in the group that received training in digital format. The statistically significant improvements in EF and BMS after the intervention are congruent with previous studies by (Aragón et al., 2015; Bull & Lee, 2014) Regarding CF, there were statistically significant differences in reaction times between the two groups that received training (regardless of format) and the control group, with the digital group obtaining better scores.

For total BMS score, the descriptive analyses showed that all groups obtained higher scores after training. However, there were only statistically significant differences between the two phases for the two groups that received training. The differences between the two groups were not significant.

These results are similar to those obtained for WM (Fernández, et al., 2019) because the modality of training presentation did not influence the results, except overall reaction times for IC.

The improvement in overall reaction times in the group that received the educational intervention in digital format may have resulted from improved participant processing speed and, therefore, a better response time; that is, the participants react faster and, therefore, they take less to inhibit a behaviour.

The improvement in BMSs in the two groups that received training may have occurred because the development of EF indirectly favours the increase in these skills, as reflected in the work by Thorell et al. (2013), Toll et al. (2011), and Wiklund-Hörnqvist et al. (2016).

The main difference with respect to the development of the two EFs is that IC develops at an early age (Carlson & Moses, 2001), while CF develops later (Bull & Lee 2014). For this reason, it is difficult to find data for early childhood education that show improvements in this EF. The results obtained in this study suggest that for IC, training with technological resources can favour aspects related to the automation of processes. For CF and IC, the results seem to indicate that training with technological resources favours the development of processes related to managing electronic devices, as indicated in research by Han, et al. (2017).

However, currently, research results on the relationship between EFs and BMSs during the early childhood education stage are contradictory. Some studies suggest a strong association between EFs and mathematical skills (Brock et al., 2009; Willoughby et al., 2012), while others consider a more general association between executive functioning and academic performance (Best et al., 2011; Welsh et al., 2010). For Booth, et al. (2014), the differences in the results could be due to the different tests used to evaluate EFs.

Ultimately, and in relation to the results obtained in the present study, along with earlier research, it could be argued that learning BMSs in early childhood education depends on a good WM as well as a good rate interference control, with a high level of CF. The importance of the latter increases with schooling, as it is related to more complex mathematical skill processes. Despite numerous studies that suggest that both WM and IC are predictive variables of mathematics performance during this stage of education, and that CF has a stronger effect at later educational stages (Aragón et al. 2015; Bull & Lee, 2014; Lan et al. 2011; Ng et al. 2014), our results point to consistent relationships between CF and BMSs sooner, at the Early Childhood level.

The relevance of these results can be seen from the perspective of Rosas et al. (2017), who noted that improving executive functioning during the early childhood education stage can favour better access to primary education, given its relationship with adequate academic performance in general and, especially, in language and mathematics.

Finally, our results support the idea that new technologies, compared with similarly structured traditional resources, lead to comparable improvement. Nevertheless, we agree with Beavis (2017) and Hendriks (2014) that instructional technologies provide specific learning related to their particular characteristics and functioning (response speed, visual-motor control, self-efficacy with computers, motivation, etc.). Further research controlling for these variables can strengthen these approaches.

A strength of this study, compared to previous studies, was including not only a control group without training but also a traditional training in a paper and pencil group, thus allowing greater generalization of the results.

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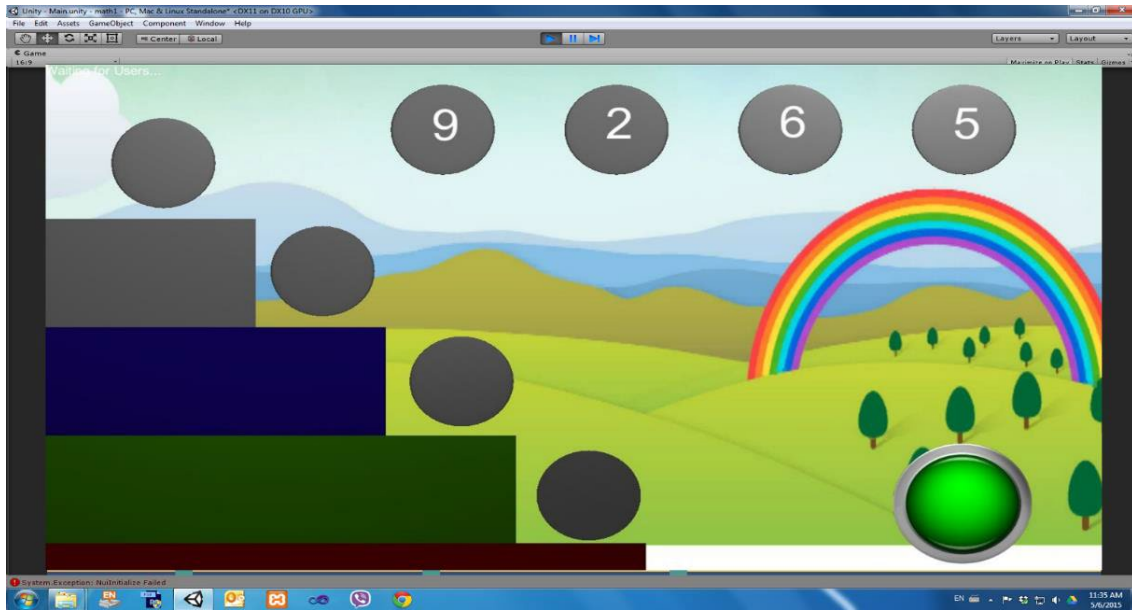
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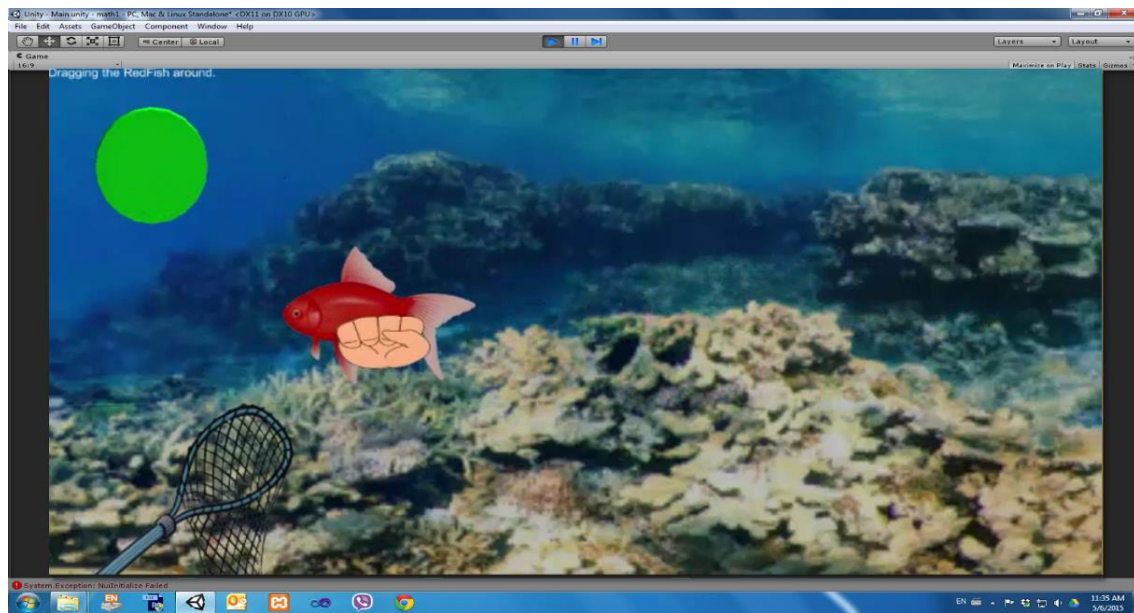
APPENDIX I: Activities to improve CF

Activity 1: We go up and down



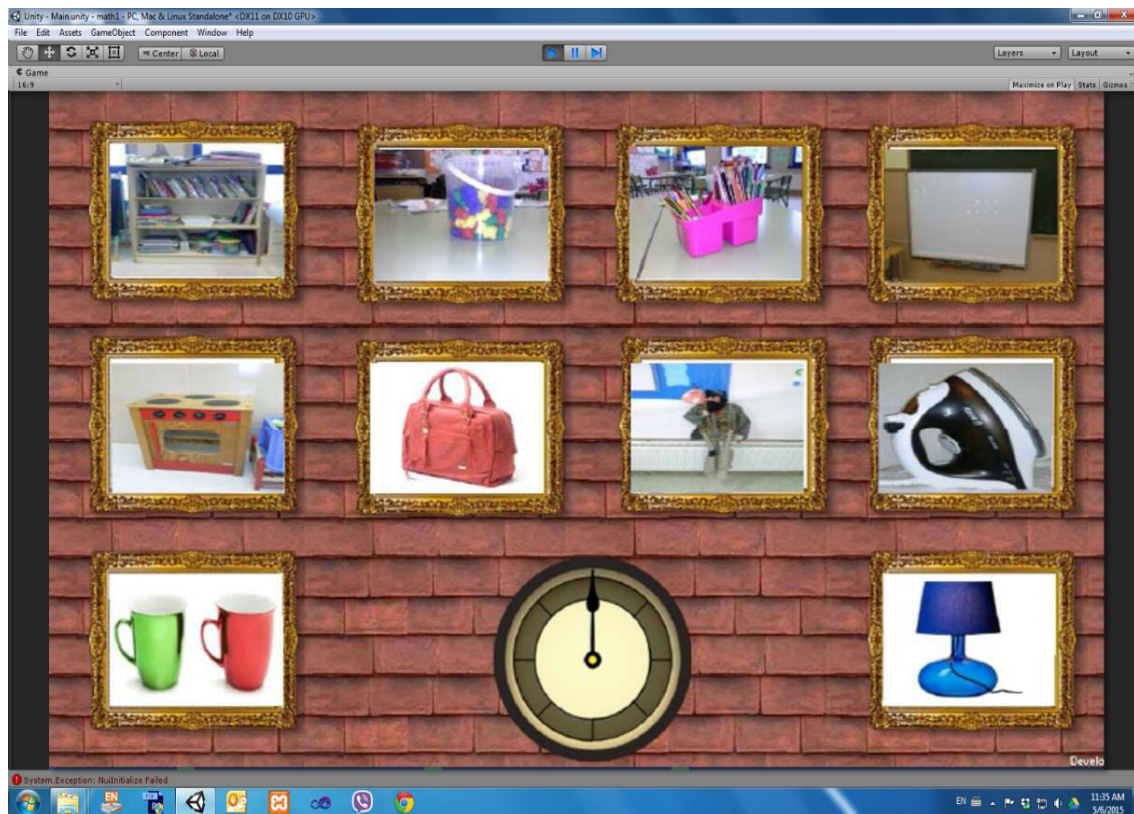
INSTRUCTION: You are going to play to order the numbers on the screen, so you have put the smallest number in the lowest rung and then place the other numbers. Then they will do a reverse pattern.

Activity 2: Fish of colours



INSTRUCTION: You are going to catch fish. However, you have to be very careful because only able to catch the fish of the colour of the circle in the top of the screen. Then they will do a reverse pattern.

Activity 3: Is it from inside or from outside?



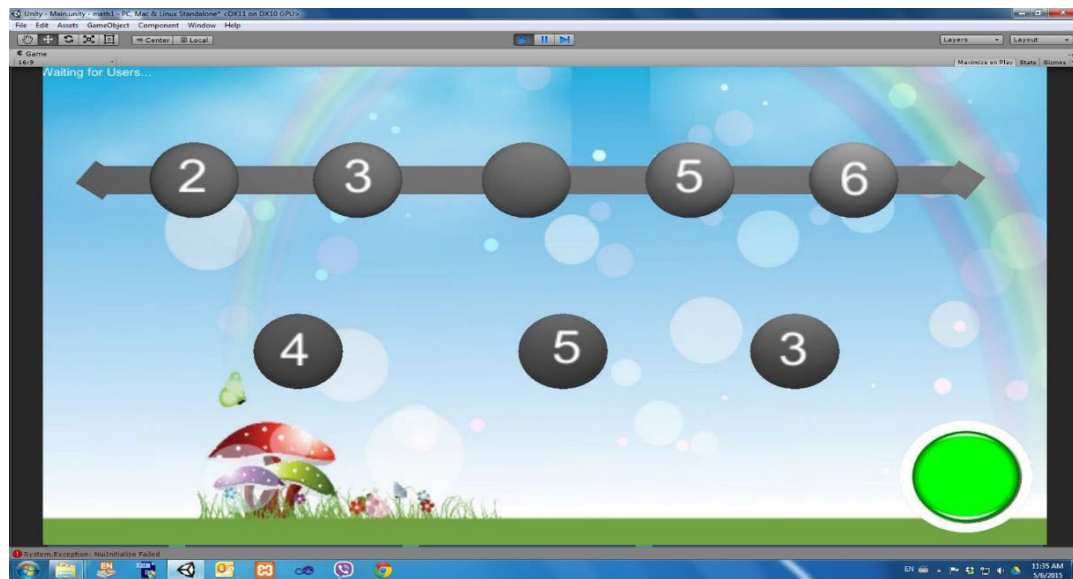
INSTRUCTION: First, it is shown a screen with ten objects (from inside and outside classroom) for a few seconds. Then, they access a screen with a male avatar for boys and a female avatar for girls. On this screen, boys and girls will have to decide if the object is from inside the classroom or from outside the classroom. If they decide that the object is from outside it will fall towards the left side where there is an image that represents a situation outside the classroom and if they decide that the object is from inside it will fall towards the right side where there is an image that represents a classroom.

The first time students do the task, they will have to raise their right hands if the object is from inside the classroom and do nothing if the object is from outside. The second time change the pattern and they have to raise their right hands for objects outside the classroom and do nothing for objects from inside.



APPENDIX II: Activities to improve IC

Activity 1: We play with the numbers



INSTRUCTION: "You have to order numbers. As you can see on the screen above there is a row with numbers and a blank space, you have to fill in that blank space with the corresponding ball from the ones below".

Activity 2: We play musical chairs



INSTRUCTION: “You have to remember how your classmates were sitting on the first screen. You are going to see several of your colleagues sitting on the screen, then they will disappear and they will appear seated, but there will be two who have changed the place. You have to look at the two who have changed the site and place them correctly, but without moving the rest of your colleagues”.

Activity 3: The statues



INSTRUCTION: “You have to imitate the movements of the avatars in the middle part of the screen. However, you can only imitate him when the balls above your head are green. When they are red, you have to stay very still, without moving.