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Virtual Intervention Programme to Improve the Working Memory and Basic Mathematical Skills in Early Childhood Education[☆]

Raquel Fernández-Abella*, Manuel Peralbo-Uzquiano, Montserrat Durán-Bouza, Juan Carlos Brenlla-Blanco, and Manuel García-Fernández

Departamento de Psicología, Facultad de Ciencias de la Educación, Universidad de A Coruña, A Coruña, Spain

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ABSTRACT

The present work proposes as the main objective the design and implementation of a virtual educational intervention programme, based on interactive learning through gesture play, to improve working memory and basic mathematical skills. In addition, the results were compared with those of the application of the programme in paper and pencil format. A factorial design of repeated measurements was used with an inter-group factor (control, paper and pencil and technology) and an intra-group factor (pretest–postest). As dependent variables, the visuospatial memory width provided by the Corsi Test was used, as well as the individual results according to the scale, and the total number of successes in the Test for the Diagnosis of Basic Mathematical Competences (TEDI-MATH). Ninety children between the ages of 5 and 6 participated and were distributed in three groups of 30 subjects: one group to which the programme was applied in virtual format, another to which the programme was applied in paper and pencil format and a control group without treatment. The results showed improvements in both working memory and basic mathematical skills in the two groups that received the intervention versus the control group. Therefore, it seems that it is the structure and content of the tasks and not so much the resources used that are responsible for the changes observed.

Programa de intervención virtual para mejorar la memoria de trabajo y las habilidades matemáticas básicas en Educación Infantil

Palabras clave:
Funciones ejecutivas
Memoria de trabajo
Habilidades matemáticas básicas
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RESUMEN

El presente trabajo plantea como objetivo principal el diseño y la puesta en práctica de un programa de intervención educativa virtual, basado en el aprendizaje interactivo a través del juego de gestos, para la mejora de la memoria de trabajo y las habilidades matemáticas básicas. Además, se comparan los resultados con los de la aplicación del programa en formato papel y lápiz. Se utiliza un diseño factorial de medidas repetidas con un factor inter-grupo (control, papel y lápiz y tecnológico) y un factor intra-grupo (pretest-postest). Como variables dependientes se utilizan la amplitud de memoria visoespacial proporcionada por el Test de Corsi, así como los resultados individuales según baremo, y el total de aciertos en el Test para el Diagnóstico de las Competencias Básicas en Matemáticas (TEDI-MATH). Han participado 90 niños y niñas de entre 5 y 6 años que se distribuyen en tres grupos de 30 sujetos: un grupo al que se aplica el programa en formato virtual, otro al que se aplica el programa en formato papel y lápiz y un grupo control sin tratamiento. Los resultados han mostrado mejoras tanto en memoria de trabajo como en habilidades matemáticas básicas en los dos grupos que han recibido la intervención frente al grupo control. Por lo tanto, parece que son la estructura y el contenido de las tareas, y no tanto el formato, los responsables de los cambios observados.

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* Corresponding author.
E-mail address: raquel.fernandez.abella@udc.es (R. Fernández-Abella).

Introduction

The major objective of this work was to design and implement an educational intervention programme based on virtual interactive learning through gesture-based games to improve working memory (WM) and basic mathematical skills (BMSs). WM constitutes one of the major components of executive functioning (EF). Although no agreement exists on how to define EF, most authors agree on including the set of processes that underlie conscious and planned behaviour directed towards a goal, responses to novel or difficult situations, and the ability to inhibit behaviours that divert from the objective pursued. Thus, EF comprises that which is necessary to deliberately control one's thoughts, emotions, and actions. These are self-regulatory, high-level cognitive processes that help control thought and action. These skills are composed of inhibitory control, planning, attentional flexibility, error detection, correction, and resistance to interference (Baggetta & Alexander, 2016; Carlson, 2005; Verdejo-García & Bechara, 2010).

Recently, Baggetta and Alexander (2016) indicated three fundamental aspects: (1) EF can be modified with experience; (2) EF improvement is related to academic skill enhancement (including BMSs); and (3) these changes occur under non-highly demanding classroom training conditions. Regardless of the type of theoretical model used to explain EF (single or multi-dimensional), WM is considered as one of its essential components. It is responsible for storing and mentally managing information (i.e., when information is no longer presently perceived). Therefore, WM is a system that maintains, temporarily and actively, a limited amount of information to achieve immediate or short-term goals (Baddeley, 1986, 2000; Diamond, 2013).

Relationship between WM and BMSs

BMSs are mental operations necessary to establish and use mathematical concepts and properties. They entail the use of algorithmic and heuristic procedures as well as the analysis and resolution of problematic situations of intra and extra mathematical natures (Brown & Borko, 1992). Logical operations with numbers, verbal numerical sequencing, numerical quantification processes, number systems, and arithmetic stand out among the basic mathematical competencies. The relationship between EF and BMSs/performance in mathematics is evident within the wide range of research conducted on both children and adults (Bull & Lee, 2014; Presentación, Siegenthaler, Pinto, Mercader, & Miranda, 2015; Raghubar, Barnes, & Hecht, 2010). Research confirms that this relationship is most important during early developmental stages (Clark, Sheffield, Wiebe, & Espy, 2013; Clements, Sarama, & Germeroth, 2016; Thorell, Veleiro, Siu, & Mohammadi, 2013). Table 1 presents the study results indicating this relationship in chronological order.

On the other hand, WM likely predicts performance in mathematics (Alloway & Alloway, 2010; Alloway, Alloway, & Wootan, 2014) more strongly than other EFs (Aragón, Navarro, Aguilar, & Cerda, 2015; Friso, Van der Ven, Kroesbergen, & Van Luit, 2013). Importantly, however, some reports show that the predictive value of inhibitory control on difficulties in mathematics is greater than that of WM during the first years of schooling (Lan, Legare, Ponitz, Li, & Morrison, 2011; Ng, Tamis-LeMonda, Yoshikawa, & Sze, 2015). Thus, the predictive value of WM might be influenced by development.

Currently, different studies indicate the existence of a relationship between WM and mathematical learning, although they argue that interpreting this relationship might be complicated. Thus, some studies have suggested that visuospatial WM has the greatest explanatory weight (Klein & Bisanz, 2000; Rasmussen & Bisanz, 2005). However, other studies highlight the importance of the predictive capacity of verbal WM (McKenzie, Bull, & Gray, 2003; Meyer, Salimpoor, Wu, Geary, & Menon, 2010). Although these results are contradictory, Table 2 shows some of these studies.

Considering these research results, the current work designed a virtual educational intervention programme to improve WM and BMSs in young children using technological resources.

Table 1
Synthesis of the research on the relationship between EF and BMSs

Authorship	Variables	Sample	Results
Bull and Scerif (2001)	– EF – BMS	93 *M* = 7 y. 4 m. (*SD* = 3.8 m.)	– BMSs are related to all assessment tasks, except for dual tasks. – Difficulties in WM and inhibitory control predict difficulties in mathematics.
Espy et al. (2004)	– EF – BMS	96 66 – *M* = 4.21 y. (*SD* = 0.87 y.) 30 – *M* = 3.76 y. (*SD* = 1.05 y.)	– WM and inhibitory control predict early arithmetic skills. – EF is related to emergent BMSs.
Bull, Espy, and Wiebe (2008)	– EF – PLM	124 *M* = 4 y. 6 m. (*SD* = 4 m.)	– A better EF performance entails better overall reading and mathematical performances. – Visuospatial WM specifically predicts math skills.
Brock, Rimm-Kaufman, Nathanson, and Grimm (2009)	– EF – BMS	173 children in ECE 36 Teachers	– WM and MP are directly related.
Toll, van der Ven, Kroesbergen, and van Luit (2011)	– EF – MP	227 *M* = 6.5 y. (*SD* = 4.3 m.)	– WM predicts MP better than preparatory mathematics skills.
Thorell et al. (2013)	– EF – AP	Sweden (*n* = 141), Spain (*n* = 219), China (*n* = 72) and Iran (*n* = 49) 6–11 y.	– WM and inhibitory control are related to AP.
Rosas, Espinoza, Garolera, and San-Martín (2017)	– EF – PLM	109 children in ECE	EF predicts: – 15–23% of academic performance. – 10–14% of reading performance. – 9–19% of MP. – WM and inhibitory control have greater predictive capacity.

Note. AP: academic performance, BMSs: basic mathematical skills, ECE: early childhood education, EF: executive functioning, m.: months, MP: performance in mathematics, PLM: performance in language and in mathematics, y.: years.

Table 2
Synthesis of the research on the relationship between WM and BMSs

Authorship	Variables	Sample	Results
Geary, Hoard, Byrd-Craven, Nugent, and Numtee (2007)	– WM – Performance in math tests – Processing speed	278 *M* = 73 m. (*SD* = 4 m.)	– Normal performance in mathematics denotes greater speed and precision in the identification of numerical sets, recovery and retention of numerical information, linear estimation, and ability to count. – Visuospatial WM is associated with a greater ability to recognize numerical sets.
Li and Geary (2013)	– WM – Processing speed	177 6 y. 2 m. (*SD* = 4 m.) 11 y. 1 m. (*SD* = 4 m.).	– Differences in visuospatial development during childhood indicate differences in mathematical learning.
Peng and Fuchs (2014)	– WM – Learning difficulties	29 studies	– Participants with difficulties in mathematics have deficits in WM.
Mammarella, Hill, Devine, Caviola, and Szűcs (2015)	– Short-term memory – Visuospatial and verbal WM	69 11–13 y.	– Difficulties in mathematics are related to visuospatial WM.
Wiklund-Hörnqvist, Jonsson, Korhonen, Eklöf, and Nyroos (2016)	– WM – MP	597 *M* = 9.34 y. (*SD* = 0.30 y.)	– Skills related to visuospatial WM predict MP.

Note. EF: executive functioning, m.: months, MP: performance in mathematics, WM: working memory, y.: years.

Currently, the design of this type of programme constitutes one of the most popular research topics because it enables active participation and improves teaching/learning processes (Connolly, Stansfield, & Hayne, 2007; Hao et al., 2010; Tüzün, Yilmaz-Soylu, Karakus, Inal, & Kizilkaya, 2009). A proofreading study by Romero, Benavides, Fernández, and Pichardo (2017) highlighted the positive results of EF intervention programmes beginning in preschool using various methods. In particular, programmes based on computerized training suggest that WM training might have beneficial effects in children as young as 4 and 6 years old (Holmes & Gathercole, 2014; Thorell, Lindqvist, Bergman, Bohlin, & Klingberg, 2009).

The current study used a system based on interactive learning through gesture-based games to complete the programme in a natural way. The gestures of users are scanned by devices that identify the child's location in real time. Recently, devices such as Microsoft Kinect, Asus Xtion Pro, and the Wii Remote (all directly originating from the gaming industry) have enabled the further development of this type of application (Han, Reily, Hoff, & Zhang, 2017). In this case, a Kinect V1 controller was used. This tracking device obtains a depth image of the environment in real time to determine the gestures made.

Therefore, the specific objectives of this study were to (a) determine whether it is possible to improve WM and BMSs performance through a programme designed for early childhood education; and (b) ascertain whether differences exist in the effects of the programme when implemented via Kinect/computerized tasks compared with paper and pencil. The need to differentiate between the benefits that result from the use of technology and merely performing the tasks requires us to control for use type. Hence, this study included a control group to account for the use of technology in which the tasks are performed with paper and pencil.

Method

Design

A repeated-measures factorial design with a between-group factor (control, paper and pencil, and technology) and a within-group factor (pretest and postest) was used. The dependent variables were range of visuospatial WM resulting from applying the Corsi Test, the results obtained from the scale, and the total number of correct answers on the Test for the Diagnosis of Basic Skills in Mathematics (TEDI-MATH).

Participants

Ninety children from a primary education public school in A Coruña were selected. The choice of the school was intentional because of the need to work with faculty interested and trained in new technologies. Participants were enrolled during the third level of the second cycle of preschool education. Forty-one boys (45.55%) and 49 girls (54.44%) participated. The inclusion criteria were that participants were enrolled in the third level of the second cycle in preschool education, and their ages ranged from 5 to 6 years.

The exclusion criteria were (a) having specific educational support or special educational needs; (b) having educational support or a curriculum adaptation; and (c) having an adapted course and therefore being older than 6 years.

Both the school and the guardians of the participants were informed of the research objectives following the recommendations of the Ethics Committee of the University of A Coruña. Authorization was requested from the school management, and informed consent was provided by the legal guardians.

Instruments

To assess visuospatial WM, the *Corsi Test from the Psychology Experiment Building Language (PEBL)* battery was used. PEBL is an open-source software programme that allows researchers to design and implement psychological experiments (Mueller, 2014). This test consists of showing a screen with eight blue squares, some of which turn yellow. The participant must click with the mouse on each one of the squares that light up, following the order from start to finish. The sequence increases in difficulty as the participants respond. It begins with a sample screen, and the task is completed after two consecutive mistakes are made. Postma, Kappelle, and de Haan (2000) presented test standardization and normative data.

The *TEDI-MATH* (Gregoire, Noël, & Van Nieuwenhoven, 2001) was used to assess BMSs. The TEDI-MATH is used to evaluate the strategies used by children during preschool and early elementary courses (between 4 and 8 years old) across five areas that constitute the major competencies of mathematics: logical operations

Table 3
Description of the tasks in the virtual educational intervention programme (Alzubi et al., 2018; Durán, Álvarez, Fernández, & Acuña, 2015)

Tasks	Description
Catch the fish	Participants must catch as many fish as the number that appears on the screen for a few seconds indicates.
Abacus	Three numbers, three posts, and a ball are displayed for a few seconds on a board. Participants must stack as many balls on each post as shown on the board.
The chair game	Several students are sitting and disappear; when they reappear, two students are in different seats. Participants must place them correctly without moving the others.
Sorting out numbers	A series of numbers are displayed for one minute. They reappear with a blank space to be completed with one of the numbers shown at the bottom.
The advanced chair game	Similar to the chair game, but each student must put all students in their places.
Avatars	Two avatars are shown with two red balls on top. The movement of the avatars must be reproduced with two virtual dolls when the balls are green but remain static when the balls are red.
The ladder	Four numbers and a ladder are shown. The numbers must be placed on each step from smallest to largest or vice versa.
Scuba diving	Different coloured fish and a coloured circle are shown. The colour of the circle varies, indicating the colour of the fish that must be captured.
Inside or outside	Ten objects are displayed inside and outside a classroom for a few seconds. An avatar appears, and participants must decide, by lifting their right hands, if the object is inside the classroom or do nothing if the object is outside the classroom (instructions can vary during the test). Students also must indicate the number of objects in the classroom and outside the classroom by adding or subtracting on a counter.

with numbers, verbal numerical sequencing, numerical quantification processes, number systems, and arithmetic. It provides scales for the cumulative percentages of each school group in 6-month periods. The TEDI-MATH is an individual test with an approximate 30-minute duration. The reliability of its indices (Cronbach's α) exceeds .90 in most cases. With regard to the current sample, Cronbach's αs were .86 for the pretest scores and .90 for the postest scores; McDonald's ω was .94 for both pretest and postest. The average variances extracted were .52 and .54, respectively.

During the intervention phase, the *Virtual Intervention Programme to Improve Working Memory and Basic Mathematical Skills in Early Childhood Education* (Alzubi, Fernández, Flores, Durán, & Cotos, 2018; Durán, Álvarez, Fernández, & Acuña, 2015) was used in both computerized and paper-and-pencil formats. This programme consists of two blocks: The first session introduces the technological devices and work methodology as well as presents an example test; the second session contains the nine tasks that comprise the intervention programme (see Table 3). These tasks were also used by the paper-and-pencil group.

In addition, a desktop computer, a motion-capture device of the body and limbs (Kinect VI), and a projection screen were used with the technology group during the intervention phase.

Procedure

After obtaining authorization from the educational centre and the signed consent of the legal guardians, a briefing was scheduled with the tutors to select the children based on the inclusion and exclusion criteria. Participants were randomly assigned to three groups: one group underwent an intervention based on the use of technology; another used pen and paper; and the third group constituted the control group. Levene's test was applied to ensure that the groups were homogeneous. Then, the pre-intervention test was conducted by applying the Corsi Test and the TEDI-MATH over a 40- to 45-minute period per participant. The procedure was performed in a classroom, where an ICT corner was created for the technology group and a non-ICT corner was established for the paper-and-pencil group. In both cases, the intervention is conducted in twenty 30-minute sessions, with three sessions per week conducted in small groups.

The material used in the ICT corner included a computer, a screen, a Kinect, and the "Virtual Intervention Programme to Improve Working Memory and Basic Mathematical Skills in Early Childhood Education". This programme consists of nine tasks that stimulate WM using numerical or quantitative elements through which mathematical operations are performed. The non-ICT corner provided the materials needed to conduct the educational intervention without technology. The number of sessions and the tasks used were the same as those employed in the technology group. At the end of the intervention, participants were re-evaluated by applying the same tests used during the initial assessment.

Data analyses

Data analyses were performed using Statistical Package for Social Sciences (SPSS), version 23. The data analyses included (1) descriptive analyses, and (2) a repeated-measures multivariate analysis including Levene's test for equality of variances to identify whether the groups were homogeneous in both the pretest and postest. Multivariate analyses were employed to identify whether differences were present in each group between the pretest and postest as well as to determine whether group interacted with the time of the assessment. Between-subject effect tests were used to identify whether significant differences were present among groups. Finally, post hoc tests were adopted to identify whether significant differences existed among groups.

Results

The analyses were conducted using SPSS by performing a repeated-measures ANOVA with a between-group factor (control, paper and pencil, and technology) and a with-group factor (pretest and postest). Scheffé's post hoc test was also applied. The variable used to analyze the changes in WM was the range of visuospatial memory measured through the Corsi Test. In the case of measures related to BMSs, both the total number of correct answers and the results of each task according to the scale were used.

Working memory

As Table 4 shows, all groups increased their scores at postest, although the increase was greater for the technological and paper-and-pencil groups. Levene's test for equality of variances indicated that the three groups were homogeneous at both the pretest $F(2, 87) = .87$, $p = .42$ and postest $F(2, 87) = 2.88$, $p = .06$.

Table 4
Descriptive analysis of length of memory

Groups	*M (SD) pre*	*M (SD) post*
Control group	2.73 (.78)	2.80 (.88)
Paper-and-pencil group	2.60 (.98)	4.43 (.59)
Technological group	2.56 (.89)	4.38 (.56)

Table 5
Descriptive analysis of the TEDI-MATH variables

Variables in the TEDI-MATH	Groups	*M (SD) pre*	*M (SD) post*
Counting	Control group	47.03 (24.56)	63.17 (26.12)
	Paper-and-pencil group	52.33 (23.73)	90.97 (7.13)
	Technological group	58.83 (26.85)	91.10 (8.38)
Numbering	Control group	48.77 (26.38)	54.87 (26.80)
	Paper-and-pencil group	55.97 (23.91)	96.10 (6.12)
	Technological group	51.13 (25.19)	93.73 (9.75)
Arabic number system	Control group	73.07 (36.51)	83.87 (32.98)
	Paper-and-pencil group	73.33 (36.36)	100 (.00)
	Technological group	70.10 (40.66)	100 (.00)
Written numerical decision	Control group	79.43 (38.19)	95.07 (18.77)
	Paper-and-pencil group	90.50 (28.99)	100 (.00)
	Technological group	88.30 (30.50)	100 (.00)
Comparison of Arabic numbers	Control group	62.53 (41.27)	74.30 (40.30)
	Paper-and-pencil group	74.43 (37.06)	100 (.00)
	Technological group	69.57 (41.20)	100 (.00)
Oral number system	Control group	43.70 (28.06)	47.97 (27.62)
	Paper-and-pencil group	41.97 (30.04)	77.50 (22.79)
	Technological group	49.60 (33.01)	73.33(29.12)
Oral numerical decision	Control group	42.50 (25.09)	46.10 (25.20)
	Paper-and-pencil group	41.43 (27.07)	76.93 (23.54)
	Technological group	47.40 (30.48)	71.00 (29.23)
Logical operations	Control group	62.27 (33.51)	65.47 (26.87)
	Paper-and-pencil group	54.47 (30.16)	83.87 (22.27)
	Technological group	60.90 (29.87)	86.67 (19.04)
Numerical sequencing	Control group	40.53 (20.64)	44.53 (22.84)
	Paper-and-pencil group	38.70 (17.36)	91.37 (22.48)
	Technological group	55.43 (30.12)	94.07 (18.21)
Numeric classification	Control group	49.93 (24.25)	64.73 (24.11)
	Paper-and-pencil group	60.03 (25.46)	80.60 (19.04)
	Technological group	51.50 (24.57)	79.03 (21.01)
Numeric conservation	Control group	55.37 (2.00)	55.00 (0.00)
	Paper-and-pencil group	56.50 (4.92)	61.87 (10.27)
	Technological group	55.73 (2.79)	61.10 (9.87)
Numeric inclusion	Control group	59.77 (33.50)	58.60 (34.38)
	Paper-and-pencil group	48.27 (29.25)	97.70 (12.59)
	Technological group	56.77 (33.55)	95.40 (17.50)
Operations with image support	Control group	51.93 (35.09)	62.00 (37.48)
	Paper-and-pencil group	43.80 (35.99)	84.73 (27.04)
	Technological group	36.40 (31.75)	89.60 (26.96)
Operations with arithmetic statement	Control group	37.20 (24.84)	51.50 (33.58)
	Paper-and-pencil group	34.87 (26.98)	65.63 (30.59)
	Technological group	39.37 (32.39)	77.80 (29.00)
Simple sums	Control group	62.30 (19.90)	67.67 (24.75)
	Paper-and-pencil group	57.13 (23.36)	84.00 (15.81)
	Technological group	60.77 (25.88)	89.33 (14.14)
Operations with verbal statement	Control group	29.87 (25.48)	22.23 (19.33)
	Paper-and-pencil group	23.00 (23.86)	45.20 (20.92)
	Technological group	24.23 (25.43)	41.73 (19.05)
Size estimation	Control group	100.00 (.00)	100.00 (.00)
	Paper-and-pencil group	100.00 (.00)	100.00 (.00)
	Technological group	100.00 (.00)	100.00 (.00)
Total correct responses	Control group	1,046.20 (262.65)	1,157.06 (259.46)
	Paper-and-pencil group	1,046.73 (273.90)	1,536.46 (131.52)
	Technological group	1,076.03 (286.05)	1,543.90 (160.67)

The ANOVA revealed significant differences between the pretest and postest, $F(1, 87) = 211.87$, $p < .01$, $\eta_p^2 = .70$, $1 - \beta = 1$. In relation to the between-subject effects, the data indicated significant differences between groups, $F(2, 87) = 11.09$, $p < .01$, $\eta_p^2 = .20$, $1 - \beta = .99$. Scheffé's test indicated no differences between the technology and paper-and-pencil groups; however, differences were found between these groups and the control group ($p < .01$). An analysis revealed the existence of a group * time of measure interaction effect, $F(2, 87) = 47.38$, $p < .01$, $\eta_p^2 = .52$, $1 - \beta = 1$. Therefore, the technology and paper-and-pencil groups were homogeneous at the postest with regard to the type of task performed but not with regard to the technology used. The interaction revealed changes at the postest only when participants belonged to one of the groups that completed the intervention programme.

Basic mathematical skills

Descriptive results of the TEDI-MATH subtests and total are shown in Table 5.

Levene's test for equality of variances was significant only at the pretest for the following variables: *written numerical decision* $F(2, 87) = 3.51$, $p = .03$, *numerical sequencing* $F(2, 87) = 11.45$, $p < .01$, *numerical conservation* $F(2, 87) = 3.55$, $p = .03$, and *numerical inclusion* $F(2, 87) = 4.70$, $p = .01$. At postest, this statistic was significant with regard to the following variables: *counting* $F(2, 87) = 36.70$, $p < .01$, *numbering* $F(2, 87) = 27.44$, $p < .01$, *Arabic number system* $F(2, 87) = 50.11$, $p < .01$, *written numerical decision* $F(2, 87) = 9.60$, $p < .01$, *comparison of Arabic numbers* $F(2, 87) = 135.99$, $p < .01$, *numerical decision* $F(2, 87) = 3.75$, $p = .02$, *logical operations* $F(2, 87) = 3.65$, $p = .03$, *numeric classification* $F(2, 87) = 4.83$, $p = .01$, *numeric conservation* $F(2, 87) = 57.65$, $p < .01$, *numerical inclusion* $F(2, 87) = 52.00$, $p < .01$, *operations with image support* $F(2, 87) = 5.96$, $p < .01$, *simple sums* $F(2, 87) = 9.12$, $p < .01$, and *total correct answers on the TEDI-MATH* $F(2, 87) = 8.96$, $p < .01$.

The repeated-measures ANOVA revealed significant differences between the pretest and postest with regard to the following variables: *counting* $F(1, 87) = 144.07$, $p < .01$, $\eta_p^2 = .62$, $1 - \beta = 1$; *numbering* $F(1, 87) = 132.56$, $p < .01$, $\eta_p^2 = .60$, $1 - \beta = 1$; *Arabic number system* $F(1, 87) = 34.30$, $p < .01$, $\eta_p^2 = .28$, $1 - \beta = 1$; *written numerical decision* $F(1, 87) = 12.17$, $p < .01$, $\eta_p^2 = .12$, $1 - \beta = .93$; *comparison of Arabic numbers* $F(1, 87) = 29.66$, $p < .01$, $\eta_p^2 = .25$, $1 - \beta = 1$; *oral number system* $F(1, 87) = 35.67$, $p < .01$, $\eta_p^2 = .29$, $1 - \beta = 1$; *oral numerical decision* $F(1, 87) = 40.70$, $p < .01$, $\eta_p^2 = .31$, $1 - \beta = 1$; *logical operations* $F(1, 87) = 32.99$, $p < .01$, $\eta_p^2 = .27$, $1 - \beta = 1$; *numerical sequencing* $F(1, 87) = 104.69$, $p < .01$, $\eta_p^2 = .54$, $1 - \beta = 1$; *numeric classification* $F(1, 87) = 53.10$, $p < .01$, $\eta_p^2 = .37$, $1 - \beta = 1$; *numeric conservation* $F(1, 87) = 16.25$, $p < .01$, $\eta_p^2 = .15$, $1 - \beta = .97$; *numeric inclusion* $F(1, 87) = 49.03$, $p < .01$, $\eta_p^2 = .36$, $1 - \beta = 1$; *operations with image support* $F(1, 87) = 83.11$, $p < .01$, $\eta_p^2 = .48$, $1 - \beta = 1$; *operations with arithmetic statement* $F(1, 87) = 100.53$, $p < .01$, $\eta_p^2 = .53$, $1 - \beta = 1$; *simple sums* $F(1, 87) = 105.15$, $p < .01$, $\eta_p^2 = .54$, $1 - \beta = .1$; *operations with verbal statement* $F(1, 87) = 20.98$, $p < .01$, $\eta_p^2 = .19$, $1 - \beta = .99$; and *total correct answers on the TEDI-MATH* $F(1, 87) = 326.83$, $p < .01$, $\eta_p^2 = .79$, $1 - \beta = 1$.

Regarding the between-subject effects, the data indicated significant differences among the groups with regard to the following variables: *counting* $F(2, 87) = 10.71$, $p < .01$, $\eta_p^2 = .19$, $1 - \beta = .98$; *numbering* $F(2, 87) = 16.51$, $p < .01$, $\eta_p^2 = .27$, $1 - \beta = 1$; *comparison of Arabic numbers* $F(2, 87) = 4.61$, $p = .01$, $\eta_p^2 = .09$, $1 - \beta = .76$; *oral number system* $F(2, 87) = 4.11$, $p = .02$, $\eta_p^2 = .08$, $1 - \beta = .71$; *oral numerical decision* $F(2, 87) = 4.60$, $p = .01$, $\eta_p^2 = .09$, $1 - \beta = .76$; *numerical sequencing* $F(2, 87) = 29.02$, $p < .01$, $\eta_p^2 = .40$, $1 - \beta = 1$; *numeric classification* $F(2, 87) = 3.65$, $p = .03$, $\eta_p^2 = .07$, $1 - \beta = .66$; *numeric conservation* $F(2, 87) = 5.79$, $p < .01$, $\eta_p^2 = .11$, $1 - \beta = .85$; *numeric inclusion* $F(2, 87) = 5.96$, $p < .01$, $\eta_p^2 = .12$, $1 - \beta = .87$; and *total correct answers on the TEDI-MATH* $F(2, 87) = 8.59$, $p < .01$, $\eta_p^2 = .16$, $1 - \beta = .96$.

Scheffé's test did not indicate differences between the technology and paper-and-pencil groups; however, differences were found between these groups and the control group for all of the variables except oral number system (in the control group) and numeric classification (in the control vs. paper and pencil groups).

With regard to the *group*time of measurement* interaction, the results indicated a significant interaction in the following variables: *counting* $F(2, 87) = 7.67$, $p < .01$, $\eta_p^2 = .15$, $1 - \beta = .94$; *numbering* $F(2, 87) = 20.96$, $p < .01$, $\eta_p^2 = .32$, $1 - \beta = 1$; *oral number system* $F(2, 87) = 6.60$, $p < .01$, $\eta_p^2 = .13$, $1 - \beta = .90$; *logical operations* $F(2, 87) = 5.85$, $p < .01$, $\eta_p^2 = .11$, $1 - \beta = .86$; *operations with image support* $F(2, 87) = 11.34$, $p < .01$, $\eta_p^2 = .20$, $1 - \beta = .99$; *operations with arithmetic statement* $F(2, 87) = 6.57$, $p < .01$, $\eta_p^2 = .13$, $1 - \beta = .90$; *operations with verbal statement* $F(2, 87) = 15.75$, $p < .01$, $\eta_p^2 = .26$, $1 - \beta = .99$; *oral numerical decision* $F(2, 87)$ $(2, 87) = 8.07$, $p < .01$, $\eta_p^2 = .15$, $1 - \beta = .95$; *numerical sequencing* $F(2, 87) = 21.69$, $p < .01$, $\eta_p^2 = .33$, $1 - \beta = 1$; *numeric conservation* $F(2, 87) = 4.97$, $p < .01$, $\eta_p^2 = .10$, $1 - \beta = .79$; *numeric inclusion* $F(2, 87) = 13.83$, $p < .01$, $\eta_p^2 = .24$, $1 - \beta = .99$; *simple sums* $F(2, 87) = 14.27$, $p < .01$, $\eta_p^2 = .24$, $1 - \beta = .99$; and *total correct answers on the TEDI-MATH* $F(2, 87) = 38.85$, $p < .01$, $\eta_p^2 = .47$, $1 - \beta = 1$.

Discussion

This research evaluated the results of the implementation of a virtual intervention programme to improve WM and BMSs in early childhood education (Alzubi et al., 2018; Durán et al., 2015). Furthermore, it assessed the benefits provided via the virtualization of more traditional methods using printed resources to examine the changes due to the intervention compared with those derived from learning in school over time. This virtual resource intervention adds innovative elements to traditional education. Its multisensory nature adds to the advantages of digital convergence, which become, a priori, beneficial from a motivational perspective. However, its direct effects on the variables analyzed are not particularly relevant compared with interventions based on printed resources. Nevertheless, other advantages of including technology exist, which (although not assessed) cannot be disregarded. Namely, it allows teachers to work with different-sized groups and with ever available and low-cost materials from one class to the next.

With regard to WM, data indicate that the tasks (and not the format in which they are presented) produced significant and favourable effects for the groups affected. WM improvements in the pencil-and-paper and technology groups were in line with past research such as Toll, van der Ven, Kroesbergen, and van Luit (2011), Thorell et al. (2013), Peng and Fuchs (2014), Mammarella, Hill, Devine, Caviola, and Szűcs (2015), Wiklund-Hörnqvist, Jonsson, Korhonen, Eklöf, and Nyroos (2016), and Rosas, Espinoza, Garolera, and San-Martín (2017). WM improvement through educational intervention programmes applied during early stages is important because of its implications for mathematics performance over subsequent years (Alloway et al., 2014). Implementing this type of educational intervention programme, regardless of the presence of new technologies (Romero et al., 2017), might contribute to enhance student access from early childhood education to primary education with regard to mathematics. The control group, which did not receive educational training, also slightly improved in relation to their pretest evaluation. This small improvement might be attributed to EF developmental processes because participants were developing their WM, and to the instruction process that infants receive during early childhood education, in which various activities are conducted that might indirectly affect WM.

Regarding BMSs, changes were observed for all three groups. Nonetheless, the two that completed the programme showed significant changes compared with the control group. These improvement in BMS might be because they are related to WM; thus, its improvement indirectly influences BMSs; these results corroborate Toll et al. (2011), Thorell et al. (2013), and Wiklund-Hörnqvist et al. (2016). Another hypothesis is that completing activities with numbers and mathematical operations reinforces regular schoolwork. This finding is evident in the progress observed on the postest regarding the skills measured by the TEDI-MATH: counting, the Arabic number system, the oral number system, logical operations, operations with image support, operations with arithmetic statements, and operations with verbal statements.

Improvements in various learning processes are often attributed to the inclusion of technology (Holmes & Gathercole, 2014; Thorell et al., 2009). The fact that the effect of technology is not often controlled might lead to the conclusion that it is technology (and not the content or structure of the programmes) that accounts for the changes observed. The current study would have reached a similar conclusion had the paper-and-pencil group not been considered. Similar conclusions were also reached by Romero et al. (2017).

The major limitation of this study is the size of the sample, which might have hindered the generalization of the results. Nevertheless, these findings are promising because WM predicts mathematics performance. Furthermore, the benefits of intervention programmes with technological resources, such as this one, enable its implementation in educational centres and in early childhood classrooms, which increases convenience and reduces the costs related to human and material resources. Future research should continue to examine the effects of intervention programmes on other forms of EF (e.g., cognitive flexibility or inhibitory control).

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