

Effects of computer-based training on children's executive functions and academic achievement

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Abstract

The educational community is deeply interested in knowing how to improve the academic performance of its students. And in particular, with regard to the skills critical to academic performance, the literature has revealed that the development of executive functions (EF) plays a key role. Although numerous studies have aimed to improve EF through computerized cognitive training interventions, the evidence of the effect derived from these interventions remains ambiguous. The purpose of this study is to investigate the effects of a computerized game-based training program on EF and its impact on academic performance in 713 Spanish Primary School students (M =10.2 years old, 51.3 % girls). The EF training was carried out in 26 participating schools (8 weeks, 3 sessions of 15-20 minutes each week), measuring both before and after the training students' executive functions through questionnaires and chronometric tests, and obtaining information on academic performance. The results showed an improvement within the training group in the validated questionnaires exploring inhibition and working memory, as well as in academic performance, compared to the control group. In contrast, no significant intergroup differences were observed in the chronometric tests measuring inhibition. These results highlight the relevance of computerized EF training programs as part of the educational activities developed at schools.

Keywords: computer-based training, executive functions, inhibition, working memory, academic achievement, elementary school students

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Topics such as scholastic success or failure have generated interest from numerous researchers who share a common goal: improvement in academic performance (Balkis, 2018). Academic performance is shown through the abilities, skills, knowledge, and attitudes developed by students in the teaching-learning process, and as has been observed in recent decades, knowledge of cognitive mechanisms in childhood can be essential to understand how this process develops (Rosen et al., 2018).

In particular, with regard to the skills that are critical for academic success, research has revealed that the development of executive functions (EF hereafter) plays a fundamental role (Diamond, 2013; Cortés et al., 2019). These executive functions have proven to be a key element in the development of skills in language and mathematics, as well as in the processing and organization of information received (Blair & Raver, 2015; Blair & Razza, 2007; Diamond & Ling, 2019; G. J. Duncan et al., 2007; Sesma et al., 2009; Zelazo & Carlson, 2012). Executive functions are understood as those neurocognitive mechanisms that control thoughts and behaviors aimed at achieving a goal or objective (Diamond, 2013). Within the complexity of the construct, it seems that there is a general consensus that there are three principal concepts at the core of EF: *inhibition, cognitive flexibility, and working memory* (Diamond, 2013; Miyake et al., 2000). From these other mechanisms emerge which are also essential for students, such as reasoning, problem solving, and planning.

Inhibition (also known as inhibitory control) refers to the ability to inhibit predominant or automated responses and do instead what is most appropriate or necessary. There are two main subcomponents of inhibitory control: response inhibition and interference control. Response inhibition involves controlling conduct and emotions in one's own behavior, suppressing a dominant response (for example, persisting in a task even though there is a temptation to quit). Controlling interference involves controlling attention and thoughts, resisting distractions in the environment (such as those present in the classroom), and maintaining concentration (Diamond, 2020). Several studies suggest that inhibitory control in the early stages of an individual's life can

predict outcomes and success throughout life. For example, in a 32-year longitudinal study, Moffitt et al. (2011) found that children aged 3 to 11 years with better inhibitory control were more likely to continue studying in adolescence, were less likely to make risky decisions, had a healthier lifestyle, and had a greater perception of happiness in adulthood. On the other hand, *cognitive flexibility* is defined as the ability to switch between different mindsets, tasks, or goals. This executive function helps students to manage fluid strategies that allow them to adapt to unexpected situations by thinking without rigidity and freeing themselves from inefficient automatisms (Diamond, 2013). Finally, *working memory* involves maintaining and using information appropriately even if it is not perceptually present (Baddeley & Hitch, 1994; Kent, 2016). That is, it is the cognitive ability that allows students to actively retain information while mentally working on that content or on any other (Engle & Kane, 2004; D'Esposito & Postle, 2015).

It has been suggested that each component of EF develop at their own pace throughout childhood and adolescence, reaching maturity at different ages (Ferguson et al., 2021). This prolonged development is associated with changes in the prefrontal cortex (Gogtay et al., 2004). The 6 to 12-year-old stage is crucial in the development of EF (Davidson et al., 2006; Ferguson et al., 2021), since neuronal plasticity is particularly high and the prefrontal cortex is especially sensitive to environmental influences (Bull et al., 2011). However, there is no general consensus on the specific age at which they typically reach their exact maturity and therefore, various authors suggest using different approaches and tasks to assess EFs (Miyake & Friedman, 2012; Zelazo et al., 2014). As a consequence, several authors have discussed the weak links between the different tasks used to measure EF and their respective measured factors, concluding that the tasks represent a dissociable measurement of capabilities (fractional EF theory) rather than a general construct (Ferguson et al., 2021; Miyake et al., 2000; Miyake & Friedman, 2012).

It is more than obvious to think that students who have the ability to act in the classroom in a thoughtful way, or who are able to stay focused despite distractions, have a greater chance of academic success. In fact, it has been demonstrated that interventions that improve executive functions result in notable improvement in these behaviors or actions (Diamond & Lee, 2011; Diamond & Ling, 2019; Kassai et al., 2019). Several authors have shown that when the inhibitory demand is reduced in certain tasks, students have an easier time solving those tasks (Cassotti et al., 2016; Houdé & Borst, 2015; Lubin et al., 2013). Along these lines, a meta-analysis carried out

by Yeniad et al., (2013) showed that cognitive flexibility was a significant predictor for math and reading skills in students between 4 and 13 years old, demonstrating the close relationship between EFs and academic performance. Also, various findings have suggested that interventions based on the improvement of EFs can reduce the gap of socioeconomic status (SES) and academic performance (Bierman et al., 2008; Raver et al., 2011), since the SES correlates with the EF skills during the early years of life (Hackman et al., 2015; Last et al., 2018).

Given that EF are subject to significant development throughout childhood and, as we have seen, they are significant predictors of many outcomes associated with learning, success, or academic performance (Karchach & Unger, 2014; Schwaighofer et al., 2015; Titz & Karchach, 2014), numerous studies have been aimed at improving EF through cognitive training interventions (Diamond & Ling, 2019). With respect to the transfer that can be derived from this type of training, the evidence is ambiguous (Pandey et al., 2018; Smid et al., 2020). Although some studies have shown positive effects of these training programs on academic performance (Diamond & Ling, 2019; Raver et al., 2011), others have not found significant effects (Morris et al., 2013). However, the findings found in different empirical studies and meta-analyses show evidence that training programs have a stronger effect in children than in adults (Karchach & Unger, 2014; Oberste et al., 2019; Zhao et al., 2018), reinforcing the idea that it is possible to improve cognitive skills and academic performance at school through computerized interventions.

In today's world of digitization, computerized training seems to be a great ally for the development of EF in middle childhood. Computerized EF training is defined as an intervention that uses a tablet, computer, or smartphone to carry out either conventional EF tasks (traditional or direct method) and/or electronic programs with game elements in order to improve EF (indirect method). The traditional method refers to training programs that use traditional cognitive tasks (Stroop, Flankers, Simon, N-back Task, Dimensional Change Card Sort, etc.) to improve children's cognitive abilities (e.g., Espinet et al., 2013). Unlike this method, game-based training uses different sensory stimuli (sounds, color, movement), providing immediate and precise feedback. In addition, they often use a narrative with animated characters, interactive environments, and information on the level of progress which is visible to the user at all times. These characteristics can make this type of task more interesting in its playability (Prins et al., 2013) and increase the intrinsic interest of children in carrying out the training (Ryan & Deci, 2000).

A recent meta-analysis of 36 studies carried out by Cao et al., (2020) showed that computerized training had a moderate effect in improving children's EF, especially in working memory, which was significantly higher after training. In spite of this, it is worth mentioning that the debate about the controversy regarding the effects of this type of trainings remain open. Some studies demonstrated that computerized training was found to be effective for working memory improvement (Klingberg, 2010; A. B. Morrison & Chein, 2011; Spencer-Smith & Klingberg, 2015), while others found the effect to be negligible (Melby-Lervåg et al., 2016; Wong et al., 2014). Similar results occur with inhibition or flexibility, where contradictory results in the transfer effect of these programs have been also found (Ackermann et al., 2018; Espinet et al., 2013; Sánchez-Pérez et al., 2018; Spierer et al., 2013; Weerdmeester et al., 2016). Nonetheless, it should be noted that many studies have claimed that the effects of these computerized training programs transcend the concept of EF itself, impacting general issues such as students' academic performance (Sánchez-Pérez et al., 2018).

Given the importance of academic performance, the prospect of being able to improve it through computerized cognitive training has great practical relevance. However, the lack of empirical studies that analyze the effect and transfer of these training programs (especially, carried out in the school context itself) on the academic performance of Primary Education students makes it necessary to carry out research in this line. Hence, the purpose of this study is to investigate the effects and moderators of a computerized game-based training program on the EFs and academic performance of a broad group of Primary Education students. Thus, this study aims to analyze the effects of computerized game-based training on the EFs of children aged 8 to 13 years old, and to explore the impact of the intervention on their academic performance. To this end, the study followed a longitudinal design with three phases (pre-test, training, and post-test) and with two groups (control and experimental).

Method

Participants

The recruitment of the sample was carried out through contact via email with public and private schools in different Spanish provinces, and through dissemination via social networks (Twitter and Facebook). All of the teachers (with the consent of the respective management team) who showed interest in having their classes participate received all the information and a registration form. Finally, 26 schools confirmed their participation, with a total of 54 groups of 4th, 5th, and 6th grade of Primary Education. Groups were randomly selected for group assignment (control or experimental).

In this experimental study, the participants were 713 Primary Education students aged between 8 and 13 years old ($M = 10.2$, $SD = 0.88$, 51.3% girls) from 26 Spanish public and private schools. The control group included 331 students ($M = 10.2$ years, $SD = 0.91$; 51% girls) and the experimental group 382 students ($M = 10.1$ years, $SD = 0.86$; 52% girls). Regarding the grade level, 31% were from 4th of Primary Education, 40% from 5th of Primary Education, and 29% from 6th of Primary Education.

Although the initial sample was slightly larger, children with special educational needs ($N = 88$), those who did not start the program intervention due to confinement or personal problems ($N = 41$), those who did not undertake the post-test measurement ($N = 35$) and, finally, those students of the experimental group who did not reach the objective set a priori of 15 completed training sessions ($N = 21$) were excluded from the analysis.

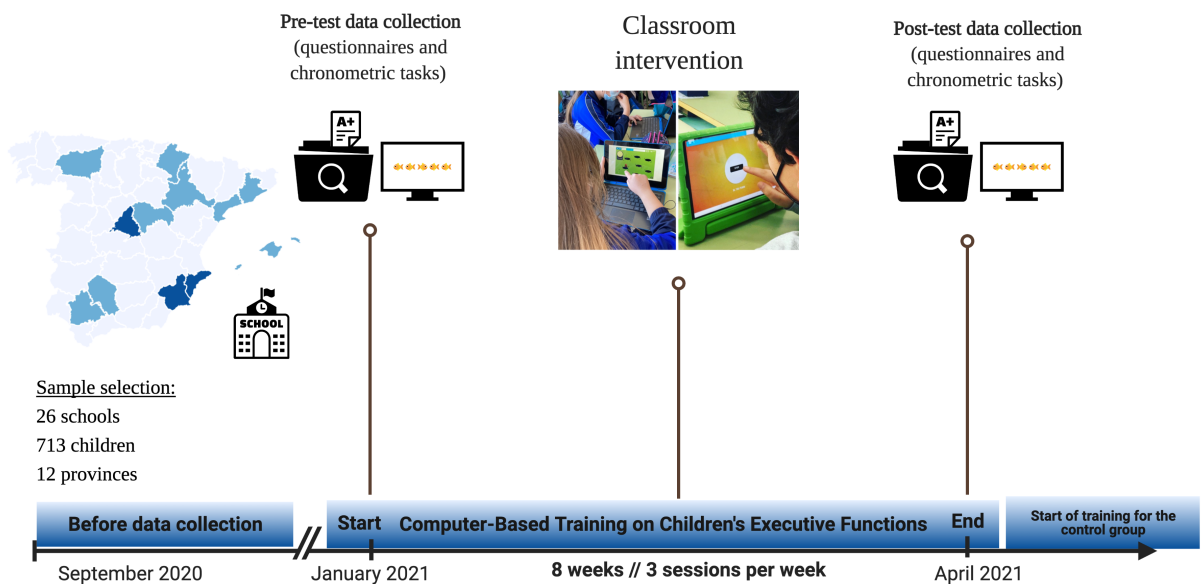
The project was approved by the Research Ethics Board of the University of Murcia (Ref: 2989/2020). As the sample consisted of underage participants, families were asked to sign an informed consent form. Students were informed that their responses would be confidential and used for research purposes only. Participation in the study was voluntary and students could withdraw at any time.

Procedure

Timeline

The initial evaluation (pre-test) began in January 2021 and was carried out over 3 weeks with all groups (see Figure 1 for a schematic representation). At the end of this phase, the intervention for the experimental group began for the next 8 weeks. One week after finishing the training, the students of both groups were evaluated again (post-test). The pre-test and post-test moments coincided with the academic evaluations at the beginning (January 2021) and at the end of the term (April). At the end of the measurements, the control group was offered the option of completing the cognitive stimulation program under the same conditions as the experimental group had initially done so that they could thus benefit from its possible usefulness.

Figure 1. Timeline of the project.



Pre-test and Post-test tasks and questionnaires

The Spanish version of *The Childhood Executive Function Inventory* (CHEXI; Catale et al., 2015) was used. This instrument was completed by the families. It consists of 24 items and assesses four aspects of the students' executive functioning (working memory, planning, regulation, and inhibitory control), resulting in two final scales: working memory and inhibition. Previous studies

have shown that the CHEXI has good internal consistency and factorial structure as well as good predictive capacity on school performance (Thorell et al., 2013). The items are described in an inverted way where it is established that a lower score of the participant in the corresponding subscales means better levels of EF.

Flanker task. This performance test is well known for evaluating the ability to inhibit irrelevant stimuli (Eriksen & Eriksen, 1974). Continuing with the version adapted to the child population of this task (see Rueda et al., 2004; Antón et al., 2014), the students had to press the key that corresponded to the direction the central fish was looking at, ignoring the other surrounding fish (on the flanks). The fish could point in the same direction as the other fish (congruent condition) or in the opposite direction (incongruous condition). If the central fish was looking to the left, the participant had to press the X key on the keyboard; if the fish looked to the right, the participant would need to press the letter M. After a short, guided training of 4 trials (two trials per condition), 40 trials (20 per condition) were randomly presented. A warning cross of 500 ms duration preceded the stimulus, which was kept on screen for a maximum time of 1500 ms. After the stimulus, the screen was blank for 500 ms. Response times for each trial and correctness of responses were recorded. Participants completed this task through the Gorilla Experiment Builder platform (Anwyl-Irvine et al., 2020).

Simon task. In this classic task (Simon & Rudell, 1967), participants saw a red circle or blue square on one side of the computer screen. If the stimulus presented was a red circle, they should press the X key; if the stimulus were a blue square, they would need to press the M key. This task includes congruent and incongruous conditions depending on the coincidence between the expected response for each stimulus and the place of appearance of the stimuli on the screen (e.g., congruent: circle red on the left side of the screen or blue square on the right side of the screen; incongruous: red circle on the right side of the screen or blue square on the left side of the screen). After a short, guided training of 4 trials (two per condition), 30 randomized trials (15 per condition) were presented. In each trial, a 500 ms long warning cross preceded the stimulus, which remained on the screen for 1500 ms. After the stimulus, the screen was blank for 500 ms.

Academic performance was estimated from the grades obtained in the corresponding quarters of the academic year. The end of the first quarter coincided with the pre-test measurement (December

2020) and the end of the second quarter (April 2020) with the post-test measurement. Numerical grades were obtained for the subjects of Language and Literature, Mathematics, Social Sciences, and Natural Sciences with numerical values from 1 (insufficient) to 10 (excellent), where 5 represents the minimum value to pass.

The computer-based training program (CTP)

The computerized training program (CTP) chosen was CogniFit (CogniFit Inc., San Francisco, CA, USA), a program that has been scientifically validated in various populations (Kraus & Breznitz, 2009; Peretz et al., 2011; Preiss et al., 2013; Shatil, 2013; Shah et al., 2017). This system allows a personalized adaptation of the training program through an initial cognitive assessment (Cognitive Assessment Battery, CAB) whose results determine the content and level of subsequent training (see Tapia & Duñabeitia, 2021). The training program is based on 34 different games with visual, auditory, and cross-modality stimuli, designed with the purpose of training a wide range of cognitive processes but focused on enhancing EF. The program was designed to be integrated into the school routine with the support of the teachers. Teachers received a brief, 30-minute initial training in order to familiarize themselves with the program. Each class had to do 3 sessions per week (preferably on alternate days) for 8 weeks. Each session included 3 games and lasted approximately 15-20 minutes. A minimum of 14 sessions was established as the objective to be achieved in order to complete the training program. Performance was automatically recorded and uploaded to a server where researchers could confirm compliance. Tutors received information by email or phone once every 2-3 weeks.

Results

To complete the statistical analysis of this study, the open-source statistical software Jamovi v.1.6 (Jamovi project; jamovi.org) was used. Descriptive analyses were completed first. The mean scores and standard deviations for both groups are shown in Table 1. Next, a series of repeated measures analysis of variance (ANOVAs) were performed to identify if there were differences in each group between the pretest and posttest, in addition to knowing if there is interaction between the group and the time of the evaluation.

Table 1. Mean scores by group in the pre-test and post-test.

	Training Group		Control Group	
	Pre-test	Post-test	Pre-test	Post-test
CHEXI Scores				
Working Memory	29.9 (9.14)	28.5 (9.19)	28.2 (8.67)	28.6 (8.70)
Inhibition	29.8 (7.33)	28.3 (7.13)	29.5 (7.31)	29.0 (7.36)
Flankers Task				
Error rates – congruent	5.94 (14.1)	7.57 (14.5)	5.94 (11.8)	6.63 (13.5)
Error rates – incongruent	25.5 (34.3)	26.8 (33.6)	30.7 (36.1)	28.7 (36.4)
Reaction times - congruent	773 (237)	698 (238)	746 (229)	704 (199)
Reaction times - incongruent	867 (391)	821 (440)	912 (491)	833 (447)
Simon Task				
Error rates – congruent	5.50 (11.8)	5.70 (9.94)	7.33 (13.7)	5.64 (11.4)
Error rates – incongruent	12.8 (20.0)	10.9 (15.8)	13.2 (19.0)	10.6 (17.7)
Reaction times - congruent	732 (265)	639 (169)	697 (223)	637 (164)
Reaction times - incongruent	772 (302)	674 (184)	744 (282)	669 (157)
Scores				
Language and Literature	7.42 (1.55)	7.74 (1.55)	7.42 (1.57)	7.30 (1.64)

Mathematics	7.38 (1.77)	7.39 (1.83)	7.26 (1.72)	7.31 (1.66)
Social Sciences	7.33 (1.89)	7.72 (1.70)	7.60 (1.77)	7.39 (1.74)
Natural Sciences	7.35 (1.72)	7.80 (1.70)	7.49 (1.57)	7.36 (1.72)

**Note.* Standard deviations are in parentheses.

To check if the training had an effect on EF tasks and questionnaires and on academic performance, a separate ANOVA was performed for each specific subcomponent of each task, taking into account the Time factor (pre-test, post-test) and the Group (experimental, control) (see Figure 2 for visual representation of the main effects).

In the CHEXI *working memory* scale, statistical differences were observed regarding Time [$F(1,711) = 4.31, p = 0.038, \eta^2_{\text{partial}} = 0.01$] and a significant interaction between Time and Group [$F(1,711) = 14.66, p < 0.001, \eta^2_{\text{partial}} = 0.02$]. Through the *post hoc* analysis with Tukey's correction, it was demonstrated in the experimental group that there was a significant difference of 1.33 points between the pre-test and post-test [$t = 4.33, p < 0.001$], while, on the other hand, in the control group no differences were found between the pre-test and the post-test [$t = -1.20, p = 0.628$]. In other words, the trained group improved their working memory scores relative to the control group.

In the CHEXI *inhibition* scale, significant differences were also observed as a function of the Time factor [$F(1,711) = 21.18, p < 0.001, \eta^2_{\text{partial}} = 0.03$], as well as a significant interaction between Time and Group [$F(1,711) = 5.40, p = 0.020, \eta^2_{\text{partial}} = 0.01$]. The trained group showed a significant difference of 1.51 points between the pre-test and post-test [$t = 5.08, p < 0.001$] while, on the other hand, in the control group no differences were found [$t = 1.56, p = 0.404$].

Regarding the *flanker task*, ANOVAs were performed taking into account the percentage of errors and the reaction times of the participants in each condition, after eliminating the outlier values that differed by more than 2.5 standard deviations from the mean per subject and condition. In both analyses, the factors of Congruency (congruent, incongruous), Time (pre-test, post-test) and Group (experimental, control) were included. Regarding the percentage of errors, a significant effect of the Congruency factor [$F(1,711) = 414.48, p < 0.001, \eta^2_{\text{partial}} = 0.37$] was found, showing a higher

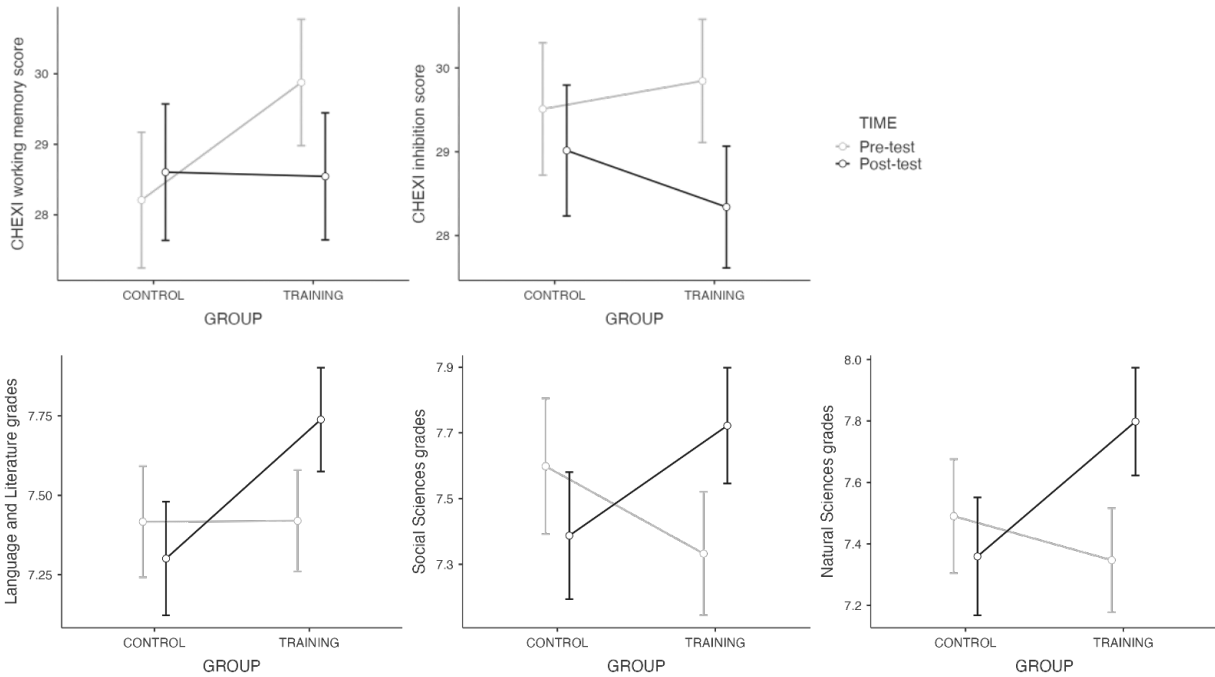
percentage of errors in the incongruous trials than in the congruent ones, but no significant effect of Time was found [$F(1,711) = 0.25, p = 0.614$], nor any interaction between the factors [$F_s < 1, p_s > 0.40$]. Regarding reaction times, both groups significantly improved their response times from the pre-test to the post-test [$F(1,593) = 14.59, p < 0.001, \eta^2_{\text{partial}} = 0.02$], and a general congruence effect was also obtained [$F(1,593) = 172.98, p < 0.001, \eta^2_{\text{partial}} = 0.23$]. The triple interaction was not significant [$F(1,593) = 2.48, p = 0.116$].

Similar results were found in the *Simon task*. Regarding the percentage of errors, we found a significant effect of Congruency [$F(1,711) = 195.54, p < 0.001, \eta^2_{\text{partial}} = 0.22$], but we did not observe a significant effect of Time [$F(1,711) = 6.20, p = 0.013$], nor a triple interaction that would suggest differential effects as a consequence of training [$F < 1, p > 0.40$]. Regarding reaction times, both groups increased their speed significantly from pre-test to post-test [$F(1,693) = 67.98, p < 0.001, \eta^2_{\text{partial}} = 0.09$], and also showed a generalized Congruency effect [$F(1,693) = 106.93, p < 0.001, \eta^2_{\text{partial}} = 0.13$]. The triple interaction was not significant [$F < 1, p > 0.98$].

Regarding *academic performance*, the grades obtained by the students changed significantly as a function of the Time factor, improving from the pre-test to the post-test [$F(1,669) = 16.13, p < 0.001, \eta^2_{\text{partial}} = 0.02$]. Significant differences were found between the scores in the different subjects [$F(3,2007) = 8.45, p < 0.001, \eta^2_{\text{partial}} = 0.01$], showing different mean values of academic performance depending on each of them. Importantly, the triple interaction between Time, Group and Subject was significant [$F(3,2007) = 17.68, p < 0.001, \eta^2_{\text{partial}} = 0.03$]. *Post hoc* analyses with Tukey's correction for multiple comparisons showed that computerized training significantly improved the scores of the experimental group in the subjects of Language and Literature (0.32 points out of 10), Social Sciences (0.39 points) and Natural Sciences (0.45 points; all $p_s < 0.001$), but not in the subject of Mathematics. On the other hand, in the control group there were no significant differences in the scores of the four subjects analyzed between the pre-test and the post-test. These results suggest that, through the CTP, the students of the experimental group improved their academic performance compared to the control group.

Figure 2. *Estimated marginal means by group in the pre-test (grey lines) and post-test (black lines) for the significant effects. Error bars represent 95% confidence intervals. Note: Lower*

CHEXI scores indicate better EF performance, and higher grades correspond to better academic achievement.



Discussion

In the present study, we analyze the effects derived from a CTP carried out in the classroom on the improvement of executive functions and academic performance in a sample of Spanish primary school students. The results indicated that the students who participated in the CTP improved the scores obtained in the executive functions questionnaire and in academic performance compared to the control group. However, in two chronometric tests classically linked to the study of inhibition (flankers and Simon tasks), no significant differences were obtained.

First, our results showed a significant effect of the CTP in relation to the children's working memory scores obtained from the families using a validated questionnaire. These findings are in line with the results presented in the recent meta-analysis carried out by Cao et al., (2020) where they indicated that the effects of CTP and its transfer effect to working memory were the most highly significant of the three main executive functions explored. Regarding the inhibition

subscale, at the end of the 8-week intervention, a significant improvement was also observed in the experimental group. These results seem to be in line with other recent studies that demonstrate a possible improvement in inhibition through a CTP (Blakey & Carroll, 2015; Sánchez-Pérez et al., 2018).

Second, it is worth noting that these differences were not replicated in the chronometric tasks that were also used, and, despite observing an improvement from pre-test to post-test in reaction times and the percentage of errors in the flanker task and in the Simon task, no significant differences were found between the two groups. Thus, the results shown differ between the scores obtained in the questionnaire and the Flankers and Simon tasks, corroborating once again the complexity involved in measuring inhibition and, more specifically, the relationship between the behavioral questionnaires and the chronometric performance tests (Burgess et al., 2006; Toplak et al., 2013). In light of these findings, it is possible to suppose that, although the processes explored may share the same neuroanatomical substrate, the two types of measures can evaluate different aspects of the same construct. While the CHEXI appears to measure the behavioral component of EF, the chronometric performance tests appear to measure the cognitive component (Anderson, 2002). The chronometric measures can represent the students' abilities to demonstrate their EF in a highly structured environment and/or activity (such as a laboratory test), while the scores obtained in questionnaires such as the CHEXI can represent the observable behaviors associated with that EF in everyday settings, such as the classroom (see Thorell & Nyberg, 2008).

In our study, while very strong correlations were observed between the results of both CHEXI scales (working memory and inhibition) both in the pre-test and in the post-test (with $r_s > .71$), the correlations of these scales with the effects (incongruous minus congruent) in the reaction times of the Simon and flanker chronometric tasks were markedly low (with $r_s < .10$ in all contrasts, both at pre-test and post-test). Similar results were observed in a sample of 844 American preschoolers (Camerota et al., 2018). Furthermore, and despite the existing relationship between the CHEXI subscales, the results of the comparisons between the incongruity indices of the two chronometric tasks showed an absence of correlation (with $r_s < .05$). Similar effects highlighting the scarce convergence of results between chronometric tasks that have traditionally been used to measure inhibition components have already been previously described in the literature (see Paap & Sawi, 2014), and our results coincide with this vision. Therefore, our findings suggest the importance of

combining the two types of measurement in order to be able to collect more complete information regarding the evaluation, intervention, and improvement of students' EFs (Toplak et al., 2009, 2013).

Consistent with the literature, in our study a significant high correlation was found between the scores of the two subscales of the CHEXI (working memory and inhibition) and the grades of the students in the subjects of Language and Literature, Mathematics, Social Sciences, and Natural Sciences. The working memory subscale is the one that obtained the strongest correlations with the aforementioned scores, both in the pre-test (with $r = -.43$) and in the post-test (with $r = -.47$). In contrast, the correlations between the inhibition subscale and scores were substantially lower (with $r = -.30$), albeit significant. These results coincide with those described in the literature, reinforcing the link between working memory and academic performance (Carretti et al., 2009; Friso-van den Bos et al., 2013; Mahone et al., 2002; McAuley et al., 2010; St Clair-Thompson & Gathercole, 2006; Van der Ven et al., 2012) and they highlight the predictive utility of CHEXI to measure EF in students (Thorell & Nyberg, 2008; Thorell et al., 2013).

Finally, and especially relevant, our results revealed a clear-cut improvement in the academic performance of students who completed the CTP. These results are in line with other recent studies (Sánchez-Pérez et al., 2018). In our case, the improvements took place in the subjects related to language and sciences, suggesting a significant contribution of the CTP in learning in a school context. There are numerous studies that corroborate the direct relationship between executive functions and academic performance (Ahmed et al., 2019; Best et al., 2011; Cortés et al., 2019; Gordon et al., 2018). This improvement of EF also has an indirect and reciprocal relationship with other key aspects in learning and therefore in academic performance such as the verbal factor, logical reasoning (Best et al., 2011), problem solving, reasoning or planning (Collins & Koechlin, 2012; Duncan et al., 2012), or skills related to reading (Borella et al., 2010; Butterfuss & Kendeou, 2018; G. J. Duncan et al., 2007; for reviews, see Follmer, 2018; Gathercole et al., 2004).

However, despite the overall positive results in this study, these claims must be interpreted with caution. These results invite future experimental research to corroborate the effects and expand the study variables. We directed our tests to the assessment of working memory and inhibition skills,

and considering the multifaceted construct of EF (Miyake et al., 2000), future studies should be aimed at exploring additional components, such as cognitive flexibility. Additionally, the fact that no significant intergroup differences were observed in the flanker and Simon tasks raises the question of the effectiveness of the program in relation to inhibitory control as a whole. In future research, the effects of this type of intervention programs could be analyzed through the inclusion of other ecological and rewarding evaluation measures of EFs carried out in the same classroom (Morrison & Grammer, 2016).

One aspect to consider for future studies is the magnification effect (Karchach & Unger, 2014), which assumes that individuals with higher performance (in our case, students with typical development) will benefit more from cognitive interventions, since they have greater (in terms of quantity and efficiency) cognitive resources than those with lower basic performance (in our case, students with atypical development). In fact, a recent meta-analysis of 90 studies by Takacs & Kassai, (2019) found that computerized training was more beneficial for children with normal development. In our study, students with atypical development were not included, and this is an aspect to work on in future studies in order to establish a higher level of inclusion.

In summary, following an optimal research design to analyze the possible results of a computerized training aimed at improving EFs (Cao et al., 2020; Diamond & Ling, 2019), a positive association was found between training, executive functions, and academic performance. Our findings suggest that the improvements obtained in the subscales of working memory and inhibition, as well as in the academic performance of the students were specifically related to the type of intervention carried out. These results have practical implications for improving learning and academic success.

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