Differential effects of educational and cognitive interventions on executive functions in adolescents

Abstract

Executive functions are critical decision-making capabilities that depend on the integrity of the prefrontal cortex. This cortical region and its dependent functions are in full development and formation during adolescence. Therefore, cognitive and educational interventions have the potential to influence the development of executive functions during this evolutionary period. We aimed to explore the effects of cognitive reflection versus typical educational interventions on executive functions in teenage students. Participants were randomly assigned to one of three interventions: cognitive reflection group (CRG), educational task group (ETG), non-intervention group (NIG). Cognitive reflection tasks, typical school tasks, and no added educational intervention, were the respective interventions in each group. The neuropsychological battery of executive functions and frontal lobes (BANFE), which allows for the evaluation of executive functions dependent on specific prefrontal regions, was used in this study. Scores in general executive functions and scores related to the dorsolateral prefrontal cortex (DLPF) were increased after the intervention in all groups, except in the ETG. However, when functions typically associated with the anterior prefrontal cortex (APF) were analyzed separately, the post-intervention scores significantly increased only in the ETG group. These findings suggest that certain educational interventions can interfere with those executive functions related to the DLPF but they can improve the APF-dependent executive functions.

Keywords: anterior prefrontal cortex, cognitive reflection tasks, dorsolateral prefrontal cortex, educational intervention, executive functions

Introduction

Executive functions are a set of cognitive processes essential for taking decisions and resolving problems (Cristofori et al. 2019). A cortical network in the prefrontal cortex controls these functions, and lesion and neuroimaging studies have shown the relevance of the integrity of this region for a correct executive function (Parks and Smaers 2018; Yuan and Raz 2014). Different topographic and functional areas of the prefrontal cortex contribute specific mechanisms to the processes that integrate the set of executive functions (Fuster 2019; Miyake et al. 2000). Thus, functions-planning, inhibitory control, attention, working memory, cognitive flexibility, memory updating, and decision-making are dorsolateral prefrontal cortex (DLPF)-dependent functions. On the other hand, the activity of the orbitofrontal cortex (OFC) has been related to impulse control, risk decisions, mood control, and social behavior. Finally, the anterior medial prefrontal cortex (APF) is involved in the monitoring of behavioral outcomes to avoid errors. This functional organization of the prefrontal cortex (Henri-Bhargava et al., 2018; Mace et al. 2019) determines the success of certain behavioral interventions aimed at boosting executive functions (Egger et al. 2019; García-Madruga et al. 2016).

The prefrontal cortex has a late development regarding the rest of the cortical areas (Romine and Reynolds 2005; Werchan and Amso 2017), and during adolescence, this region experiences intense neuroanatomical and functional changes (Arain et al. 2013; Fuster 2002). Environmental stimuli are strong determinants of this development (de Greeff et al. 2018; Teffer and Semendeferi 2012; Verburgh et al. 2014) and, therefore, educational (Rosas et al. 2019) and cognitive (Benzing et al. 2019; Nouchi et al. 2013; Wass 2015) interventions may modulate this process. Several studies have analyzed the effect of a particular intervention program, such as card/board games or computerized cognitive training, on executive functions in childhood or adolescence (Benzing et al. 2019). In general, these programs have shown improvement effects on executive functions in these age groups (Cardoso et al. 2018; Dias and Seabra 2015; Riccio and Gomes 2013). However, the influence on executive functions associated with specific prefrontal areas (i.e., DLPF, OFC, APF) of educational and cognitive interventions has not been directly compared in adolescents. Considering the changing state of the prefrontal cortex during this period (Tsujimoto 2008; Werchan and Amso 2017) and the particular executive demands of each intervention (Diamond and Lee 2011), educational and cognitive interventions could differentially influence specific executive functions and the underlying prefrontal activities (Diamond and Ling 2016). The effectivity of physical (Álvarez-Bueno et al. 2017) and cognitive (Shaheen 2014) interventions for improving executive functions has been explored in young children, but *ad hoc* comparisons between educative and cognitive programs in adolescents are necessary. Thus, to explore this hypothesis, the effect of educational and cognitive interventions on executive functions in adolescent was evaluated. We used the neuropsychological battery of executive functions and frontal lobes (BANFE) for measuring executive functions (Flores, Ostrosky, Lozano 2012, 2014). This battery allows for the evaluation of specific cognitive processes, mainly dependent on the DLPF, OFC or APF. According to the executive functions associated with each of these cortical areas (Yoshida et al. 2010), we expect an improvement in the functions related to the DLPF after the implementation of a program of cognitive reflection tasks that potentially requires functions-planning, inhibitory control, attention, working memory, and decision-making (Panikratova et al. 2020). Additionally, a program of educational tasks, such as the resolution of problems and other common scholar activities that require continuous behavioral monitoring for error prevention, could improve executive functions related to the APF (Yoshida and Ishii 2006). The educational and cognitive tasks of these programs should not particularly impact impulse control, risk decisions, mood control or social behavior, and therefore, no effect on OFC-dependent executive functions is expected with any of these interventions (Jennings et al. 2019). Although the process of physical and cognitive development is different between both genders (Ardila et al. 2011; Riley et al. 2018; Teeuw et al. 2019), to our knowledge the effects of different interventions in adolescents have not been systematically studied by sex. Considering therefore the lack of evidence on possible differential effects of cognitive and educational interventions based on sex, this pilot study was not designed to include this variable as a principal outcome measure.

In summary, as a first step in understanding these possible relationships, we conducted this exploratory preliminary interventional study aimed to compare the effects of cognitive reflection versus typical educational interventions on specific executive functions in teenage students. The hypotheses raised are thus tentative and supported by the differential involvement of the prefrontal regions in specific executive functions (Gilbert et al. 2010; Mace et al. 2019), as well as based on the potential of different interventions to influence such functions, but they do not derive from a well-demonstrated linear relationship between these components.

Method

Participants

The inclusion criteria in the study were to be a student at the participating center, within the age group, and with no medical or psychiatric conditions that could prevent the normal participation in this study. The school monitored these criteria, and therefore confidentiality was preserved. Thirty healthy adolescents (18 boys and 12 girls, mean age 13.4 ± 1.01), recruited from different classrooms of a public school of the Ensenada city in Baja California State, Mexico, voluntarily participated in this study. The participants did not receive any incentive for taking part in the study. School directors provided permission for interventions and the parents were reported about the study. In addition, the children gave their verbal assent before each intervention program. The study was approved by the Ethics Committee of the Autonomous University of Baja California, Mexico, according to the international norms for social and psychological research. Table 1 shows the demographic characteristics of the sample.

Neuropsychological battery of executive functions and frontal lobes (BANFE)

BANFE is a neuropsychological battery designed to evaluate executive functions as cognitive processes typically dependent on the prefrontal cortex. Thus, this battery evaluates metamemory, figurative meaning, and abstract attitude as APF processes. The evaluated DLPF processes are verbal fluency, mental flexibility, responses production, visuospatial and sequential planning, reverse sequencing, visuospatial and verbal working memory. Finally, inhibitory control, compliance with rules, and risk-benefit processing are evaluated as OFC-dependent processes. The scores of this battery range from 40 (worst performance) to 135 (highest performance). Global scores can be grouped to get an overall performance index, and partial indices of performance regarding the three prefrontal regions evaluated can also be obtained. The evaluation tests included in this battery have shown high convergent and clinical validity (Stuss and Levine 2002). The psychometric reliability through the inter-rater method is high ($\alpha = 0.80$) (Flores, Ostrosky, Lozano 2012, 2014). The convergent validity has been estimated according to the measures previously reported for each neuropsychological test included in this battery (Flores, Ostrosky, Lozano 2012, 2014). The criterion validity of these tests has been shown in numerous studies (Carone 2007; Selnes 1991; Spreen & Strauss 1998).

Procedure

To compare the intervention measures of this study, we followed a randomized, between subject (with three parallel groups) and within-subject (pre- and post-intervention measures), controlled design. The different BANFE tests are applied in a standardized order, and the participants perform these tests following the standard procedure described for each one (Carone 2007; Flores, Ostrosky, Lozano 2012, 2014; Selnes 1991; Spreen & Strauss 1998). No computerized tests were applied. This neuropsychological battery was individually administered in a classroom where only the evaluator and the participant were present. A first evaluation of executive functions through the BANFE was performed in each participant as a baseline measure. This evaluation was completed in approximately one hour. After this first evaluation, participants were randomly assigned to one of three intervention groups ($n = 10$): cognitive reflection group (CRG), educational task group (ETG), and non-intervention group (NIG). All interventions were implemented by the same researchers and consisted in group activities. The intervention in the CRG consisted of 10 one-hour sessions, once per week. In each session, participants were encouraged to provide ideas and reflections about current and controversial issues, such as legalization of abortion, euthanasia, legalization of cannabis, etc., which requires the activation of cognitive processes linked to reasoning and judgment (Patel et al. 2019; Pennycook et al. 2016; Sirota and Juanchich 2018). Each one-hour session was focused on a single and different topic of discussion, which was treated verbally in the group. This activity was thus intended to promote typical DLPF cortex-dependent cognitive functions such as reasoning, attention, memory, functions-planning, and decision making (Turnbull et al. 2019). The intervention in the ETG also consisted of 10 one-hour sessions, once per week. In each session, all participants of this group performed the same set of educational tasks additional to the school program, for example solving mazes, drawing, arithmetic operations, etc., in a grouped manner. The set of tasks was different in each of the sessions. These activities were carried out mentally or using pencil and paper. Feedback of performance was provided to each participant, although an evaluation of the results was not carried out. The set of these tasks involves demanding monitoring for error prevention, which is a typical function associated to the APF. The ten sets of educational tasks are shown in Table 2. Finally, the NIG followed the usual school program without any added educational or cognitive intervention. Therefore, this was a control group without any experimental intervention added to the participants' school activities. After the end of each of these interventions, executive functions were evaluated again in all groups via the BANFE, as previously described.

Statistical analysis

The analyses were conducted for the data of 28 participants, as two adolescents did not complete all the interventions. The remaining 28 adolescents participated in all the interventions and the respective data were analyzed. The final number of participants in each group was: CRG ($n = 9$), ETG ($n = 9$), NIG ($n = 10$). Differences in the BANFE direct scores were analyzed by a 3×2 mixed model ANOVA, with group (CRG, ETG and NIG) as between-subjects factor, and time (pre- and post-intervention) as within-subject factor. In the case of significant effects, post-hoc t-tests were conducted to analyze the differences between groups in each intervention time. Because the most widely used estimate of effect size for sample comparisons in experimental psychology is based on the Cohen's *d* calculation (Cohen 1988; Lakens 2013), and this method has shown to be robust even in the case of violations of the normality assumption (McGraw and Wong 1992), we reported this effect size value for each comparison. The standard interpretation of Cohen's *d* values are $d = 0.2$ as small effect size, $d = 0.5$ as medium effect size, and $d = 0.8$ as large effect size (Cohen 1988; Lakens 2013). The critical level of significance in all tests was set to $p < 0.05$. Due to the sample size, we also conducted non-parametric analyses as confirmatory tests. Sex differences within each group were analyzed via non-parametric analyses as well. All analyses were carried out using the SPSS software.

Results

The analyses of the BANFE values conducted by the Kolmogorov-Smirnov test showed a normal distribution of the data for the pre-intervention ($p = 0.2$) and post-intervention ($p = 0.2$) measures. Shapiro-Wilk tests also confirmed a normal distribution of data ($p = 0.535$ and $p = 0.833$ for pre-intervention and post-intervention data, respectively). The Levene test confirmed the variance homogeneity assumption ($p = 0.606$ and $p = 0.334$ for pre-intervention and post-intervention data, respectively).

Overall BANFE scores

Figure 1A shows the overall scores for executive functions of the 3 groups pre- and post-intervention. Figure 2A depicts both the total data dispersion in each of these experimental conditions, and separately for girls and boys. There were no between group differences in the baseline BANFE scores ($p > 0.05$). The mixed repeated measures ANOVA revealed a significant effect of the main factor time ($F_{1,25} = 26.8$, $p < 0.001$, $\eta_p2 = 0.518$, 1-β =). The scores of the CRG were significantly lower ($t_8 = -3.6$, $p = 0.006$, $d_{\text{Cohen}} = -0.86$) in the pre-intervention time ($\overline{x} = 85.3$), compared to the post-intervention time ($\overline{x} = 101.1$). The scores of the ETG were lower in the pre-intervention time ($\overline{x} = 89.6$), compared to the post-intervention time ($\overline{x} = 95.3$), but this difference was not significant ($t_8 = -2.1$, $p = 0.06$, $d_{\text{Cohen}} = -0.36$). The scores of the NIG were significantly lower ($t_9 = -2.98$, $p = 0.015$, $d_{\text{Cohen}} = -0.76$) in the pre-intervention time ($\overline{x} = 97.5$), compared to the post-intervention time ($\overline{x} = 108.3$). There was no significant effect of the main factor group ($F_{2,25} = 1.34$, $p = 0.272$, $\eta_p2 = 0.099$, 1-β =), and the interaction between group and time was not significant ($F_{2,25} = 1.91$, $p = 0.16$, $\eta_p2 = 0.133$, 1-β =).

OFC scores

Figure 1B depicts the executive functions scores associated with the orbitofrontal cortex of the 3 groups pre- and post-intervention. Figure 2B depicts the data dispersion in each of these conditions, and separately for girls and boys. There was no significant effect of the main factors group ($F_{2,25} = 0.245$, $p = 0.785$, $\eta_p2 = 0.022$, 1-β =) and time ($F_{1,25} = 0.722$, $p = 0.405$, $\eta_p2 = 0.032$, 1-β =). The interaction between group and time was not significant ($F_{2,25} = 1.75$, $p = 0.196$, $\eta_p2 = 0.138$, 1-β =).

DLPF cortex scores

Figure 1C depicts the executive functions scores associated with the DLPF cortex of the 3 groups pre- and post-intervention. Figure 2C shows the data dispersion in each of these conditions, and separately for girls and boys. There was a significant effect of the main factor time ($F_{1,25} = 15.90$, $p = 0.001$, $\eta_p2 = 0.389$, 1-β =). The scores of the CRG were significantly lower ($t_8 = -2.4$, $p = 0.04$, $d_{\text{Cohen}} = -0.78$) in the pre-intervention time ($\bar{x} = 84.8$), compared to the post-intervention time ($\bar{x} = 99.7$). The scores of the ETG were not significantly different ($t_8 = -0.96$, $p = 0.36$, $d_{\text{Cohen}} = -0.25$) between the pre-intervention ($\bar{x} = 91.1$) and post-intervention times ($\bar{x} = 94.4$). The scores of the NIG were significantly lower ($t_9 = -4.0$, $p = 0.04$, $d_{\text{Cohen}} = -0.78$) in the pre-intervention time ($\bar{x} = 99.0$), compared to the post-intervention time ($\bar{x} = 110.1$). There was no significant effect of the main factor group ($F_{2,25} = 2.28$, $p = 0.123$, $\eta_p2 = 0.155$, $1-\beta =$), and the interaction between group and time was not significant ($F_{2,25} = 1.86$, $p = 0.176$, $\eta_p2 = 0.130$, $1-\beta =$).

APF cortex scores

Figure 1D shows the executive functions scores associated with the APF cortex of the 3 groups pre- and post-intervention. Figure 2D shows the data dispersion in each of these conditions, and separately for girls and boys. There was a significant effect of the main factor time ($F_{1,25} = 6.35$, $p = 0.018$, $\eta_p2 = 0.203$, $1-\beta =$). The scores of the CRG were not significantly different ($t_8 = -0.88$, $p = 0.40$, $d_{\text{Cohen}} = -0.46$) between the pre-intervention ($\bar{x} = 79.7$) and post-intervention times ($\bar{x} = 89.6$). The scores of the ETG were significantly lower ($t_8 = -2.6$, $p = 0.02$, $d_{\text{Cohen}} = -0.88$) in the pre-intervention time ($\bar{x} = 88.7$), compared to the post-intervention time ($\bar{x} = 103.0$). The scores of the NIG were not significantly different ($t_9 = -1.6$, $p = 0.144$, $d_{\text{Cohen}} = -0.79$) between the pre-intervention ($\bar{x} = 92.7$) and post-intervention times ($\bar{x} = 104.4$). There was no significant effect of the main factor group ($F_{2,25} = 2.80$, $p = 0.080$, $\eta_p2 = 0.183$, $1-\beta =$) or the interaction between group and time ($F_{2,25} = 0.098$, $p = 0.907$, $\eta_p2 = 0.008$, $1-\beta =$).

The results of the confirmatory non-parametric analysis for each intervention group in each BANFE dimension, and separately by sex, are shown in Table 3.

Discussion

Executive functions can be improved through different interventions (Diamond 2013). The brain network involved in these functions is located in the prefrontal cortex (Miller 2000), and this cortical region experiences deep changes during adolescences (Arain et al. 2013; Romine and Reynolds 2005; Teffer and Semendeferi 2012). Thus, different interventions in this age group could have discernible effects on specific executive functions and their underlying prefrontal areas (Benzing et al. 2019; Nouchi et al. 2013; Rosas et al. 2019; Wass 2015). However, to our knowledge, direct comparisons between the effects of educational and cognitive interventions on executive functions in adolescents have not been established so far. The present study revealed improvement effects on overall and DLPF-dependent executive functions after a cognitive intervention (CRG) and when no intervention was implemented (NIG), but not after an additional educational program (ETG). However, only this educational intervention (ETG) improved the APF-dependent executive functions.

The results of this study show the differential effects of two kinds of interventions on the executive functions related to three prefrontal areas, i.e., DLPF, OFC, and APF. An intervention not typically educational, such as the motivation to carry out a deep reflection and opinion on controversial issues (intervention implemented in the CRG), was associated with increased scores in the overall executive functions and the DLPF cortex-dependent executive functions, the latter being congruent with the proposed cognitive processes demanded by cognitive reflection tasks, which are strongly linked to this cortical region

(Patel et al. 2019; Pennycook et al. 2016; Sirota and Juanchich 2018). This improvement was also observed in the group without intervention beyond the school program (NIG), and no significant differences were found between these two groups. However, an educational intervention (implemented in the ETG), consisting of additional activities to the school program, such as solving mazes, drawing, and arithmetic operations, was associated with differential effects on specific executive functions. Unlike the interventions in the CRG and NIG, the ETG did not result in a better performance in the overall executive functions and the DLPF cortex-dependent executive functions. There were no differences in this group pre- and post-intervention, which suggests that this kind of intervention could interfere with the expected improvement in these functions in the course of time during adolescence. Considering that the tasks included in this group were typical educational activities, it can be argued that the inclusion of additional school activities could mainly affect the development of the DLPF cortex-dependent executive functions. This possibility is, however, uncertain, and further studies with extensive samples and longer follow-up periods could provide more evidence. Interestingly, only the ETG showed a significant post-intervention improvement in the functions related to the APF cortex. All groups showed a tendency to improve these functions after their respective interventions, but this improvement was significant only in the ETG. The APF is mainly involved in monitoring behavioral outcomes and avoiding behavioral errors (Ramnani and Owen 2004). Therefore, it is feasible that the addition of school and educational activities in this group, which adds an error monitoring effort, had an improvement effect on these APF-dependent executive functions. Instead, the activities implemented in the CRG may not have promoted this monitoring function sufficiently to be reflected in the APF cortex scores. On the other hand, the cognitive and educational interventions of this study had no effect on the executive functions related to the OFC, and neither did the usual scholar program (NIG). This result is coherent with the fact that this area is mainly involved in impulse control, risk decisions, and affective and social behaviors (Rudebeck and Rich 2018), and these functions were not the target of any of the interventions (not even of the usual scholar activities) because the tasks used in both cases do not demand such OFC-dependent executive functions (Flores et al., 2014). Overall, these results agree with the hypotheses raised, although the interference effect of educational tasks on the DLPF cortex-dependent executive functions was unexpected.

The preliminary findings of this pilot study suggest that though the addition of educational interventions to the usual school program in adolescents can interfere with specific executive functions related to the DLPF, they can improve the APF-dependent executive functions. This has a relevant impact on the implementation of educational programs aimed to promote the development of executive functions (Kolb et al. 2012). In addition, the results may be of importance in the treatment of developmental disorders that affect cognitive functions related to anterior prefrontal areas. However, this is a pilot study that included a reduced sample size to initially explore the hypotheses raised, and therefore this limitation makes it necessary to carry out new studies with more representative samples and longer follow-up periods. Another limitation of this study, derived from the size of each group, is that differences between girls and boys were not analyzed using parametric tests. However, in each intervention group and pre-post measure, non-parametric tests revealed non-significant sex differences. These results, along with the dispersion data showed in Figure 2, do not allow to conclude a strong influence of the sex factor on results, although future studies should address this variable in depth.

Conclusions

Although the results of this study are preliminary, they point to the fact that cognitive and educational interventions may have differential effects on specific executive functions in adolescents. Cognitive tasks, as cognitive reflection, promote the executive functions related to the DLPF cortex, but in a similar magnitude to non-intervention. Conversely, educational tasks selectively improve performance in executive functions that depend on the activity of the APF cortex. The unexpected effect of educational tasks on the DLPF cortex-dependent executive functions may be due to an overload in this area derived from excessive school stimulation, or to an interference of these tasks on the development of functions mainly dependent on this area. Larger samples and the inclusion of groups with diverse educational tasks to be compared and with different degrees of difficulty could provide more evidence on the possible interference effect of this kind of intervention. The results of the present study may have implications on the implementation of educational programs for improving cognitive functions.

Declarations

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or non-for-profit sectors

Conflicts of interest/Competing interests

Authors declare that they have no conflict of interest

Availability of data and material

Data are available as supplemental material and are also available from the authors upon request

Code availability

Not applicable

Authors' contributions

All the authors contributed equally to this work

Ethics approval

The study was approved by the Ethics Committee of the Autonomous University of Baja California, Mexico, according to the international norms for social and psychological research

Consent to participate

School directors provided permission for interventions and the parents were reported about the study. In addition, the children gave their verbal assent before each intervention program and they did not receive any incentive for taking part in the study.

Consent for publication

Consent for possible publication of results was provided by parents

References

A., D., & K., L. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science*, *333*(6045), 959–964. http://www.sciencemag.org/content/333/6045/959.full.pdf%5Cnhttp://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed10&NEWS=N&AN=2011465182

A., H.-B., D.T., S., & M., F. (2018). Clinical Assessment of Prefrontal Lobe Functions. *CONTINUUM Lifelong Learning in Neurology*, *24*(3, BEHAVIORAL NEUROLOGY AND PSYCHIATRY), 704–726. http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L622515615

Álvarez-Bueno, C., Pesce, C., Cavero-Redondo, I., Sánchez-López, M., Martínez-Hortelano, J. A., & Martínez-Vizcaíno, V. (2017, September 1). The Effect of Physical Activity Interventions on Children's Cognition and Metacognition: A Systematic Review and Meta-Analysis. *Journal of the American Academy of Child and Adolescent Psychiatry*. Elsevier Inc. https://doi.org/10.1016/j.jaac.2017.06.012

Arain, M., Haque, M., Johal, L., Mathur, P., Nel, W., Rais, A., et al. (2013). Maturation of the adolescent brain. *Neuropsychiatric Disease and Treatment*. https://doi.org/10.2147/NDT.S39776

Ardila, A., Rosselli, M., Matute, E., & Inozemtseva, O. (2011). Gender Differences in Cognitive Development. *Developmental Psychology*, *47*(4), 984–990. https://doi.org/10.1037/a0023819

Benzing, V., Schmidt, M., Jäger, K., Egger, F., Conzelmann, A., & Roebers, C. M. (2019). A classroom intervention to improve executive functions in late primary school children: Too 'old' for improvements? *British Journal of Educational Psychology*. https://doi.org/10.1111/bjep.12232

Cardoso, C. de O., Dias, N., Senger, J., Colling, A. P. C., Seabra, A. G., & Fonseca, R. P. (2018). Neuropsychological stimulation of executive functions in children with typical development: A systematic review. *Applied Neuropsychology: Child*. https://doi.org/10.1080/21622965.2016.1241950

Carone, D. (2007). E. Strauss, E. M. S. Sherman, & O. Spreen, A Compendium of Neuropsychological Tests: Administration, Norms, and Commentary : A Review of: "(3rd ed.), Oxford University Press, New York, 2006." *Applied Neuropsychology*, *14*(1), 62–63. https://doi.org/10.1080/09084280701280502

Cohen, J. (1988). Statistical power analysis for the behavioural sciences / jacob cohen (2nd ed.). *Statistical Power Anaylsis for the Behavioral Sciences*.

Cristofori, I., Cohen-Zimerman, S., & Grafman, J. (2019). Executive functions. In *Handbook of Clinical Neurology*. https://doi.org/10.1016/B978-0-12-804281-6.00011-2

de Greeff, J. W., Bosker, R. J., Oosterlaan, J., Visscher, C., & Hartman, E. (2018). Effects of physical activity on executive functions, attention and academic performance in preadolescent children: a meta-analysis. *Journal of Science and Medicine in Sport*. https://doi.org/10.1016/j.jsams.2017.09.595

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*. https://doi.org/10.1146/annurev-psych-113011-143750

Diamond, A., & Ling, D. S. (2016). Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience*, *18*, 34–48. https://doi.org/10.1016/j.dcn.2015.11.005

Dias, N. M., & Seabra, A. G. otuz. (2015). The Promotion of Executive Functioning in a Brazilian Public School: A Pilot Study. *The Spanish journal of psychology*. https://doi.org/10.1017/sjp.2015.4

Egger, F., Benzing, V., Conzelmann, A., & Schmidt, M. (2019). Boost your brain, while having a break! The effects of long-term cognitively engaging physical activity breaks on children's executive functions and academic achievement. *PLoS ONE*, *14*(3). https://doi.org/10.1371/journal.pone.0212482

Flores, J.C; Ostrosky, F., Lozano, A. (2014). BANFE-2. Batería Neuropsicológica de Funciones Ejecutivas y Lóbulos Frontales-2. *Manual Moderno*. https://s3.amazonaws.com/academia.edu.documents/52346412/Binder_Manual-Banfe-completo_12-DIC-2013-1.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1527173855&Signature=cZqsnpWbavGv33%2B4xvBEtZfOk7w%3D&response-content-disposition=inline%3B filename%3DBat

Fuster, J. M. (2002). Frontal lobe and cognitive development. *Journal of Neurocytology*. https://doi.org/10.1023/A:1024190429920

Fuster, J. M. (2019). The prefrontal cortex in the neurology clinic. In *Handbook of Clinical Neurology*. https://doi.org/10.1016/B978-0-12-804281-6.00001-X

García-Madruga, J. A., Gómez-Veiga, I., & Vila, J. (2016). Executive functions and the improvement of thinking abilities: The intervention in reading comprehension. *Frontiers in Psychology*, *7*. https://doi.org/10.3389/fpsyg.2016.00058

Gilbert, S. J., Henson, R. N. A., & Simons, J. S. (2010). The scale of functional specialization within human prefrontal cortex. *Journal of Neuroscience*, *30*(4), 1233–1237. https://doi.org/10.1523/JNEUROSCI.3220-09.2010

Jennings, J. H., Kim, C. K., Marshel, J. H., Raffiee, M., Ye, L., Quirin, S., et al. (2019). Interacting neural ensembles in orbitofrontal cortex for social and feeding behaviour. *Nature*, *565*(7741), 645–649. https://doi.org/10.1038/s41586-018-0866-8

Kolb, B., Mychasiuk, R., Muhammad, A., Li, Y., Frost, D. O., & Gibb, R. (2012). Experience and the developing prefrontal cortex. *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.1121251109

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, *4*(NOV). https://doi.org/10.3389/fpsyg.2013.00863

Mace, R. A., Waters, A. B., Sawyer, K. S., Turrisi, T., & Gansler, D. A. (2019). Components of executive function model regional prefrontal volumes. *Neuropsychology*, *33*(7), 1007–1019. https://doi.org/10.1037/neu0000563

McGraw, K. O., & Wong, S. P. (1992). A Common Language Effect Size Statistic. *Psychological Bulletin*, *111*(2), 361–365. https://doi.org/10.1037/0033-2909.111.2.361

Miller, E. K. (2000). The prefontral cortex and cognitive control. *Nature Reviews Neuroscience*. https://doi.org/10.1038/35036228

Miyake, A., Emerson, M. J., & Friedman, N. P. (2000). Assessment of executive functions in clinical settings: Problems and recommendations. *Seminars in Speech and Language*. https://doi.org/10.1055/s-2000-7563

Nouchi, R., Taki, Y., Takeuchi, H., Hashizume, H., Nozawa, T., Kambara, T., et al. (2013). Brain Training Game Boosts Executive Functions, Working Memory and Processing Speed in the Young Adults: A Randomized Controlled Trial. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0055518

Panikratova, Y. R., Vlasova, R. M., Akhutina, T. V., Korneev, A. A., Sinitsyn, V. E., & Pechenkova, E. V. (2020). Functional connectivity of the dorsolateral prefrontal cortex contributes to different components of executive functions. *International Journal of Psychophysiology*, *151*, 70–79. https://doi.org/10.1016/j.ijpsycho.2020.02.013

Parks, A. N., & Smaers, J. B. (2018). The Evolution of the Frontal Lobe in Humans. In *Digital Endocasts*. https://doi.org/10.1007/978-4-431-56582-6_14

Patel, N., Baker, S. G., & Scherer, L. D. (2019). Evaluating the Cognitive Reflection Test as a Measure of Intuition/Reflection, Numeracy, and Insight Problem Solving, and the Implications for Understanding Real- World Judgments and Beliefs. *Journal of Experimental Psychology: General*. https://doi.org/10.1037/xge0000592

Pennycook, G., Cheyne, J. A., Koehler, D. J., & Fugelsang, J. A. (2016). Is the cognitive reflection test a measure of both reflection and intuition? *Behavior Research Methods*, *48*(1), 341–348. https://doi.org/10.3758/s13428-015-0576-1

Ramnani, N., & Owen, A. M. (2004). Anterior prefrontal cortex: Insights into function from anatomy and neuroimaging. *Nature Reviews Neuroscience*. https://doi.org/10.1038/nrn1343

Riccio, C. A., & Gomes, H. (2013). Interventions for executive function deficits in children and adolescents. *Applied Neuropsychology: Child*. https://doi.org/10.1080/21622965.2013.748383

Riley, J. D., Chen, E. E., Winsell, J., Davis, E. P., Glynn, L. M., Baram, T. Z., et al. (2018). Network specialization during adolescence: Hippocampal effective connectivity in boys and girls. *NeuroImage*, *175*, 402–412. https://doi.org/10.1016/j.neuroimage.2018.04.013

Romine, C. B., & Reynolds, C. R. (2005). A model of the development of frontal lobe functioning: Findings from a meta-analysis. *Applied Neuropsychology*. https://doi.org/10.1207/s15324826an1204_2

Rosas, R., Espinoza, V., Porflitt, F., & Ceric, F. (2019). Executive Functions Can Be Improved in Preschoolers Through Systematic Playing in Educational Settings: Evidence From a Longitudinal Study. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2019.02024

Rudebeck, P. H., & Rich, E. L. (2018). Orbitofrontal cortex. *Current Biology*.

https://doi.org/10.1016/j.cub.2018.07.018

Selnes, O. A. (1991). A Compendium of Neuropsychological Tests: Administration, Norms, and Commentary. *Neurology*, *41*(11), 1856–1856. https://doi.org/10.1212/wnl.41.11.1856-a

Shaheen, S. (2014). How Child's Play Impacts Executive Function-Related Behaviors. *Applied Neuropsychology: Child*, *3*(3), 182–187. https://doi.org/10.1080/21622965.2013.839612

Sirota, M., & Juanchich, M. (2018). Effect of response format on cognitive reflection: Validating a two- and four-option multiple choice question version of the Cognitive Reflection Test. *Behavior Research Methods*, *50*(6), 2511–2522. https://doi.org/10.3758/s13428-018-1029-4

Spreen, O., & Strauss, E. (1998). A compendium of neuropsychological tests: administration, norms, and commentary. New York: Oxford University Press.

Stuss, D. T., & Levine, B. (2002). Adult clinical neuropsychology: Lessons from studies of the frontal lobes. *Annual Review of Psychology*. https://doi.org/10.1146/annurev.psych.53.100901.135220

Teeuw, J., Brouwer, R. M., Guimarães, J. P. O. F. T., Brandner, P., Koenis, M. M. G., Swagerman, S. C., et al. (2019). Genetic and environmental influences on functional connectivity within and between canonical cortical resting-state networks throughout adolescent development in boys and girls. *NeuroImage*, *202*. https://doi.org/10.1016/j.neuroimage.2019.116073

Teffer, K., & Semendeferi, K. (2012). Human prefrontal cortex. Evolution, development, and pathology. In *Progress in Brain Research*. https://doi.org/10.1016/B978-0-444-53860-4.00009-X

Tsujimoto, S. (2008, August). Review: The prefrontal cortex: Functional neural development during early childhood. *Neuroscientist*. https://doi.org/10.1177/1073858408316002

Turnbull, A., Wang, H. T., Murphy, C., Ho, N. S. P., Wang, X., Sormaz, M., et al. (2019). Left dorsolateral prefrontal cortex supports context-dependent prioritisation of off-task thought. *Nature Communications*, *10*(1). https://doi.org/10.1038/s41467-019-11764-y

Verburgh, L., Königs, M., Scherder, E. J. A., & Oosterlaan, J. (2014). Physical exercise and executive functions in preadolescent children, adolescents and young adults: A meta-analysis. *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsports-2012-091441

Wass, S. V. (2015). Applying cognitive training to target executive functions during early development. *Child Neuropsychology*. https://doi.org/10.1080/09297049.2014.882888

Werchan, D. M., & Amso, D. (2017). A novel ecological account of prefrontal cortex functional development. *Psychological Review*, *124*(6), 720–739. https://doi.org/10.1037/rev0000078

Yoshida, W., Funakoshi, H., & Ishii, S. (2010). Hierarchical rule switching in prefrontal cortex. *NeuroImage*, *50*(1), 314–322. https://doi.org/10.1016/j.neuroimage.2009.12.017

Yoshida, W., & Ishii, S. (2006). Resolution of Uncertainty in Prefrontal Cortex. *Neuron*, *50*(5), 781–789. https://doi.org/10.1016/j.neuron.2006.05.006

Yuan, P., & Raz, N. (2014). Prefrontal cortex and executive functions in healthy adults: A meta-analysis of structural neuroimaging studies. *Neuroscience and Biobehavioral Reviews*. https://doi.org/10.1016/j.neubiorev.2014.02.005

FIGURES LEGEND

Figure 1. Mean BANFE scores for each group and standard error. (A) Overall BANFE scores for each group (NIG, non-intervention group; CRG, cognitive reflection group; ETC, educational task group) pre- and post-intervention. (B) Scores related to the orbitofrontal cortex. (C) Scores related to the dorsolateral prefrontal (DLPF) cortex. (D) Scores associated to the anterior prefrontal (APF) cortex (*significant differences between pre-intervention and post-intervention scores)

Figure 2. Total data dispersion of the BANFE scores of the NIG (non-intervention), CRG (cognitive reflection) and ETC (educational task) groups, and separately for girls and boys. (A), (B), (C) and (D), total and sex data dispersion for the overall BANFE scores, and for the scores related to the orbitofrontal cortex, the dorsolateral cortex, and the anterior prefrontal cortex, of each group pre- and post-intervention, respectively. The girls' scores are represented by black circles.