

**Executive functions in adolescence: A longitudinal study comparing evaluations before and after the COVID-19 pandemic**

G. Nathzidy Rivera-Urbina<sup>1</sup>, María Fernanda Orozco Roldán<sup>1</sup>, Andrés Molero-Chamizo<sup>2</sup>

<sup>1</sup>Autonomous University of Baja California, Mexico

<sup>2</sup>University of Huelva, Departamento of Psychology. Huelva, Spain

Correspondence address:

G. Nathzidy Rivera-Urbina

Autonomous University of Baja California, Mexico

E mail: [nathzidy.rivera@uabc.edu.mx](mailto:nathzidy.rivera@uabc.edu.mx)

Blvd Juan A. Zertuche y Blvd de los lagos d/n Fracc. Valle Dorado C.P. 22890

Ensenada, Baja California, Mexico

### **Abstract**

The change in the educational model derived from the COVID-19 pandemic might have an impact on cognitive development, particularly on Executive Functions (EFs). The aim of this study is to explore cognitive performance in adolescents at two time points, before and after the pandemic. We also analyzed possible sex differences in the results. We evaluated EFs using the Neuropsychological Battery of Executive Functions and Frontal Lobes (BANFE-2), which includes four cognitive indices corresponding to specific cognitive functions and associated prefrontal areas: Orbitofrontal Cortex (OC index -OCI-), Anterior Prefrontal Cortex (APCI), Dorsolateral Prefrontal Cortex (DCI), and Prefrontal cortex as an index of global EFs (EFI). The ANOVA conducted to compare the evaluations before and after the pandemic revealed no significant pre-post-pandemic differences in any sex and in any BANFE-2 index, except for the OCI, in which post-pandemic performance was impaired in boys (pre and post percentile = 96.61 vs. 66.53), but not in girls (pre and post percentile = 93.55 vs. 95.0). Our findings are thus compatible with the idea of a different vulnerability to change in the educational model between sexes, and they also reveal which specific EFs may have been affected during the pandemic.

**Keywords:** Adolescents, BANFE-2 test, COVID-19, Executive functions, Prefrontal cortex

## **Introduction**

In March 2020, a global pandemic caused by the SARS-CoV-2 virus was declared by the World Health Organization. This pandemic led to the widespread declaration of a state of alarm in the world. The lockdown resulting from the state of alarm confined citizens to their homes, and the school and work activities were carried out, except basic exceptions, in virtual and telematic modes or with non-face-to-face approaches. To the best knowledge of the authors, no previous research is available to analyze and understand how the isolation could affect cognitive capacities at critical stages of neuropsychological development. Some evidence shows that COVID-19 pandemic was associated with cognitive decline in adults (Hadad et al., 2022; Tavarés-Junioer et al., 2022). The most frequently reported cognitive impairments involve executive functions (EFs), attention, and episodic memory (Gonzalez-Fernandez et al., 2023, Tavarés-Junior et al., 2022), in addition to some psychiatric symptoms, such as depression and anxiety (Largent et al., 2023). A longitudinal study conducted by Porter et al. (2021) revealed that young people, around 15 years old, showed a better emotional well-being state during the pandemic, and were less engaged in online socialization methods than middle-aged adults (around 46 years old). Recently, worse academic performance in university students has been reported during the COVID-19 pandemic, compared to the results of pre-pandemic face-to-face evaluations (Vicario et al., 2024). However, few studies have explored the impact of the pandemic on EFs in young people, and this impact has generally been analyzed using self-administered scales (Chere & Kirkham, 2021; Ji & Earle, 2021; Lavigne, et al., 2021; Shuai, et al., 2021). EFs include high-order cognitive abilities such as abstract thinking, reasoning, inhibitory control, working memory, planning future actions, motivational modulation, decision-making, behavior

modulation and affective regulation. Anatomically, EFs depend on a cortical network distributed in several regions of the prefrontal cortex. In the context of neuropsychology, deficits associated with the development of EFs are expressed in cognitive alterations ranging from self-regulation difficulties to perseverations, planning difficulty, poor working memory capacity, and limited cognitive flexibility. Since the correct evolution of EFs is an essential aspect in the integral development of young people, the neuropsychological consequences of the pandemic, social isolation, and sudden adaptations in teaching procedures in adolescents should be analyzed in depth.

In the present study we show data related to EFs in pre- and post-pandemic periods. In high school students, we compare cognitive performance before and after the transition to the virtual teaching method derived from the COVID-19 pandemic. The main objective of this study was to analyze the development of EFs once the virtual teaching method was assumed during the pandemic and compare the results with evaluations carried out during conventional pre-pandemic teaching. Considering the reported cognitive performance differences depending on sex (Hyde, 2014) and the evidence of sex differences in the development of cognitive functions (Lee et al., 2023), we explored EFs before and after the pandemic separately in girls and boys to analyze the mediating role of the factor sex in the results.

## **Method**

### *Participants*

The inclusion criteria in the study were to be a student at the participating center, be within the analyzed age group, and voluntary participation. Any medical or psychiatric condition that could prevent the normal participation in this study was considered an exclusion criterion. The school staff monitored these criteria, and therefore the confidentiality of personal data was preserved. Twenty-two adolescent students, 13 male and 9 female (the mean age in the 2019-2020 course was  $12.18 \pm 0.50$ , and the mean age in the 2021-2022 course was  $14.45 \pm 0.59$ ), with equivalent socioeconomic status, were recruited from a public school of the Ensenada city in the Baja California State, Mexico. The participants did not receive any incentive for taking part in this study. School directors provided permission for respective interventions, and the parents were reported about the characteristics and objectives of the study. All children provided verbal assent for participation in the study before each intervention program. The study was approved by the Ethics Committee for human research of the Autonomous University of Baja California, Mexico, according to the international norms for social and psychological research.

### *Assessment Instruments*

EFs were measured using the Neuropsychological Battery of Executive Functions and Frontal Lobes, second edition (BANFE-2) (Flores et. al., 2014). This test was designed to evaluate cognitive processes, particularly EFs, that depend mainly on different regions of the prefrontal cortex. This test is widely used in research to evaluate EFs in the Mexican population (Bermudez-Rivera et al., 2023, Mancilla-Corona et al., 2023, Patraca-Camacho et al., 2022, Roniguer et al., 2022). The BANFE-2 test is categorized into 4 indices, each corresponding to specific cognitive functions and their associated prefrontal areas:

Orbitofrontal Cortex (OC index -OCI-), Anterior Prefrontal Cortex (APCI), Dorsolateral Prefrontal Cortex (DCI), and Prefrontal Cortex as an index of global EFs (EFI). The tests applied to obtain the OCI are Stroop effect for colors, cards game, mazes, and Stroop effect for colors and words. The APCI is obtained using the following tests: semantic classifications, selection of popular sayings, and metamemory tests. The tests used to obtain the DCI are a self-directed pointing test, consecutive subtraction, consecutive sum, alphabetical ordering, and visuospatial working memory tests. Finally, to obtain the EFI, maze tasks, card classification, semantic classification, verbal fluency, and tower of Hanoi tests are applied. In all tests, higher scores indicate better cognitive performance. Figure 1 shows the anatomical cortical regions related to each specific BANFE-2 index, and tests used for respective cognitive evaluations.

#### **INSERT FIGURE 1 APPROXIMATELY**

##### *Procedure*

The outcome measures were the pre-pandemic (October-November, year 2019) and post-pandemic (May-June, year 2022) evaluations realized via the four indices of the BANFE-2. The BANFE-2 test was individually administered in a school classroom. Only the evaluator and the participant were present in each individual evaluation. Overall, the evaluations were completed in approximately one hour. Figure 2 depicts the time course of the study.

#### **INSERT FIGURE 2 APPROXIMATELY HERE**

##### **Data analysis**

The analyzes were conducted for the data of 22 participants. Pre- and post-pandemic differences in the BANFE-2 scores were obtained for each index (OCI, APCI, DCI and EFI)

and sex (male vs. female). A 2×2 repeated measure ANOVA, with the variable sex as a between-group factor, and evaluation (pre- vs. post-pandemic) as a within-subject factor, was conducted for each BANFE-2 index. When the interactions were significant, post-hoc *t* tests with Bonferroni correction were performed for comparisons. The critical level of significance in all tests was set to  $p < 0.05$ . The analyses were carried out using SPSS software.

## Results

The results of the ANOVA conducted to analyze the results of the evaluations obtained before and after the COVID-19 pandemic in each sex are shown in Table 1. The ANOVA corresponding to the APCI revealed that there was no significant effect of the factors sex ( $F_{1,20} = 1.862, p = 0.188$ ) and evaluation ( $F_{1,20} = 4.276, p = 0.52$ ). The interaction between sex and evaluation was also not significant ( $F_{1,20} = 0.158, p = 0.695$ ). The ANOVA for the DCI did not show significant effects of the factors sex ( $F_{1,20} = 2.684, p = 0.117$ ) and evaluation ( $F_{1,20} = 0.817, p = 0.377$ ), and the interaction between these factors was not significant either ( $F_{1,20} = 1.325, p = 0.263$ ). The ANOVA conducted for the OCI did not show a significant effect of the factor sex ( $F_{1,20} = 3.780, p = 0.066$ ) but revealed a significant effect of the factor evaluation ( $F_{1,20} = 5.603, p = 0.028$ ) and the interaction between these factors ( $F_{1,20} = 5.687, p = 0.027$ ). Post-hoc comparisons revealed that the post-pandemic OCI scores were significantly reduced in boys (pre- and post-pandemic percentile = 96.61 vs. 66.53,  $p = 0.002$ ), but not in girls (pre and post percentile = 93.55 vs. 95.0,  $p = 0.992$ ). The ANOVA for the EFI did not show significant effects of the factors sex ( $F_{1,20} = 4.201, p = 0.054$ ) and evaluation ( $F_{1,20} = 0.004, p = 0.953$ ). The interaction between these factors was not significant ( $F_{1,20} = 2.459, p = 0.133$ ). Figure 3 shows the scores obtained in each BANFE-2 index for each evaluation (before and after the COVID-19 pandemic) and sex.

**INSERT TABLE 1 APPROXIMATELY HERE**

**INSERT FIGURE 3 APPROXIMATELY HERE**

### **Discussion**

This study aimed to explore possible influences of the COVID-19 pandemic and the forced change of education modality during this period on EFs performance in teenagers. For this purpose, we compared the EFs evaluations realized before and after the pandemic in a group of high-school students. We explored four EF indices, related with four specific prefrontal cortex regions, using a neuropsychological test that provides measurements in each of these domains, the BANFE-2. In accordance with the reported differences between sexes in cognitive performance during the stages prior to adulthood, we evaluated the effect of the change in the teaching modality separately in boys and girls. The results reveal no significant pre- vs. post-pandemic differences in the EFI, DCI and APCI scores in any of the sexes. These findings suggest that the evolution of most EFs was not affected by the change of educational modality derived from the pandemic. Interestingly, once the conventional face-to-face education modality was reinstated, there was a significant decrease in the scores related to the orbitofrontal cortex (OCI) in comparison with the scores obtained before the virtual teaching mode was implemented during the pandemic. More specifically, this effect was selectively noted in boys but not in girls, which suggests that the effect of the pandemic on teaching was dependent on sex and was reflected in the development of those EFs dependent on the orbitofrontal region, with worse performance in these functions only in boys. The tasks included in the OCI are aimed to explore cognitive functions related to the orbitofrontal cortex, such as inhibitory control, compliance with rules, and taking decisions based on risks-benefits processing, among others. Thus, this BANFE-2 index allows to

evaluate the ability to inhibit automatic responses and select responses based on non-immediacy criteria, as well as the ability to respond and operate in uncertain conditions, learn the risk-reward relations and make decisions according to the calculated risks, and plan behavior in advance.

In a recent review and meta-analysis, Gaillard et al. (2021) reported two differences in cognitive performance linked to sex: one of them related to response inhibition, with higher scores in women, and the other related to spatial working memory, with higher scores in men. Although these results refer to adults, greater resilience in response inhibition in women could explain the greater vulnerability of boys to the cognitive effects of the pandemic in our study, as reflected in a worse evolution of their OCI scores. Nevertheless, the evidence for sex-dependent cognitive differences in child and adolescents is unclear. Thus, it has been reported better scores in tasks related to decision making in boys than in girls (Lensing and Elsner, 2018). Hormonal fluctuations and stress responses derived from social isolation during the pandemic might be differential factors with different cognitive influence depending on sex. However, a more plausible explanation for our results refers to the different rhythms of orbitofrontal maturation between sexes that could condition the sensitivity to the change in the educational model and its effects on cognitive performance (Wierenga et al., 2019). Our findings are thus compatible with the idea of cognitive evolution determined by critical stages of development, in which adolescence is one of them (Larsen and Luna, 2018), and with the possibility that neurobiological and neurocognitive development is a differentiated process between the two sexes (Denno et al., 1982; Chung et al., 2017; Schulte et al., 2020). This differentiated maturational rhythm and neurobiological

development could make one of the sexes more sensitive to the cognitive effect of the educational change forced by the pandemic.

With respect to the effects found on specific cognitive functions, there are several factors that could have affected performance in those tasks included in the OCI after the pandemic. Thus, a restriction in socialization resulting from social isolation might be a determinant factor in tasks performance associated with orbitofrontal activity, as measured by the OCI, assuming that the abilities evaluated by this index, particularly the inhibitory control, are largely dependent on social contacts and social rules. This possibility is consistent with the fact that other EFs, such as those related to the anterior and dorsolateral prefrontal cortex (working memory, mental flexibility, visual-spatial planning, and numbers and words sequencing), do not critically depend on social interactions for their development, and these functions might thus be in a better disposition to follow their natural course of maturation, without being strongly conditioned to the type of educational modality, that is, face-to-face or virtual/telematic teaching.

Other factor to consider regarding the effects of a change in the educational modality in the context of the COVID-19 pandemic refers to the characteristics of the biological maturation of the prefrontal cortex. The different cytoarchitectonic and functional regions of the prefrontal cortex have a late evolutionary course, with respect to primary and other associative cortical areas, including sensory and motor areas. These regions of the prefrontal cortical network also show differences in the rate of maturation. It can be argued that the cognitive functions evaluated through the OCI were dependent on cortical maturational processes different from other prefrontal areas and their functions. This phenomenon would make these EFs, and the orbitofrontal cortex that supports them, more vulnerable to changes

in social relationships and changes in teaching modalities than other functions and prefrontal regions, which would have been reflected in the scores obtained in this index.

Some limitations of this study should be overcome in future similar studies. The sample size was limited according to the COVID-19 pandemic scenario, in which carrying out post-pandemic studies and recruiting children and adolescents to participate in research was especially complex. Despite this, the analyzed sample allowed to observe a selective effect of the pandemic and the change of educational modality on EFs dependent on the orbitofrontal cortex, but not on other EFs dependent on other prefrontal areas. The evaluations carried out by index and sex also showed that this effect was tied to sex. Another limitation in the present study might be attributed to the fact that the outcome measure was only analyzed using a single test, which could not be compared with others tests and assessments due to the multiple restrictions derived from the post-pandemic situation. Future studies should address these limitations in order to systematically explore in detail the effects of changes in educational modality and social restrictions on EFs in adolescence.

#### Conclusions

The COVID-19 pandemic brought a critical change in the education modality with unknown consequences on cognitive functions in young people. The results of the present study suggest that the social restriction imposed to control the effects of the pandemic and the virtual/telematic teaching modality that was implemented in educational systems to adapt to the situation of social isolation had significant effects on selective EFs, particularly those dependent on the orbitofrontal cortex, and that this was a sex-dependent effect. This double differential effect, by cognitive function and sex, may be attributed to the particular interactions between the maturation of the orbitofrontal cortex and the social context during

the pandemic, considering the involvement of this cortical region in cognitive functions especially sensitive to social influences. Since no other prefrontal cognitive function was significantly affected in neither sex by the educational change and the restrictions derived from the pandemic, these findings should be taken into account in future studies to elucidate the specific influences of virtual/telematic teaching during social restrictions on EFs development.

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## Figure legends

**Figure 1. Cortical regions associated with the specific cognitive functions evaluated by the four indices of the Neuropsychological Battery of Executive Functions and Frontal Lobes (BANFE-2), and specific tests used in each index.** Stroop A, Stroop effect for colors; Stroop B, Stroop effect for colors and words.

**Figure 2. Time course of the study.** The four indices of the BANFE-2 (OCI, Orbitofrontal cortex index; APCI, Anterior prefrontal cortex index; DCI, Dorsolateral prefrontal cortex index; EFI, Prefrontal cortex-global executive functions index) were obtained in two different time points, before (pre) and after (post) the COVID-19 pandemic.

**Figure 3. Percentile scores for each BANFE-2 index and each evaluation (pre- and post-COVID-19 pandemic).** 3A shows the results of the evaluations in girls. 3B shows the results of the evaluations in boys. OCI, Orbitofrontal cortex index; APCI, Anterior prefrontal cortex index; DCI, Dorsolateral prefrontal cortex index; EFI, Prefrontal cortex-global executive functions index. (\*)  $p < 0.05$ .