Reading comprehension in undergraduates during the COVID-19 pandemic. Associations with executive function difficulties, reading habits and screen times.

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Abstract

The COVID-19 pandemic and its concomitant restriction measures drastically altered the routines and learning formats of students from all levels. In addition, it has been shown that pandemic-related stress negatively impacted their mental health and cognitive functioning. Undergraduates have been signaled out as one of the populations most vulnerable to pandemic-related stressors. The following work examined the link between executive functions, perceived stress and reading comprehension among Argentinean university students during lockdown measures. In addition, potential effects of reading habits and screen exposure were considred. An executive function behavioral rating scale (ADEXI), a reading comprehension test and the PSS-10 stress questionnaire were administered to two-hundred social science students through an online survey. Executive difficulties increased with perceived stress, while lower inhibition was associated with longer TV times and being male. Stress and executive function associations can be interpreted as a detrimental effect, reverse or bidirectional causation. In turn, working memory issues led to worse comprehension (mediating the impact of perceived stress) while distal factors such as print exposure and mother education were positive predictors of reading outcomes (as expected). This finding suggests that undergraduates' difficulties to manipulate online information interfered with expository text processing, resulting in poorer comprehension performance.

Introduction

The coronavirus disease (COVID-19) pandemic constitutes a global health crisis and has been a major public health emergency of international concern since december 2019 (World Health Organization, 2020). In their efforts to reduce COVID-19 spread, several governments implemented containment measures that included social distancing, school and university closure and lockdowns of varying (sometimes prolonged) duration (Loades et al., 2020). Pandemic-related fears and worries, as well as containment measures constituted a severe and sustained world-wide stressor, raising concerns about the populations' well being and mental health (Fernández et al., 2022). Several studies found increased incidence and risks for psychopathological symptoms and mental health disorders (particularly, anxiety and depression) through the course of the pandemic, both at international (WHO, 2022; for meta-analyses, see: Dragioti et al., 2021; de Sousa et al., 2021; Leung et al., 2022) and local levels (Canet-Juric et al., 2020; Del Valle et al., 2022; Fernández et al., 2022). In addition, there is evidence that pandemic-related stressors have taken a toll on the populations' cognitive functioning, leading to a perceived cognitive decline with respect to pre-pandemic times (Castanheira et al., 2021; Fiorenzato et al., 2021; Kira et al., 2021; Podlesek et al., 2021).

One of the adult populations signaled out as vulnerable to pandemic-related stressors is university students (see Li et al., 2021 for a meta-analysis; WHO, 2020). Besides pandemic-related uncertainty and worries, university students had to face additional challenges, including changes in their academic trajectory and career outlooks, disturbance (or cessation) of social activities and interactions and adapting to digital learning environments (Mosleh et al., 2022; Whatelet et al., 2020). It has been shown that college students felt more vulnerable to COVID-19 than the general population (Stangier et al., 2021; Wang et al., 2022), and exhibited increased prevalence of distress (Wang et al., 2022) anxiety and depression (Li et al., 2021). However, few studies have focused on undergraduates' cognitive functioning and relevant language skills (such as reading comprehension), during the pandemic. A notable exception is Mesghina et al., 2021, who found that distress-related vulnerability to distraction (mind-wandering) affected undergraduates' lesson outcomes. On a related note, evidence from children and adolescent studies did indicate that confinement and remote schooling were associated with worse executive function (EF) outcomes (Hanno et al., 2022; Lavigne-Cerván et al., 2021a,b). Therefore, it is of interest to examine how perceived stress was related to EF in undergraduates, and how potential EF issues might have contributed to their reading skills. We elaborate on the links between these variables in the following sections.

The link between executive functions, stress and the COVID-19 pandemic

The term “executive functions" (EF) refers to a set of cognitive processes involved in planning, executing, monitoring and adapting goal-directed behaviors (Miyake & Friedman, 2012). It includes the skills to: manipulate and update contents within working memory, suppress irrelevant information and/or contextually inadequate responses and shift between behaviors, strategies and cognitive processes to flexibly adapt behavior to situational demands (Lezak et al., 2012). Executive functioning can be assessed through cognitive performance-based instruments (such as neuropsychological tests) or behavioral rating scales, such as the *Behavior Rating Inventory of Executive Function-Adult Version* (BRIEF-A, Roth, Isquith, & Gioia, 2005) or the *Adult Executive Function Inventory (*ADEXI, Holst & Thorell, 2018). It has been argued that these measures capture different types of information, with the former representing performance efficiency in optimal settings and the latter indicating the frequency of goal achievement in typical settings (Toplak et al., 2013). Behavioral scales have been shown to reflect expected EF patterns in clinical populations, correlate with physiological markers, and to provide evidence of the predictive power of the EF construct over real world behavior (García-Molina et al., 2007, Isquith et al., 2013). In addition, both performance-based and behavioral rating measures of EF have been shown to predict academic achievement throughout development (Best et al., 2011; see Cortés-Pascual et al., 2019 for a meta-analysis; Gerst et al., 2017) and specifically in adults (Reynoso Orozco & Méndez-Luévano, 2018). Therefore, EF constitutes a relevant cognitive domain when considering undergraduates’ academic performance.

It is generally accepted that stress interferes with cognitive functions, and, particularly, with EF (see Sandi et al., 2013 and Deligkaris et al., 2014 for reviews; Shields et al., 2015, 2016 for meta-analysis). Stress can be broadly defined as a situation where “a demand exceeds the regulatory capacity of an organism” (Starcke et al., 2016, p.2; see also McEwen 2003, 2004). Stress can be further classified in two categories (each with their own unique effects): *acute*, when it consists in recent, transient and single stressors or *chronic*, referring to long-lasting and ongoing situations that may or may not be constantly present or threatening (Shields et al., 2016). It has been argued that, during the stress response, cognitive processes (including EF components) are hijacked to deal with the stressor at hand, thus depleting available resources for other goal-oriented tasks (LeBlanc, 2009; Mather & Sutherland, 2011; Plessow et al., 2011; cited in Shields et al., 2016). Other hypotheses involve cortisol-mediated mechanisms (Shields et al., 2015, 2016) or cytokine-induced inflammatory responses (Shields et al., 2017). Regardless of the mechanisms, it would be expected that the stressful conditions of COVID-19 pandemic would take their toll on the populations’ EF. Several studies showed it was indeed the case, since COVID-19 related stressors (Kira et al., 2021, Podlesek et al., 2021), as well as stress-related psychopathology (Fiorenzato et al., 2021) were found to be significant predictors of lower EF scores in adults. However, none of these studies specifically examined the situation of college undergraduates, nor did they consider the association with relevant academic skills, such as reading comprehension.

The contribution of executive functions to reading comprehension

Reading comprehension is a crucial skill for academic achievement through all levels of the education system (Meneghetti, et al. 2006; Royer et al., 1990; Clinton-Lisell et al., 2022). It involves a variety of linguistic processes, ranging from visual word processing to word to text integration (Perfetti & Stafura, 2014), that have been summarized by the Simple View of Reading framework as the interplay between word decoding and language comprehension (Hoover & Tunmer, 2018). In addition, reading comprehension recruits cognitive processes such as EF (see Butterfuss & Kendeou, 2018 for a review and Follmer, 2018 for a meta-analysis). The most influential EF model for reading comprehension (Butterfuss & Kendeou, 2018) conceptualizes EFs as three separate but connected set of processes: 1) working memory (hereinafter, “WM”) *updating*, 2) *shifting* (also known as “cognitive flexibility”, hereinafter “CF”) and 3) *inhibition.* WM is a short-term system for retention and active manipulation of verbal and visuospatial information, deploying memory and controlled attention resources. WM updating refers to the ability of monitoring, adding or removing contents from this system. Shifting (or CF) can be defined as the ability to switch between mental processes and sets to generate appropriate behavioral responses. Inhibition is the ability to suppress interference in order to achieve a goal. It encompasses the control of interference generated by distracting or task-irrelevant external stimuli, and response inhibition, which suppresses automatic or prepotent, but task-irrelevant responses (Diamond, 2013).

Many theoretical models of reading comprehension, such as the Construction- Integration model (Kintsch, 1988), the Landscape model (van den Broek et al., 1999), or the Reading Systems Framework (Perfetti & Stafura, 2014), imply or explicitly describe the role of EFs (Butterfuss & Kendeou, 2018). When comprehending text, WM provides a cognitive workspace to maintain information from the incoming input, integrating it with the unfolding text representation and prior knowledge. In this way, WM allows (and constrains) model construction and inference generation (Daneman & Merikle, 1996). Shifting also plays an important role by supporting the switch from mental sets and the formation of new concepts, integrating new and sometimes unexpected input with the unfolding text representation, adequating forward inference-making processes (by selecting and alternating between relevant pieces of information), alternating between reading strategies, and engaging in metacognitive processing, such as monitoring one's comprehension (Butterfuss & Kendeou, 2018). Finally, inhibition helps readers to avoid the activation of irrelevant information, be it from environmental stimuli or long-term memory systems supporting relevant text representation construction and preventing WM overload (Butterfuss & Kendeou, 2018). Considering the contribution of executive processes to reading comprehension, it would be expected that the incidence of EF difficulties among university students during the pandemic would be associated with worse reading outcomes, a possibility that will be specifically addressed in the present study.

The current study

Despite the evidence that pandemic and confinement-related stressors were associated with worse cognitive functioning in children, adolescents and adults, none of the previous studies focused on undergraduates' EF. Moreover, the potential incidence of university students' EF performance on their reading comprehension skills has remained unexplored. Therefore, the current study set out to examine the link between perceived stress, EF and expository text comprehension in university students during the COVID-19 pandemic. In addition, we considered the effect of relevant contextual variables, such as current leisure and study reading times, screen media exposure and their changes with respect to pre-pandemic times. It has been shown that recreational reading and text comprehension skills share a bidirectional causality (Mol & Bus, 2011), and there is evidence that reading frequency increased for adults during the pandemic (Salmerón et al., 2020). Furthermore, lifelong print exposure, as indexed by author recognition tests (ART) (Mol & Bus, 2011), might be a more accurate indicator of reading habits than self-report measures, and was included as well. Longer screen media times, on the other hand, have been associated with worse language and EF outcomes among children (Nathanson et al., 2014; Lillard et al, 2015; Swing et al., 2010) and adults (Hoang et al., 2016), and several studies indicate that screen exposure became much more frequent during the pandemic (Trott et al., 2022). Thus, an additional objective of the present work was to examine the associations between the aforementioned outcome variables, reading habits and screen times among undergraduates, in the context of the COVID-19 pandemic.

Methods

Participants

Two hundred university students (79% female; Age: 26.6 ± 9.18 years) completed our cross-sectional study. Participants were currently taking courses in psychology, psychopedagogy, education or other social sciences (69.5% in private management universities). More than half of the participants (58%) had completed less than 50% of their graduate studies (see Table 1 for more details). Regarding maternal education levels, most of the participants' mothers (59.3%) had reached university level education and only 15.1% had primary school education.

INSERT TABLE 1

Instruments

Adult Executive Functioning Inventory (ADEXI, Holst & Thorell., 2018). The ADEXI is a 14 items EF inventory that assesses the incidence of Inhibition and Working Memory deficits. Items are scored on a 5-point Likert-like scale ranging from "It does not describe me" to "It describes me very well." Higher scores indicate worse EF functioning. One global and two dimension scores can be calculated: *working memory* (EF-WM) and *inhibition* (EF-I) difficulties. The ADEXI has been validated on clinical (ADHD) and non-clinical samples, and it has been shown to correlate with other behavioral rating inventories and performance-based measures (Holst & Thorell., 2018). A Spanish adaptation, carried out on an Argentinean population, showed predictive validity and high internal consistency (Cronbach's $\alpha > .72$ for individual and global scores).

Reading comprehension test (Sampedro et al., 2011). Reading comprehension of expository texts was assessed by an online version of a pencil and paper assessment tool (Sampedro et al., 2011). This test is based on the multi-componential model of reading (De Beni, 2003; Abusamra et al., 2009). It requires reading an expository text ("El surgimiento del Maratón" – "The rise of Marathon", adapted from a Wikipedia article) and answering 11 multiple-choice questions, that assess different aspects of comprehension, from basic text scheme and lexical semantics to inference making, text hierarchy and metacognitive skills. Text difficulty was estimated "normal", according to the INFLESZ scale (Barrio-Cantalejo et al., 2008). In this online version, the test was administered as an online survey through Google Forms platform. The text was presented in a linear, continuous and fixed format, and remained available while the subjects answered the questions. The internal consistency of the test was found to be acceptable (Cronbach's $\alpha = .67$). In order to control for potential screen format effects (Chen et al.,, 2014), participants were asked the device in which they read (laptop, tablet or smartphone).

Perceived stress scale (PSS-10, Cohen et al., 1983). The argentinean adaptation of the 10-item version of the instrument was applied (Reyna et al., 2019). Participants were required to rate how often they considered different life situations as "stressing" within the last month, answering on a 0–4 likert rating scale. The instrument showed adequate internal consistency (Cronbach's $\alpha = .789$).

Author recognition test (ART, (Cunningham and Stanovich, 1990). ART is an objective (but indirect) measure of lifelong print exposure. It consists of a list of authors, half of them actual fiction (or non-fiction) writer names, and half of them foils, which is given to the subjects with the instruction of marking only those names they recognize as writers (regardless of whether they read their work). A local version of the test was applied (Tabullo et al., 2018, 2020), including 18 real items and 18 foils. Performance was calculated as the number of author names identified correctly minus the number of foil errors. The test showed good internal consistency (Cronbach's $\alpha = .88$).

Reading and screen times. Our participants reported their leisure (defined as reading for non-study purposes) and study reading times, as well as their frequency of TV, social networks, web-surfing (for non-study purposes) and video-game use (regardless of the device). Online lesson times were also considered. Responses were marked on a 1–7 likert scale (1. does not do it; 2. a couple of days a week; 3. less than 1 hour a day; 4. 1–2 hours a day; 5. 2–3 hours a day; 6. 3–4 hours a day; 7. more than 4 hours a day). In addition, they informed perceived changes in their reading and screen media times with respect to pre-pandemic levels, answering in a 1–5 likert scale (1. much less than before – 5. much more than before) .

Sociodemographic measures. Participants were asked their age, gender, career choice, percentage of studies completed and their mother's education level. This variable (representative of their origin socioeconomic level) was chosen because of its relevance for language and literacy outcomes (Hoff, 2003, 2006; Dickson, 2016).

Procedure

Data collection was carried out virtually throughout June and July 2020, while social distance and lockdown measures were effective and all school and academic activities were restricted to online or remote formats. Students were invited to participate through university mailing lists and social networks. All participants were informed that their participation would be voluntary, anonymous and that they could withdraw from the experiment at any time, without any negative consequences. Contact information of the research group was also provided in order to clarify doubts that might arise in relation to the care of rights in research contexts. Those who chose to take part followed the survey's link and expressed their consent with a click before moving on to the questionnaires. All questionnaires and tests were administered through a Google Forms survey.

This study was performed in accordance with the ethical principles for research with human subjects recommended by the Declaration of Helsinki (World Medical Association, 2013), as well as the ethical guidelines for research with human participants of the American Psychological Association (2010). In addition, this research was conducted following the ethical regulation 5344/99 by the National Scientific and Technical Research Council of Argentina (CONICET) and was approved and supervised by CONICET's committee.

Statistical Analyses

Statistical analysis was carried out in SPSS v25 and JAMOVI software. Associations between study variables were examined by Pearson correlation coefficients. In order to identify significant predictors of each EF domain scores, separate hierarchical linear regression models were carried out. The first step of the models included sociodemographics (gender, age, mother education, percentage of complete studies). The second step included current reading and screen times, as well as their respective perceived changes, ART scores, EF-WM, EF-I and PSS-10 scores. Casewise diagnostics were applied to deal with outliers (standardized residuals above 3 or below − 3) (Cousineau and Cartier, 2010). Since no outliers were detected, no data was removed from the analysis. Assumptions of normality, homoscedasticity and linearity were verified by inspection of: normal quantile plots of residuals, standardized residuals scatter plots and observed versus predicted values, respectively. Independence of error assumption was met for all models (1.82 < Durbin-Watson < 2.21). Variance inflation factors indicated that multicollinearity was not a concern in any of the models (1.06 < VIFs < 1.30). Adjusted R squared values and standardized coefficients (with their corresponding confidence intervals) are reported.

In order to test all direct effects simultaneously and to identify potential indirect effects, we ran a path analysis using the *PATHj* module (a JAMOVI implementation of the R *lavaan* package) (Galluci, 2021). The model included stress, all reading and screen times, ART scores, gender and mother education as exogenous variables, EF-WM, EF-I and reading comprehension as endogenous variables (see Fig. 1). Direct and indirect effects are reported as standardized coefficients. Given the continuous nature of outcome variables, the Maximum Likelihood method was applied for parameter estimation (Shi & Madeou-Olivares, 2019). A bootstrapping procedure with 10,000 bootstrap samples was used to examine the significance of direct, indirect (mediated effects), and total effects and 95% bias-corrected confidence intervals for each variable in the model.

Results

Descriptive statistics

A complete list of descriptive statistics for the study variables can be found on Table 1. Average performance on the reading comprehension test was 68.9 ± 18%. Executive function difficulties scores were: *EF-WM =* 22.6 ± 6.93 and *EF-I =* 10.3 ± 3.32. Perceived stress score was 21.3 ± 7.53. Regarding students' reading habits, during the pandemic, 75% of our sample reported reading recreationally less than one hour a day (or lower), while study times were longer than 3 hours a day for 45.5% of the participants. Leisure screen times were similarly low for TV and video games (*<1 hour or lower:* 58.5% and 82%, respectively), and considerably longer for social networks and web surfing (*> 3 hours or higher*: 38.5% and 21.5%, respectively) (see supplementary Table 1 for details). Online classes occupied most of the daily screen times, taking more than 3 hours on a typical day for 43% of the participants (see supplementary Table 2). With respect to pre-pandemic levels, similar proportions of participants reported reading less or more (around 36%), while the majority (66%) perceived an increase on screen times (see supplementary Table 2). The Pearson correlations matrix of the study variables and its description can be found in the supplementary materials (supplementary Table 3).

INSERT TABLE 1 HERE

EF predictors: perceived stress reading habits and screen times

The models' fit improved significantly after the addition of the target variables for both EF-WM (ΔR^2 = 0.170, p < .001; R^2 = .120, *F*(16,182) = 2.69, p < 0.001) and EF-I (ΔR^2 = 0.109, p = .012; R^2 = .085, *F*(16,182) = 2.09, p = 0.01) scores. Perceived stress predicted worse EF-WM (β = 0.345) and EF-I (β = 0.248) scores (p's < 0.001). In addition, inhibition difficulties increased for men (β = -0.358, p = 0.036) and longer TV times (β = 0.171, p = 0.025) (see Table 2).

INSERT TABLE 2 HERE

Reading comprehension predictors: EF, perceived stress reading habits and screen times

After controlling for age, sex, mother education, % career and device; the inclusion of the target variables increased the explained variance significantly (ΔR^2 = 0.112, p = .032, *F*(20,176) = 2.32, *p* = 0.002). Reading comprehension scores improved with print exposure (β = 0.288; *p* < 0.001) but decreased with EF-WM issues (β = -0.176; *p* = 0.037). No significant effects of perceived stress, reading or screen times were observed. In addition, those participants with university-level maternal education performed better than those with primary-school level (β = 0.687; *p* = 0.002) (see Table 3 for details).

INSERT TABLE 3 HERE

Path analysis: associations between reading comprehension EF, perceived stress reading habits and screen times

The model fitted our data well (χ^2 (5) = 5.94, p = .313; CFI = 0.991; TLI = 0.927; RMSEA = 0.031, SRMR = 0.010). Perceived stress had direct effects over both EF measures (β's > .246, p's < .001), while gender (*β = -.153)* and TV times (*β = .154)* exerted direct effects over EF-I (p's < .03) (see Table 4). Regarding reading comprehension, direct effects of ART, mother education (β's > .285, p's < .001) and EF-WM (β =.181, p = .019) were observed (see Table 4). In addition an indirect effect of stress over reading comprehension was mediated by EF-WM scores (β =-.062, p = .034) (see Supplementary Table 4).

INSERT TABLE 4 HERE

Discussion

This study has been the first to examine the link between reading comprehension and executive function deficits among university students during the COVID-19 pandemic, considering potential effects of perceived stress, reading habits and screen times. Perceived stress was the main predictor of EF difficulties, while inhibition deficits were specifically associated with TV and gender. Incidence of working memory (but not inhibition) issues was associated with lower expository text comprehension performances while it improved with mother education and print exposure (ART). In addition, EF-WM scores mediated the negative effect of stress on reading comprehension. These findings are discussed in detail in the following sections.

Executive functions: the role of perceived stress

Perceived stress was the most consistent predictor of executive function difficulties on both dimensions among university students. This finding is congruent with a recent study that showed how COVID-19-related stressors predicted ADEXI EF-WM and EF-I scores on a general adult population sample (Kira et al., 2021). Using structural equation modeling, another recent study found that affective and physical stress responses mediated the effect of pandemic-related stressors over executive functioning (observing stronger effects for confinement) (Podlesek et al., 2021). However, this particular study did not find significant contributions of perceived stress (PSS-4 scale) on cognitive decline. On a related note, a study conducted on a large Italian population sample during COVID-19 lockdown found an association between anxiety and depression symptoms and executive functions impairment (Fiorenzato et al., 2021). In addition, being a young adult female, under 45 years, working from home or being underemployed were all identified as relevant risk factors for worsening cognition and mental health. It has been proposed that stress impairs executive process (working memory, cognitive inhibition and cognitive flexibility) in order to bias processing and enhance responses to highly salient environmental stimuli, thus facilitating engagement with (or avoidance of) current stressors. On the other hand, stress would also lead to an enhancement of executive motor control (response inhibition), in order to optimize the coping response (Shields et al., 2016). Importantly, while it has been proposed that stress-induced cortisol release might be responsible for executive functions impairment (see Shields et al., 2015 for a review), it has been shown that the effects of acute stress on EF differ qualitatively from those of cortisol administration (which seems to affect only working memory performance) (Shields et al., 2015, 2016). Alternative explanations for stress-related impairments of executive functions include: up regulation of sexual hormones, cathecolaminergic and CRH activity (corticotrophin-releasing hormone) and immune system alterations, which have documented effects on EF (Arnsten, 2009; Shansky and Lipps, 2013; Uribe-Mariño et al., 2016), or psychological factors, like stress-induced rumination, which also diminishes cognitive control (Philippot and Brutoux, 2008). Along this line, it has been claimed that excessive worry displaces resource allocation (such as working memory) from executive control (Eysenck et al, 2007), and it has been shown that pandemic-related worry does affect the maintenance of task-relevant information in working memory (Castanheira et al., 2022). Importantly, it should be noted that the aforementioned biological hypotheses apply to the effects of acute stressors, while most pandemic-related stressors are better described as chronic. Chronic stressors are also known to affect executive functioning (see Sandi et al., 2013 and Deligkaris et al., 2014 for reviews). This negative impact can be explained in terms of *resource depletion* (Baumeister & Heatherton, 1996; Shields et al, 2017), which states that chronic stressors hijack and deplete available cognitive processing resources, or an *immunologic model of self-regulatory failure* (Shields et al., 2017), which proposes that stress-induced proinflammatory cytokine activity may alter neural, cognitive, and behavioral dynamics, thus contributing to executive control deficits. On this regard, chronic stressors may affect EF by inducing structural plasticity, such as changes on prefrontal cortex (PFC) (McEwen, 2004; McEwen & Sapolsky, 1995), hippocampal and amygdalar volumes (Arnsten, 2009; Girotti et al., 2018), altered PFC dendritic architecture or disruption of PFC activity during EF tasks (Liston et al., 2009).

Due to the correlational nature of our findings, we cannot draw definitive conclusions on the directionality of the stress and EF association, which means we need to consider alternative hypotheses. It could be possible that perceived stress is the result, rather than the origin, of EF difficulties. It has been argued that EF might influence not only effective coping stress conditions, but also affect stress exposure, reactivity, recovery and restorative processes (see Williams et al., 2009 for a review). On the same note, a recent study showed that PFC activity during emotion and cognitive control tasks measured at the beginning of 2020 predicted perceived stress burden along the pandemic (Monninger et al., 2022). Thus, we cannot discard that worse WM functioning led our participants to higher vulnerability towards pandemic stressors, thus increasing perceived stress levels. Furthermore the lack of pre-pandemic measures of EF prevents us from claiming that the observed EF deficits are a consequence of pandemic-related stressors, while this interpretation is certainly in line with studies that did include pre-pandemic comparisons (Kira et al., 2021). On the other hand, both interpretations are not necessarily mutually exclusive: the anomalous and stressful conditions of the pandemic might have had an impact on the participants' EFs, while the consequent EF deficit might have rendered them less able to cope with stressfull conditions, thus leading to increased perceived stress levels.

Regarding the remaining contributors to EF deficits, we only found significant effects of gender and TV times for EF-I scores. While there is little support for gender differences on EF (for a review, see Grissom & Reyes, 2018), worse inhibitory control performance (Mansouri et al., 2016) and higher impulsivity (Petry, 2002; Fillmore, 2004) has been observed for males. These differences have been interpreted in terms of the impact of evolutionary trends, hormone exposure or other developmental factors over brain development (Mansouri et al, 2016). According to this view, evolutionary pressure might have favored higher self-regulation and inhibition skills in women (Hosseinni-Kamkar & Norton, 2014). The higher incidence of inhibition difficulties on men observed in our sample could be explained in this way (although we cannot discard the influence of socio-cultural conditioning in this regard). The fact that inhibition issues were associated with longer TV times is in line with previously observed detrimental effects of TV on EF development among children (Nathanson et al., 2014; Lillard et al, 2015; Swing et al., 2010) and adults (Hoang et al., 2016). In particular, TV times longer than 3 hours a day during young adulthood (around 25 years) predicted worse inhibitory control performance 25 years later (Hoang et al., 2016). Furthermore, longer daily screen times may affect inhibitory control network development in children by decreasing fronto-striatal connectivity, as well as increasing reward-seeking tendencies that promote impulsive and/or addictive behaviors (Chen et al., 2022). In addition, altered brain potentials have been observed for TV binge-watchers during inhibitory control tasks (Dieterich et al., 2021). Sedentary behaviors and poor dietary patterns associated with TV viewing have also been pointed out as potential contributors to worse cognitive outcomes (Hoang et al., 2016). Nevertheless, as was the case in perceived stress, we cannot rule out the possibility of reverse or bidirectional causality: inhibition deficits might have favored less cognitively demanding and instantly gratifying activities, such as watching TV, which in turn may have contributed to worse cognitive outcomes.

To sum up, perceived stress was specifically associated with WM and inhibition difficulties among university students, while gender and TV times were associated with EF-I scores. Both findings can be interpreted in terms of detrimental effects of these predictor variables on EF outcomes, reverse or even bidirectional causality effects.

Reading comprehension: distal factors and executive functions

As expected, lifelong fiction print exposure was one of the main predictors of reading comprehension, a finding that is in line with most of the literature (see Mol & Bus, 2011 for meta-analysis and Breadmore et al., 2019 for a recent review). In particular, Mol & Bus (2011) showed that the contribution of print exposure to oral and reading comprehension increased along preschool and school years, reaching a maximum in early adulthood. The link between reading comprehension and print exposure has been explained by its association with vocabulary (Landi, 2010; Tabullo, 2020), as well as other proximal linguistic and cognitive factors of literacy (Breadmore et al., 2019). Moreover, the reciprocal association between reading experience and literacy skills has been described in terms of an upward spiral of causality: while more proficient readers tend to read more, reading frequency increases comprehension and fluency proficiency (Mol & Bus, 2010). It is worth noting that students' current reading times were not significant predictors of comprehension (as has been the case in: Acheson et al., 2008; Tabullo et al., 2020), and were not associated with ART scores either. This might be indicating that students' reading frequencies during the pandemic were not representative of their typical (pre-pandemic) reading experience. Interestingly, leisure reading times were negatively associated with perceived stress. Since no causality can be inferred, it might have been possible that more stressed students had been drawn away from cognitively demanding activities such as reading. Conversely, recreational reading might have been an effective coping mechanism to reduce perceived stress. This is in line with studies showing that relaxation and emotional regulation were among the top reasons for reading during the pandemic among children and adolescents (Clark & Picton, 2020, 2021).

An additional distal factor that significantly predicted comprehension performance was maternal education. Mother's education level has been signaled out as the most important SES variable for language outcomes (Hoff, 2003, 2006), and predicted reading skill in adolescents (Dickson, 2016) and adults (Jiménez-Pérez et al., 2020). It has been proposed that its effects on literacy development are mediated by related proxy child-directed speech (Hoff, 2003, 2006); home literacy environment, and literacy practices and beliefs (González et al., 2016). In this way, highly educated mothers are more likely to provide their children with larger and more diverse linguistic input, as well as to share and promote early literacy experiences.

The finding that executive functioning contributed to reading comprehension scores is largely consistent with previous research (Butterfuss & Kendeou, 2018; Follmer, 2018). While most of the evidence comes from performance-based measures, a recent study (Leshem et al., 2021) showed that behavioral general EF ratings predicted global text comprehension (referring to text-level meaning representation, as opposed to sentence-level meaning) in adults. More specifically, we observed that WM difficulties were associated with worse expository text comprehension. A previous study that combined performance and behavioral EF ratings also found that WM was the main contributor for reading comprehension across measurement-type for school-aged children (Gerst et al., 2017). Working memory refers to the ability to actively sustain and manipulate information within short-term memory systems and it can be classified by its content in two distinct processes: verbal and visuospatial (Diamond, 2013). During reading, WM provides a cognitive workspace to maintain information from textual input and integrate it with the unfolding text representation and long-term memory systems. In this way, WM allows (and constrains) model construction and inference generation. In addition, it has been proposed that "updating", the ability to selectively activate and sustain target-relevant information in WM while inhibiting non-relevant stimuli, might mediate the relation between WM capacity and reading comprehension (Butterfuss & Kendeou, 2018). Given the limited capacity of WM, efficient updating would be crucial for the activation of relevant sources of information while building mental text models or elaborating forward inferences. There is plenty of empirical evidence to support the contribution of WM to reading comprehension throughout lifespan (for a recent meta-analyses, see Follmer et al., 2018 and Peng et al., 2018). Meanwhile, the ADEXI WM factor indexes difficulties in managing attentional and mnesic resources to maintain and integrate relevant information during goal-oriented tasks. Therefore, it is quite expected that those students with increased deficits in selecting and manipulating online information will find it more difficult to extract and integrate text meaning into coherent global models. On the other hand, it should be noted that while some of the evidence points to a domain-specific contribution of verbal WM systems to comprehension for older and more skilled readers (Peng et al., 2018), the ADEXI scale does not focus on verbal-information processing (although it has shown significant correlations with verbal working memory measures, see Holst & Thorell, 2018).

It might have been the case that the current WM deficits were due to pandemic or confinement related stress, and the observed associations between PSS-10 and ADEXI scores certainly support this view. Moreover, path analysis suggested that higher stress levels were associated with worse reading comprehension performance, an effect that was fully mediated by EF-WM scores.

Regarding inhibition, we found no significant associations with students' comprehension performance. Previous works have pointed out that the evidence of inhibition processes' contributions to reading is mixed, probably due to the variability in the measures and sub-components considered and a potential domain-specificity of the effects (Follmer et al., 2018). Therefore, it might be possible that the inhibition processes indexed by ADEXI are not those more closely related to comprehension for this age range.

In short, we found that university student's comprehension of an expository text improved with distal factors, such as lifelong print exposure and maternal education, while current WM problems seemed to interfere with it. In addition, perceived stress might have contributed to worse reading outcomes by increasing WM difficulties. On the other hand, we found no evidence of current reading or screen times effect, or other contextual factors such as screen device (Chen et al., 2014) or the degree of progress of their studies.

Study limitations and future directions

We should point out the following limitations in our study: 1) The use of self-report measures might have led to social desirability or other response bias; 2) We cannot rule out the potential influence of volunteer selection bias. The fact that the study was shared through social media and university mailing lists (making it difficult to reach students with connectivity problems), and the relatively low sample size may also limit the generalizability of our findings; 3) Lack of vocabulary skill measures, which are relevant predictors of reading comprehension. However, it has been shown that EF contributes significantly to reading comprehension even after controlling for vocabulary and reading fluency skills (Georgiou & Das, 2018). 4) Relatedly, it would have been useful to count with pencil and paper assessments of the students' reading comprehension skills, since the outcomes and processing demands of reading might differ between paper and screen formats, even in the case of linear traditional texts (as opposed to hypertext formats) (see Delgado et al., 2018 for a meta-analysis). Future studies might address these potential divergences, considering the increasing presence of screen-based formats in leisure and study reading. 5) The lack of performance-based assessments of EF, which might have provided additional information but were more difficult to administer under lockdown conditions. Nevertheless, the validity and complementarity of behavioral rating EF measures has been established in the literature (Toplak et al., 2013; Isquith et al., 2013). 6) The lack of pre-pandemic baseline measures prevents us from concluding that the observed levels of perceived stress and EF difficulties are directly related to COVID-19 lockdown or social restrictions measures, although other studies suggest that this might be the case indeed (Kira et al., 2021; Fiorenzato et al., 2021). 7) We did not consider relevant variables for executive functioning such as: physical activity, dietary and sleep habits; or stress, such as personality traits, coping strategies or cortisol levels. Future studies including such predictors might increase the predictive power of their statistical models. 8) Due to the correlational nature of our findings, we cannot rule out reverse or bidirectional causation between our variables. 9) Lack of follow up measures, which would have been informative of the trajectory of reading comprehension and executive functioning through the pandemic. Future longitudinal studies might enlighten the nature of the interactions between the study variables as students adapt to the post-pandemic times.

Conclusion

The COVID-19 pandemic and its concomitant restriction measures drastically altered the routines and learning formats of students from all levels, including undergraduates. Our study showed that EF difficulties increased with perceived stress, while inhibition deficits were associated with longer TV times. Expository text comprehension was lower for those students with worse WM functioning (which also mediated stress effects), while it improved with distal factors such as print exposure and mother education. Our results are in line with previous studies that highlight the impact of COVID-19 stressors on cognitive functions and mental health, and extend those findings by showing the influence of EF deficits on a relevant academic skill during the pandemic.

Declarations

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Compliance with Ethical Standards:

Conflict of interest statement: All authors declare that they have no conflict of interest.

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the CONICET research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study.

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Tables

Table 1

Descriptive Statistics of Measure Variables

Variables	M (SD) / %	Minimum	Maximum	n
Sociodemographic data				
Gender				200
male	21%			
female	79%			
Age (years)	26.6 (9.18)	18	43	200
Mother education				200
Primary	15.1%			
Secondary	25.6%			
University	59.3%			
% complete studies				200
1st year	25.5%			
25%	21%			
50%	11.5%			
75%	14.5%			
Last year	27.5%			
Reading Times				200
Leisure reading	2.38(1.55)	1	7	
Study reading	5.13(1.58)	1	7	
Change	2.89(1.40)	1	5	
Screen Media Times				200
TV	3.15(1.73)	1	7	
Video games	1.99(1.59)	1	7	
Internet	4.87(1.55)	1	7	
Web	4.18(1.62)	1	7	
Online lessons	4.75(1.87)	1	7	
Change	3.78(1.29)	1	5	
ART scores	2.79 (3.07)	-4	10	
ADEXI				200
EF-I	22.6(6.93)	9	43	
EF-WM	10.2(3.32)	4	20	

Table 2

Linear regression coefficients for EF measures

						95% Confidence Interval	
Predictor	**Estimate**	**SE**	**t**	**p**	**Stand. Estimate**	**Lower**	**Upper**
EF-WM: Full model							
gender:							
female – male	-0.2022	1.2664	0.160	0.873	0.0292	-0.3311	0.3895
Meduc							
Sec vs Prim	-0.5696	1.6024	-0.355	0.723	-0.0821	-0.5381	0.3738
Univ vs Prim	-1.1787	1.4982	-0.787	0.432	-0.1700	-0.5963	0.2563
age	-0.0367	0.0639	-0.574	0.567	-0.0485	-0.2152	0.1182
pcarreer	-0.2167	0.3295	-0.658	0.512	-0.0492	-0.1968	0.0984
ART	0.2867	0.1588	1.805	0.073	0.1260	-0.0118	0.2638
lreading	-0.3968	0.3237	-1.226	0.222	-0.0889	-0.2319	0.0542
sreading	-0.1927	0.3669	-0.525	0.600	-0.0440	-0.2092	0.1212
changread	0.1616	0.3579	0.452	0.652	0.0325	-0.1094	0.1743
TV	0.2430	0.2966	0.819	0.414	0.0609	-0.0858	0.2077
vgame	0.1238	0.3022	0.410	0.682	0.0283	-0.1081	0.1648
snetwork	-0.0606	0.3888	-0.156	0.876	-0.0136	-0.1852	0.1581
web	0.4545	0.3481	1.306	0.193	0.1059	-0.0541	0.2659
online class	0.3593	0.3061	1.174	0.242	0.0972	-0.0662	0.2605
changescr	0.6576	0.4435	1.483	0.140	0.1229	-0.0406	0.2863
PSS-10	0.3188	0.0666	4.786	< .001	0.3449	0.2027	0.4870
EF-I: Full model							
gender:							
female – male	-1.1916	0.5646	-2.1104	0.036	-0.3586	-0.6939	-0.0233
Meduc							
Sec vs Prim	0.8343	0.7847	1.063	0.289	0.2511	-0.2149	0.7171
Univ vs Prim	1.0366	0.7337	1.413	0.159	0.3120	-0.1237	0.7477
age	-0.0279	0.0313	-0.890	0.375	-0.0768	-0.2473	0.0936
pcarreer	-0.1159	0.1613	-0.718	0.473	-0.0549	-0.2058	0.0959
ART	-0.0313	0.0778	-0.403	0.688	-0.0287	-0.1695	0.1121
lreading	-0.2249	0.1585	-1.419	0.158	-0.1051	-0.2513	0.0411
sreading	-0.0374	0.1796	-0.208	0.835	-0.0178	-0.1867	0.1510
changread	0.0290	0.1752	0.165	0.869	0.0121	-0.1328	0.1571
TV	0.3276	0.1453	2.255	0.025	0.1714	0.0214	0.3215
vgame	0.0208	0.1480	0.140	0.888	0.0099	-0.1296	0.1494
snetwork	0.1371	0.1904	0.720	0.472	0.0640	-0.1114	0.2394
web	0.1032	0.1705	0.606	0.545	0.0502	-0.1133	0.2138
online class	-0.0392	0.1499	-0.262	0.794	-0.0221	-0.1891	0.1448
changescr	-0.0588	0.2172	-0.271	0.787	-0.0229	-0.1900	0.1442
PSS-10	0.1097	0.0326	3.362	< .001	0.2476	0.1023	0.3929

Notes. EF-WM: ADEXI working memory score, EF-I: ADEXI inhibition score, Meduc: mother education, Prim: primary education, Sec: secondary education, Univ: university education, pcareer: percentage complete of career; ART: Author recognition test scores, lreading: leisure reading times, sreading: study reading times, changread: change in reading times, TV: tv times, vgame: videogame times, snetwork: social network times, web: web surfing times, online class: online lessons times; changescr: changes in screen times, PSS-10: Perceived stress scale score.

Table 4

Linear regression coefficients for reading comprehension scores

						95% Confidence Interval	
Predictor	**Estimate**	**SE**	**t**	**p**	**Stand. Estimate**	**Lower**	**Upper**
gender:							
female – male	-0.0883	0.3799	-0.2325	0.816	-0.0444	-0.4212	0.3325
age	-0.0222	0.0185	-1.1970	0.233	-0.1026	-0.2719	0.0666
Medu:							
Sec vs Prim	0.6152	0.4696	1.3101	0.192	0.3092	-0.1566	0.7750
Univ vs Prim	1.3667	0.4428	3.0866	0.002	0.6869	0.2477	1.1261
rdevice							
laptop vs smart	-0.0511	0.3454	-0.1480	0.883	-0.0257	-0.3683	0.3169
tablet vs smart	0.9953	1.1462	0.8683	0.386	0.5003	-0.6367	1.6372
pcarreer	0.0742	0.0953	0.7788	0.437	0.0586	-0.0899	0.2070
EF-WM	-0.0504	0.0239	-2.1035	0.037	-0.1759	-0.3408	-0.0109
EF-I	0.0540	0.0477	1.1309	0.260	0.0906	-0.0675	0.2486
PSS-10	0.0284	0.0205	1.3861	0.167	0.1076	-0.0456	0.2608
ART	0.1893	0.0472	4.0069	< .001	0.2886	0.1465	0.4308
sreading	0.0105	0.1071	0.0979	0.922	0.0083	-0.1596	0.1762
lreading	-0.0407	0.0952	-0.4280	0.669	-0.0318	-0.1785	0.1149
changeread	0.0915	0.1052	0.8697	0.386	0.0638	-0.0809	0.2085
TV	0.1454	0.0873	1.6659	0.098	0.1278	-0.0236	0.2791
vgame	-0.0141	0.0873	-0.1618	0.872	-0.0113	-0.1493	0.1266
snetwork	-0.1753	0.1134	-1.5462	0.124	-0.1330	-0.3027	0.0368
web	0.0855	0.1028	0.8317	0.407	0.0692	-0.0950	0.2333
online class	0.0297	0.0889	0.3345	0.738	0.0280	-0.1370	0.1929
changescr	-0.0647	0.1305	-0.4958	0.621	-0.0413	-0.2058	0.1232

Notes. EF-WM: ADEXI working memory score, EF-I: ADEXI inhibition score, Meduc: mother education, Prim: primary education, Sec: secondary education, Univ: university education, rdevice: current reading device , pcareer: percentage complete of career; ART: Author recognition test scores, lreading: leisure reading times, sreading: study reading times, changread: change in reading times, TV: tv times, vgame: videogame times, snetwork: social network times, web: web surfing times, online class: online lessons times; changescr: changes in screen times, PSS-10: Perceived stress scale score.

Table 4

Path analysis regression coefficents

				95% Confidence Intervals				
Dependent	Predictor	Estimate	SE	Lower	Upper	β	z	p
EF-WM	TV	0.34399	0.2661	-0.1776	0.86557	0.0865	1.2926	0.196
	vgame	0.16560	0.2913	-0.4054	0.73660	0.0380	0.5684	0.570
	snetwork	0.06784	0.3734	-0.6641	0.79974	0.0147	0.1817	0.856
	web	0.51246	0.3330	-0.1402	1.16515	0.1187	1.5389	0.124
	online class	0.29907	0.2944	-0.2780	0.87610	0.0806	1.0158	0.310
	lreading	-0.28897	0.3070	-0.8907	0.31272	-0.0647	-0.9413	0.347
	sreading	-0.30873	0.3487	-0.9921	0.37466	-0.0702	-0.8854	0.376
	ART	0.24041	0.1554	-0.0642	0.54502	0.1050	1.5469	0.122
	PSS-10	0.31763	0.0633	0.1935	0.44174	0.3445	5.0159	< .001
	gender1	0.47629	1.1765	-1.8296	2.78215	0.0277	0.4048	0.686
	age	-0.04361	0.0602	-0.1616	0.07440	-0.0577	-0.7243	0.469
	Meduc pri vs sec	-0.51575	1.5592	-3.5718	2.54029	-0.0326	-0.3308	0.741
	Meduc pri vs univ	-0.67991	1.4553	-3.5323	2.17245	-0.0481	-0.4672	0.640
EF-I	TV	0.29512	0.1299	0.0405	0.54975	0.1545	2.2715	0.023
	vgame	0.01249	0.1422	-0.2663	0.29125	0.0060	0.0878	0.930
	web	0.10614	0.1626	-0.2125	0.42478	0.0511	0.6529	0.514
	gender1	-1.26944	0.5744	-2.3952	-0.14372	-0.1533	-2.2102	0.027
	PSS-10	0.10896	0.0309	0.0484	0.16956	0.2459	3.5246	< .001
	snetwork	0.11864	0.1823	-0.2387	0.47595	0.0536	0.6508	0.515
	Meduc pri vs univ	0.86187	0.7612	-0.6301	2.35383	0.1133	1.1322	0.258
	Meduc pri vs univ	1.05463	0.7105	-0.3379	2.44715	0.1552	1.4844	0.138
	age	-0.03313	0.0294	-0.0907	0.02448	-0.0913	-1.1271	0.260
	online class	-0.03612	0.1437	-0.3178	0.24559	-0.0202	-0.2513	0.802
	lreading	-0.22171	0.1499	-0.5155	0.07203	-0.1032	-1.4793	0.139
	sreading	-0.02516	0.1702	-0.3588	0.30847	-0.0119	-0.1478	0.882
	ART	-0.03630	0.0759	-0.1850	0.11241	-0.0330	-0.4784	0.632
Readcomp	EF-I	0.06104	0.0453	-0.0278	0.14986	0.1025	1.3471	0.178
	EF-WM	-0.05192	0.0222	-0.0954	-0.00842	-0.1813	-2.3396	0.019
	ART	0.18673	0.0449	0.0987	0.27472	0.2847	4.1597	< .001
	lreading	-0.03102	0.0850	-0.1975	0.13548	-0.0242	-0.3652	0.715
	sreading	0.04328	0.0832	-0.1198	0.20634	0.0344	0.5202	0.603
	PSS-10	0.02343	0.0193	-0.0144	0.06121	0.0887	1.2153	0.224
	Meduc pri vs univ	0.55655	0.4476	-0.3207	1.43377	0.1228	1.2435	0.214
	Meduc pri vs univ	1.35640	0.4175	0.5380	2.17476	0.3350	3.2486	0.001
	gender1	-0.00852	0.3373	-0.6695	0.65250	-0.0017	-0.0253	0.980
	age	-0.00701	0.0159	-0.0382	0.02421	-0.0324	-0.4399	0.660

Notes. EF-WM: ADEXI working memory score, EF-I: ADEXI inhibition score, Meduc: mother education, Pri: primary education, Sec: secondary education, Univ: university education, pcareer: percentage complete of career; ART: Author recognition test scores, lreading: leisure reading times, sreading: study reading times, changread: change in reading times, TV: tv times, vgame: videogame times, snetwork: social network times, web: web surfing times, online class: online lessons times; changescr: changes in screen times, PSS-10: Perceived PSS-10 scale score.

Figures

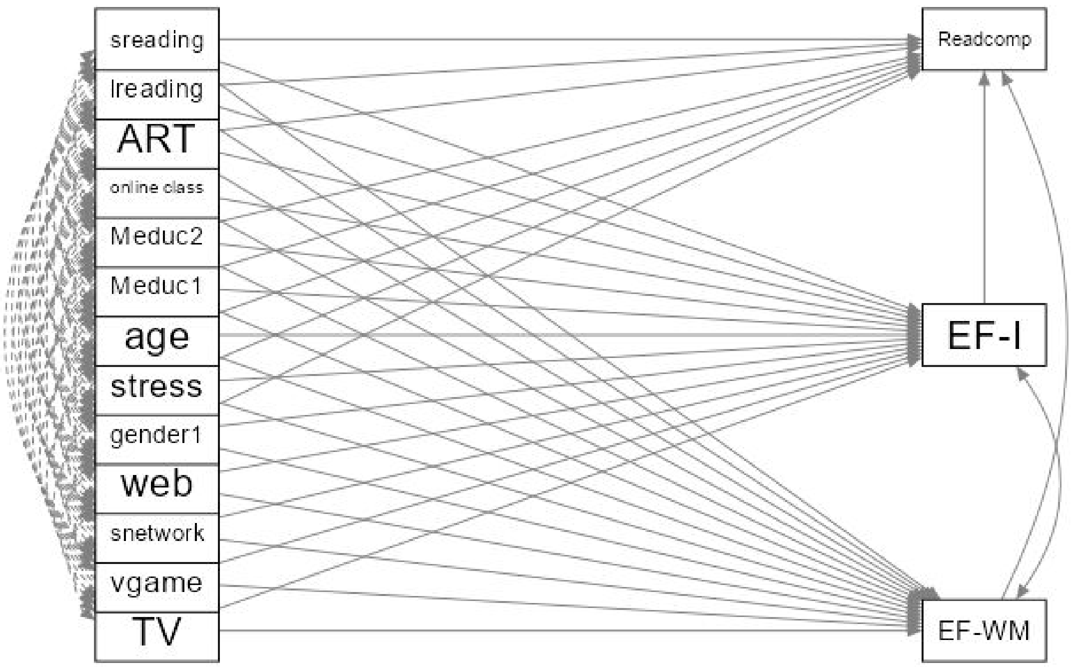

Figure 1

Path analysis model of executive function and reading comprehension scores. Notes. EF-WM: ADEXI working memory score, EF-I: ADEXI inhibition score, Meduc: mother education: 1= secondary vs. primary education, 2: university vs. secondary education; ART: Author recognition test scores, lreading: leisure reading times, sreading: study reading times, TV: tv times, vgame: videogame times, snetwork: social network times, web: web surfing times, online class: online lessons times, stress: Perceived PSS-10 scale score.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryTables1and2.docx
- SupplementaryTable3.docx
- SupplementaryTable4.docx