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RESEARCH ARTICLE

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Executive function in adolescents with problematic smartphone use

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ABSTRACT

Adolescence is a crucial stage for prefrontal cortex development, a brain area responsible for control goal-oriented behaviours, known as executive functioning (EF). Consequently, adolescents have a greater risk of problematic smartphone use (PSU). The current study aimed to examine the EF in adolescents with and without PSU. The participants included 110 students (44.5% males) ranging in age from 13 to 18 years (M = 15.77; SD = 1.84). They completed a PSU scale and a set of tasks that assess the components of the EF system. Parents were also asked to evaluate their children's EF using a behaviour rating inventory. We found significant differences between problematic and non-problematic smartphone users on parent-report measures but not on performance-based measures. These results indicate that adolescents with PSU may show greater difficulties in regulating their own behaviour and emotional responses, but they can manage their cognitive processes effectively.

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Executive functioning; problematic smartphone use; adolescents

Introduction

Executive functioning (EF) refers to a group of higher-order cognitive processes involved in planning, initiating and regulating goal-directed behaviours (Kim-Spoon et al., 2017). They are linked to the functioning of frontal lobe circuits (Goldstein & Naglieri, 2014) and allow us to solve problems, understand abstract concepts and make plans and decisions. Throughout the years, different models and frameworks have been proposed to define and conceptualize the main components of the EF system (Baddeley & Della Sala, 1996; Luria, 1973; Stuss and Benson, 1986). In the present study, we have followed the EF organization analyzed by Verdejo-García and Bechara (2010), whose main independent components are updating, inhibition, shifting, planning and decision making.

Updating consists of monitoring and manipulating information. This function, in turn, is composed of working memory, reasoning and fluency skills (Verdejo-García & Pérez-García, 2007). Working memory involves holding information online and working with it mentally or while performing another cognitive task. Reasoning is the ability to determine the abstract relationship underlying analogies, see patterns among items and generate inferences (Cristofori et al., 2019; Diamond, 2013). Finally, verbal fluency is the ability to search for and retrieve phonological and semantic information from lexical/semantic memory networks (Henry et al., 2015).

Inhibition is the ability to control one's attention and behaviour to override an internal predisposition or external stimuli, and instead do what is most appropriate. Inhibition overlaps substantially with self-regulation, which refers to processes that enable us to control and regulate our emotions (Diamond, 2013).

Shifting refers to the ability to flexibly change from one task or mental operation to another. It allows adapting to environmental change and adjusting to demands or priorities. There is a large overlap between shifting and other concepts such as switching and cognitive flexibility (Cristofori et al., 2019; Diamond, 2013).

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Planning is the ability to organize the actions needed to achieve a specific goal (Cristofori et al., 2019). It involves defining the intermediate steps, determining the required sequence and being aware of the environmental context to anticipate potential contingencies.

Decision making refers to the cognitive process of assessing and selecting a logical choice among several options. Since individual decisions are made in the context of a set of preferences, needs and values of that individual, it can be a reasoning or emotional process (Swami, 2013). Previous research has found that emotional processes are involved in decisions under ambiguity (when there is no explicit information about the possible outcomes related to the decision) and that cognitive processes in combination with emotional processes are involved in decisions under risk (when explicit information about the probabilities of the outcomes is known) (Trotzke et al., 2015).

EF develops during adolescence and emerging adulthood, which is a period characterized by poorer impulse control (Rodrigue et al., 2019). The prefrontal areas of the adolescent brain involved in behaviour regulation processes are still developing, increasing their vulnerability to risk behaviours. Research suggests that this may lead adolescents to engage in behaviours aimed at satisfying short-term gratifications (e.g. substance use, school dropout, poor dietary habits, etc.) despite potential negative long-term consequences (Rubio and Buedo-Guirado, 2021; Thoma et al., 2011). In fact, several studies have shown that a poorer EF is associated with the substance addiction (Gustavson et al., 2017). This association could be explained by immature EF being a risk factor that predisposes individuals to drug experimentation; however, in turn, addictive substances would influence the neuromodulation of frontal circuits and, therefore, disturb the maturation of these brain regions (Gustavson et al., 2017; Piechatzek et al., 2009).

EF has also been found to be impaired in addictive behaviours such as food addiction (Rodrigue et al., 2019), pathological buying (Trotzke et al., 2015), and problematic smartphone use (PSU) (Warsaw et al., 2021). PSU, also known as smartphone abuse or smartphone addiction (Fu et al., 2020), implies the inability to control the impulse to use the mobile device, leading to an excessive or inappropriate utilization. It has been associated with adverse outcomes such as depression (Pereira et al., 2020). PSU is characterized by an increase in the intensity and the frequency of use that interferes with daily occupational, social, or recreational activities; feelings of withdrawal in the absence of the smartphone; and continuation of the behaviour despite the negative consequences. These symptoms are similar to those associated with substance addiction (Lopez-Fernandez et al., 2014; Wegmann et al., 2020). Nevertheless, PSU is not included in the diagnosis and statistical manuals of mental disorders, and considering it as an addiction is a controversial matter (Billieux et al., 2015). Beyond the agreed term to refer to this issue, there has been an increase in the prevalence of PSU amongst adolescents since the widespread use of smartphones. A recent meta-analysis of studies published between 2012 and 2022 has shown that the prevalence of PSU has increased over time (Lu et al., 2024). The authors estimated that the overall prevalence of PSU was 37.1%. In Spain, the prevalence of adolescents who would be developing PSU is 33%, a figure similar to that of other countries (Andrade et al., 2021).

The findings on the relationship between PSU and EF abilities are inconsistent (Liebherr et al., 2020; Toh et al., 2021; Wilmer et al., 2017). On one hand, previous research found that PSU was related to deficits in inhibition, attentional capacity, working memory, shifting ability and decision-making (Hartanto and Yang, 2016; Warsaw et al., 2021). Smartphone-dependent individuals showed impaired decision-making under ambiguity but not under risk; the same result was found for pathological buying and gambling (Trotzke et al., 2015). Increased smartphone use was also found to be related to low self-control (Fabio et al., 2022) and dysfunctional impulsivity (Rubio and Buedo-Guirado, 2021). Conversely, several studies revealed no associations between PSU and EF abilities (Gao et al., 2020; Toh et al., 2021). For example, Gao et al. (2019) did not find impairment in inhibitory control in problematic SNS users. In fact, some authors have demonstrated that general smartphone use may have beneficial effects on certain processes of working memory, shifting, attention and inhibition (Liebherr et al., 2020; Wilmer et al., 2017). This is in line with the idea that efficient use of the smartphone involves higher-order cognitive processes (Toh et al., 2021). The heterogeneity of the results may be due to methodological differences between previous smartphone studies concerning the tasks used to assess PSU and to an inadequate operationalization of EF as a consequence of the lack of consensus on the main components of the EF system. Moreover, a significant gap exists between laboratory-based assessments and real-world EF traditional EF tests often fail to capture the complexities of daily life, as they account for only a fraction of the variance in real-world executive abilities (Chaytor et al., 2006). This discrepancy underscores the need for more ecologically valid assessment tools. Ecological validity refers to the degree to which an assessment represents individuals' interactions in their authentic contexts. One approach to achieve veridicality in the FE assessment is to rely on parent-report measures. Parent ratings can provide relevant insight and information on a child's everyday behaviour (Wallisch et al., 2018). Nevertheless, previous studies claim that those two types of measurements assess different underlying EF constructs. Ten Eycke and Dewey (2016) administered performance-based and parent-reported FE measures to children, as well as measures of attention, mathematics, reading and motor performance. They found that both FE measures were associated with reading and mathematics abilities. Nevertheless, only the parent-reported measure was related to attention, and the performance-based measures were associated with motor function. Therefore, if we take the tasks and questionnaires together, they can provide more applicable information than if we take them separately (Wallisch et al., 2018).

Since adolescence may be considered a risk stage for addictive behaviours, it is important to understand the cognitive correlates of PSU to develop future prevention and treatment interventions for this wide-spread phenomenon that has a negative impact on mental health (Rodrigue et al., 2019). Therefore, the aim of this study is to evaluate the dimensions of executive functions in adolescents with and without abusive use of smartphones. We hypothesized that problematic smartphone users would show greater EF difficulties in their daily life and poorer performance on EF tasks (measuring working memory, reasoning, fluency, shifting, inhibition and decision-making abilities) than non-problematic smartphone users.

Methods

Participants

The research sample consists of 110 adolescents (49 males and 61 females) who were between 13 and 18 years old (M = 15.77; SD = 1.84). Participants were recruited from high schools and universities of the provinces of Granada and Jaen through non-probabilistic (snowball) sampling. The inclusion criteria were: (1) aged 13–18 years; (2) regular use of a smartphone and social networks (Facebook, Instagram, etc.); and (3) no history of neurological or psychiatric disorders. All participants had normal or corrected-to-normal vision. Using the smartphone addiction scale (SAS-SV) cut-off point, 55 adolescents were classified as problematic smartphone users, and 55 adolescents were defined as non-problematic smartphone users. The groups did not differ significantly in gender and age (see Table 1).

Measures

Problematic smartphone use

The short Spanish version of the smartphone addiction scale (SAS-SV; Kwon et al., 2013; adapted by Lopez-Fernandez, 2017) was used to classify participants into problematic and non-problematic smartphone users. This scale evaluates the presence of six addictive symptoms: preoccupation, loss of control, disruption, disregard, withdrawal and tolerance. It contains 10 items that were rated by participants on a 6-point scale ranging from 1 ('totally disagree') to 6 ('totally agree'). The authors offer a cut-off point (a score of 32) to classify them into problematic and non-problematic smartphone users. This scale has been validated in the Spanish population, with a Cronbach's alpha of 0.88 (Lopez-Fernandez, 2017).

Working memory

The subtests digit span and letter-number sequencing from the Wechsler Intelligence Scale for Children Fourth Edition (WISC-IV; Corral et al., 2005; Wechsler 2003) and the Wechsler Adult Intelligence Scale Third Edition (WAIS-III; Wechsler, 1997; Seisdedos & Wechsler, 1999) were used to assess working memory in adolescents between 13 and 16 and older than 16 years, respectively. The Wechsler Intelligence Scale comprises short tests that measure children's and adults' intellectual ability and cognitive domains that impact performance: verbal comprehension, perceptual reasoning, working memory and processing speed. The digit span consists of two parts (forward and backward), which measures short-term memory and working memory, respectively. In digit span forward, series of numbers with increasing difficulty levels are

Table 1. Demographic data.

	Sex				Age			
	Men	Women	χ2	*p*	M	SD	*t*	*p*
Problematic smartphone use	41.8%	58.2%	0.33	0.35	15.93	1.74	0.88	0.38
Non-problematic smartphone use	47.3%	52.7%			15.62	1.93		

Note. *N* = 110; M = mean; SD = standard deviation.

presented, and the participant must repeat them in the same order; while in digit span backward, the participant must recite them in reverse order. There are two trials for each series of numbers, which are scored with 0 or 1 point. There are 16 trials in total for each part in the WISC-IV version and 16 trials for the digit span forward test and 14 trials for the digit span backward test in the WAIS-III. The task ends when the participant fails two trials of the same series. The performance on digit span is measured by adding the total scores of each part and converting it to a scale score based on age.

Letter-number sequencing measures attention span, short-term memory and sequencing abilities. The task consists of remembering a series of digits and letters with increasing difficulty level. The participant must repeat the numbers first in chronological order and then in alphabetical order. There are three trials for each series of numbers which are scored with 0 or 1 point. There are 30 trials in total in the WISC-IV version and 21 trials in the WAIS-III. The task ends when the participant fails three trials of the same series. The performance on letter-number sequencing is measured by adding the scores of each trial and converting this total score to a scale score based on age.

Reasoning

The subtest similarities from the WISC-IV (Corral et al., 2005; Wechsler, 2003) and the WAIS-III (Seisdedos & Wechsler, 1999; Wechsler, 1997) were used to measure verbal abstract reasoning, concept formation and logical thinking. In this task, two concepts are presented, and the participant is asked to tell how they are alike, what they have in common or what they are (e.g. 'How are red and blue alike?'). A total of 23 pairs of concepts are presented in the WISC-IV and 19 in the WAIS-III. Each item is scored with 0, 1 or 2 points. A 2-point answer expresses a general classification; a 1-point answer expresses a specific characteristic or a certain function that is common to both concepts; and a 0-point answer expresses specific characteristics of each word, incorrect generalizations or differences between the pair of words. The performance on similarities is measured by adding the scores of each question and converting this total score to a scale score based on age.

Verbal fluency

The controlled oral word association test (COWAT; Benton & Hamsher, 1976) is a widely used procedure for assessing verbal fluency. The purpose of the test is to evaluate the production of words within a limited amount of time. The COWAT phonemic category consists of naming as many words as possible that begin with a given letter within a 1-min time period. There are three trials administered, each employing a different letter: F, A and S. Before starting the task, participants are instructed to exclude proper nouns and the same word using a different suffix. The COWAT semantic category consists of naming as many words as possible that belong to a semantic group within a 1-min time period. In this study, we used two trials with 'animals' and 'fruits' as semantic groups. The participants were also instructed to exclude the same word using a different suffix. Performance on the COWAT (phonemic and semantic) was measured by calculating the total number of acceptable words produced for all three letters and for the two semantic groups, respectively.

Inhibition

Inhibition was assessed by the Delis-Kaplan executive function system colour-word interference test (D-KEFS CWIT; Delis et al., 2001). The CWIT is a version of the Stroop task. It is one of the most commonly administered verbal processing speed tests and is part of a battery of neuropsychological tests (D-KEFS) designed to measure executive functions in children and adults (between 8 and 89 years of age). CWIT consists of four trials with increasing difficulty level: (1) colour naming, (2) word reading, (3) inhibition and (4) inhibition/switching. In the colour naming trial, a page containing a matrix of 10 × 5 coloured squares (red, green and blue) is presented to the participant. The task consists of saying the names of the colours. In the word reading trial, a page containing the words 'red', 'green' and 'blue' printed in black colour is presented to the participant, who is asked to read the words. The inhibition trial consists of a page containing the words printed in incongruous colours. The participant is asked to say the colour of the ink in which each word is printed (while avoiding reading the words). Finally, in the inhibition/switching trial, a similar page as in the third trial is presented, but some of these words are enclosed in boxes. The participant is asked to say the colour of the ink in which each word is printed (as in the third trial), but to read the word when the word appears inside a box. In all trials, the participant is instructed to say the name of the colours or read the words as quickly as possible without making mistakes. Task performance is measured by time to completion on each of the four trials, and there are three primary contrast measures that can be calculated by comparing the results of the different conditions: (1) inhibition vs. colour naming, which is calculated by subtracting the completion time of Condition 1 from the Condition 3; (2) inhibition/switching vs. inhibition, which is the subtraction of Condition 4 minus Condition 3; and (3) inhibition/switching vs. combined naming + reading, which is the result of subtracting the combination of Conditions 1 and 2 from Condition 4. In the present study, we used the first contrast measure (inhibition vs. colour naming) to assess inhibition.

Shifting

The participants were administered the PEBL computerized version (Mueller, 2011) of the Wisconsin card sorting test (WCST; Grant & Berg, 1948) to assess flexibility. The WCST is a card matching task composed of 4 stimulus cards and a deck of 64 response cards. The stimulus cards appear in a row across the top of the screen and show the following figures: (1) one red triangle, (2) two green stars, (3) three yellow crosses and (4) four blue circles. Meanwhile, the response cards appear one at a time at the bottom of the screen and contain one to four figures (triangles, stars, crosses or circles) of one of the possible colours (red, green, yellow or blue). The aim of the task is to match the response card to one of the stimulus cards according to one of the figures dimensions (colour, shape or number), but that sorting rule is unknown to the participants. After each response, the participants receive feedback (the words 'correct' or 'incorrect' appear on the screen), so they have to discover the sorting rule through a process of trial and error. In addition, before starting the task, participants are instructed that the sorting rule changes and that they must then establish the new sorting rule. It changes randomly without warning after ten correct responses in a row (which is called a 'completed category'). The WCST ends when six categories are completed or 128 trials are performed. The WCST provides several measures, such as perseverative errors (perseverative responses that are incorrect), number of categories completed, failure-to-maintain-set and trials to complete the first category; however, the most common measure used to assess flexibility is perseverative responses (persistent responses made on the basis of an incorrect sorting rule).

Additionally, the flexibility contrast measure of the D-KEFS CWIT (Delis et al., 2001) was used. It was calculated by subtracting the completion time of Conditions 1 and 2 combined from Condition 4.

Decision making

The participants completed the computerized A'B'C'D' version (Mueller, 2011) of the Iowa gambling task (IGT; Bechara et al., 1994). IGT is a widely used card task that assesses decision-making under ambiguity. Participants were instructed to choose 100 cards from four decks (A, B, C and D) in any sequence. After each selection, the monetary value related to that card was revealed and it could be a gain or a loss. The aim of the task was to earn as much money as possible. The participants were told that some decks were advantageous over other decks, but they did not know which ones they were beforehand. There were two disadvantageous or high-risk decks (A and B) and two advantageous or low-risk decks (C and D). In deck A, there were frequent small punishments; in deck B, punishments were greater but less frequent; deck C had frequent but small rewards; and deck D had infrequent large rewards. Task performance was calculated by subtracting the total number of cards selected from the disadvantageous decks (A and B) from the total number of cards selected from the advantageous decks (C and D).

Behaviours related to executive function

The behaviour rating inventory of executive function-2 (BRIEF-2; Gioia et al., 2000; adapted by Maldonado et al., 2017) was also used to measure adolescents' EF. The BRIEF-2 was designed to be completed by teachers and parents of children (between 5 and 18 years of age). In the current study, we asked the parents of the participants to complete the parent version of the BRIEF-2. It has a high ecological validity since it contains 63 items that describe the behaviours of adolescents, which they may show in their daily lives. Parents have to rate how often these behaviours have been a problem in the past 6 months on a 3-point scale (0 'never', 1 'sometimes' or 2 'often'). These items evaluate 9 scales that correspond to the following domains of EF: inhibition, flexibility, emotional control, initiative, working memory, planning, organization of material, self-monitoring and task monitoring. The BRIEF-2 also includes a global index of executive function; 3 regulation indices (cognitive, emotion and behavioural regulation indices); and 3 validity scales (inconsistency, negativity and infrequency). Higher T-scores ($M = 50$, $SD = 10$) indicate greater problems in that executive function. The reliability coefficients of the original scale were greater than 0.80 for all scales and indexes in the general population (Gioia et al., 2000). The scores in the Spanish version of this scale also demonstrated good reliability, with Cronbach's alpha values between 0.66 and 0.87 for the scales of the parents version and between 0.74 and 0.91 for the teacher version (Maldonado et al., 2017).

Procedure

This study was approved by the Research Ethics Committee of the University of Granada (946/CEIH/2019). Two individual evaluation sessions were carried out. Prior to the session, participants and their parents (for adolescents under 18) completed and signed an informed consent form about the anonymity and confidentiality of the survey. Then, the participants voluntarily answered an interview about demographic variables and subsequently completed the SAS-SV and some of the research tasks (letter-number sequencing, similarity, digit span and IGT). During the second session, the remaining tasks were administered (D-KEFS CWIT, COWAT and WCST). In addition, one of the parents of the participants was asked to assess the EF of their children through the BRIEF-2. The entire procedure was completed in approximately 90 min (45 min for each evaluation session).

Data analysis

Statistical analyses were conducted using SPSS data analysis package (version 23.0). First, chi-square tests and Student's *t*-tests were used to compare proportions and means of demographic variables between the non-problematic smartphone users and problematic smartphone users. Pearson correlations were also performed to analyze the relationship between variables. Second, to test the assumptions of normality and homogeneity of variance, the Kolmogorov–Smirnov test and Levene's test were applied. Student's *t*-test for independent samples and the Mann–Whitney U test (for the variables in which groups did not have equal variances and the data were not normally distributed) were performed to carry out group comparisons between problematic and non-problematic smartphone users. Given the large number of dependent variables, we used the Benjamini–Hochberg correction to control the false discovery rate, adjusting *p*-values to reduce the number of false positives that may be incorrectly identified as significant (type I errors). Effect sizes (Cohen's *d*) for the Mann–Whitney U test were calculated following the formulas presented by Tomczak and Tomczak (2014) and McGrath and Meyer (2006). For the IGT measures, a mixed repeated measures ANOVA was applied, with blocks as within-subject factor and groups as within-subject factor. Since the assumptions of sphericity and homogeneity of variances were violated, the lower-bound estimate was used. Finally, to compute sensitivity power analyses for the statistical tests employed, G*Power was used (Faul et al., 2007). This tool allowed us to calculate what effects our design is sensitive enough to detect with a sample of 110 participants with 80% power (alpha = .05). The Student's *t*-test would be sensitive to effects of $d = .635$ and the Mann–Whitney U test is sensitive to effects of $d = .626$.

Results

The results of the correlation analyses are presented in Table 2. PSU was positively correlated with the emotional control dimension ($r = .190$; $p = 0.047$). This means that a higher level of PSU is associated with greater difficulties to manage emotional responses. We also found that PSU was negatively correlated with

Table 2. Correlations between problematic smartphone use and executive functioning measures.

	Problematic smartphone use
Digit span	−.008
Letter-number sequencing	−.018
Similarities	−.087
COWAT phonemic category	.080
COWAT semantic category	−.022
D-KEFS CWIT inhibition (part 1 vs. 3)	−.073
D-KEFS CWIT shifting (part 1 + 2 vs. 4)	.014
WCST perseverative responses	.020
IGT block 1	−.325**
IGT block 2	−.138
IGT block 3	.043
IGT block 4	−.052
IGT block 5	.017
IGT total blocks	−.089
BRIEF executive function: global index	.181
BRIEF inhibition	.157
BRIEF flexibility	.122
BRIEF emotional control	.190*
BRIEF initiative	.132
BRIEF working memory	.139
BRIEF planning	.076
BRIEF organization of material	.139
BRIEF self-monitoring	.157
BRIEF task-monitoring	.040
BRIEF behavioural regulation index	.173
BRIEF emotion regulation index	.183
BRIEF cognitive regulation index	.131

* $p < .05$.
** $p < .01$.
COWAT = controlled oral word association test; D-KEFS CWIT = Delis-Kaplan executive function system colour-word interference test; WCST = Wisconsin card sorting test; IGT = Iowa gambling task; BRIEF-2 = behaviour rating inventory of executive function-2.

the performance in block 1 of the IGT ($r = -.325$; $p = 0.001$). No significant correlations were found for the remaining tasks.

The means, standard deviations, *t*-tests and Mann–Whitney U tests between problematic smartphone users and non-problematic smartphone users are presented in Table 3. Adolescents from the PSU group scored higher on the global index of executive function assessed by the BRIEF-2 ($U = 1063.5$, $p = 0.048$) and the emotional control dimension ($U = 1080$, $p = 0.048$). In addition, the emotion regulation index ($t = 2.91$, $p = 0.04$) was higher in adolescents who showed PSU. The effect size of those significant results, measured by Cohen's *d*, was $d \approx 0.53$, indicating a medium effect. Nevertheless, the scores on the performance on all the tasks did not differ significantly between the groups ($p > 0.05$), with a small-sized effect ($d < 0.40$).

Regarding the IGT, a mixed ANOVA was conducted to examine if there were significant differences in task performance across the five blocks according to problematic and non-problematic smartphone users. There was no significant interaction between blocks and groups, $F(1, 108) = 1.32$, $p = 0.253$, $\eta^2_p = 0.012$. The main effect of group was also not significant, $F(1, 108) = 0.746$, $p = 0.390$, $\eta^2_p = 0.007$. However, the test indicated a significant main effect of blocks, $F(1, 108) = 11.91$, $p = 0.001$, $\eta^2_p = 0.099$. Bonferroni post-hoc tests revealed significant differences between block 1 and the other blocks, as shown in Table 4.

In Figure 1, we present the IGT performance by blocks of each group. As shown in the figure, problematic smartphone users also scored lower than the controls on blocks 2, 3 and 4 of the IGT. Finally, it should be mentioned that, although it was not a significant result, the performance in block 5 of the group with PSU was better than the group of non-problematic smartphone users.

Discussion

This study aimed to examine the EF in adolescents with PSU by comparing the performance on tasks measuring updating, inhibition, shifting and decision making between problematic and non-problematic smartphone users. We also used parent-report measures of their children's EF to provide a valid ecological indicator of competence in solving everyday problems. Based on the literature, participants from the PSU

Table 3. Differences between groups (*t*-tests and Mann–Whitney U test).

	Non-problematic smartphone users M(SD)	Problematic smartphone users M(SD)	*t*/U	Cohen's *d*
Working memory				
Digit span	17.36 (3.24)	17.04 (4.17)	1382	0.151
Letter-number sequencing	11.18 (3.27)	11.40 (2.80)	1459.5	0.061
Reasoning				
Similarities	11.33 (2.06)	11.00 (2.55)	1350	0.188
Verbal fluency				
COWAT phonemic category	30.49 (7.79)	29.89 (9.17)	**0.37**	0.095
COWAT semantic category	37.13 (6.26)	35.29 (6.87)	**1.47**	0.310
Inhibition				
D-KEFS CWIT Part 1 vs. 3	16.46 (10.13)	15.70 (6.72)	1443	0.253
Shifting				
WCST perseverative responses	37.33 (9.36)	38.90 (11.58)	1258	0.294
D-KEFS CWIT Part 1 + 2 vs. 4	5.58 (10.53)	7.75 (9.82)	1242.5	0.312
Behaviour rating of executive function (BRIEF-2)				
Executive function: global index	51.42 (8.72)	56.85 (11.12)	1063.5*	0.530
Inhibition	52.75 (10.55)	56.84 (11.58)	1197	0.366
Flexibility	52.69 (11.54)	57.40 (10.68)	**2.22**	0.437
Emotional control	53.22 (9.94)	58.84 (11.11)	1080*	0.509
Initiative	45.82 (7.03)	50.15 (10.25)	1179	0.389
Working memory	49.07 (7.57)	52.38 (10.09)	1252	0.301
Planning	49.58 (7.56)	53.24 (10.43)	1215	0.346
Organization of material	8.91 (2.63)	9.29 (2.59)	1308	0.235
Self-monitoring	53.02 (9.54)	58.13 (10.48)	1014	0.595
Task-monitoring	49.31 (9.96)	51.13 (9.99)	1282.5	0.265
Behavioural regulation index	53.18 (10.04)	58.09 (11.29)	1135.5	0.441
Emotion regulation index	53.58 (11.02)	59.85 (11.56)	**2.91***	0.534
Cognitive regulation index	49.33 (7.92)	53.13 (10.76)	1207	0.354

Note. $N = 110$; M = mean; SD = standard deviations; t = student t-test; U = Mann–Whitney U test; COWAT = controlled oral word association test; D-KEFS CWIT = Delis-Kaplan executive function system colour-word interference test; WCST = Wisconsin card sorting test; BRIEF-2 = behaviour rating inventory of executive function-2.
* $p < .05$ (p-value adjusted for multiple comparisons).

Table 4. Post hoc comparisons for Iowa gambling task (IGT) blocks.

		Mean difference	SE	p_{Bonf}
Block 1	Block 2	−2.073*	.560	.003
	Block 3	−3.800**	.673	<.001
	Block 4	−4.018**	.709	<.001
	Block 5	−3.873**	.904	<.001
Block 2	Block 3	−1.727	.628	.070
	Block 4	−1.945	.694	.060
	Block 5	−1.800	.929	.554
Block 3	Block 4	−0.218	.530	1.000
	Block 5	−0.073	.747	1.000
Block 4	Block 5	0.145	.611	1.000

* $p < .05$.
** $p < .001$.

group were expected to exhibit a poorer profile of executive functioning compared to the non-problematic smartphone users. This hypothesis was supported for the parent-report measures but not for the performance-based outcomes. First, according to the evaluation of the parents through the BRIEF-2 questionnaire, individuals with PSU showed greater difficulties in EF, specifically in emotional regulation. They also reported more problems in emotional control compared to the group without PSU. These results suggest that adolescents with a higher level of PSU have greater difficulties in regulating their own emotional responses. This finding is in line with the research that revealed that increased smartphone use was related to low self-control and dysfunctional impulsivity (Fabio et al., 2022; Rubio and Buedo-Guirado, 2021). Moreover, people who exhibit poor emotional regulation are more vulnerable to stress and tend to engage in risky behaviours such as PSU (Van Deursen et al., 2015). Therefore, young people may use smartphones as a maladaptive coping strategy to deal with negative emotions, instead of resorting to problem-solving strategies or social support.

On the other hand, we did not find differences between problematic and non-problematic smartphone users in the performance of the EF tasks used in this study. The only significant result found according to these performance-based outcomes was that PSU was negatively correlated with the first part of the IGT. A possible explanation for this result is that IGT is a decision-making task under ambiguity in which emotional

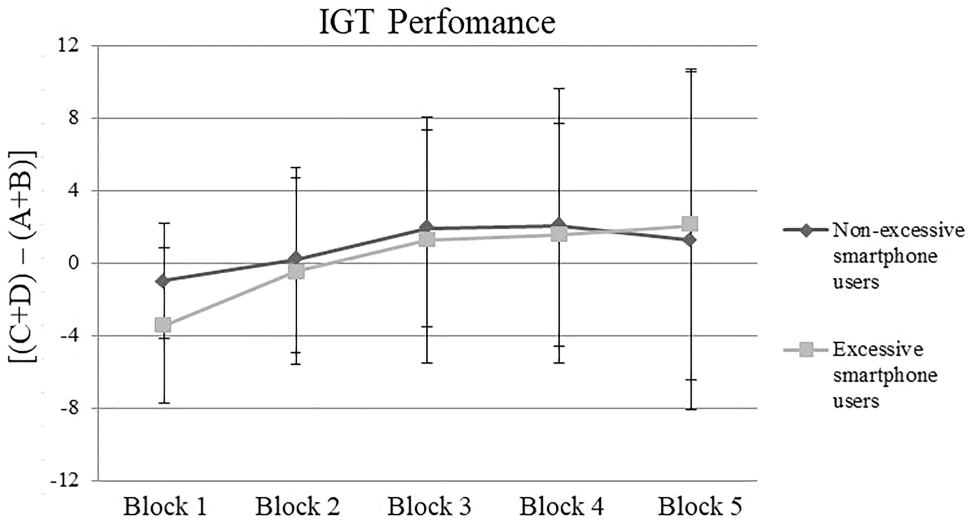

Figure 1. Iowa gambling task (IGT) performance of problematic and non-problematic smartphone users.

processes are involved and not in combination with cognitive processes, as occurs in risk decision-making (Trotzke et al., 2015). Furthermore, no differences were found between these groups in the cognitive regulation dimensions of the BRIEF-2. Although, this result is incongruent with previous research that has shown negative associations between PSU and executive functions (Hartanto and Yang, 2016; Warsaw et al., 2021), our findings replicate some studies that have failed to find associations of PSU with inhibition, working memory and shifting abilities (Gao et al., 2020; Toh et al., 2021).

The performance-based results, along with those found related to the parent-report measures, indicate that some aspects of executive functions – probably those related to emotional regulation – may be reduced in PSU but without impairments in EF competence, which involves cognitive abilities such as holding information while working with it mentally; reasoning; retrieving phonological or semantic information; focusing on a certain stimulus while suppressing attention to others; and flexibly changing from one task to another. These different outcomes between abilities can be explained from the EF classification in 'hot' and 'cold' components (Zelazo and Carlson, 2012). This perspective distinguishes the executive functions involved in affective and social situations that generate motivation and emotion (hot EF), such as decision making under uncertainty, from those that are purely cognitive and require to solve decontextualized or abstract problems (cold EF), such as working memory (Fernández García et al., 2021). According to this classification, the executive functions in which adolescents with PSU would show difficulties would therefore be hot functions.

The hot and cold EF perspective is also supported by several studies suggesting that performance-based measures of EF may not measure the same underlying mental constructs or domains as rating measures (Ten Eycke and Dewey, 2016). A review by Toplak et al. (2013) revealed a minimal correlation between these two types of assessment methods. The explanation of the authors for this lack of convergence is that they actually concern two different cognitive domains: algorithmic and reflective levels. The algorithmic level refers to the efficiency of the cognitive processes involved in behavioural control. It is assessed through performance-based tests administered in highly standardized conditions. In contrast, the reflective level is concerned with the choice of action that is appropriate given the beliefs and goals of the individual and thus making an optimal decision. Only the rating measures evaluate this control of behaviour in the real environment aimed at achieving goals (Stanovich, 2011). Therefore, algorithmic and reflective levels provide different information about cognitive functioning. While performance-based measures of EF indicate how efficient processing is, rating measures provides information about success in achieving goals (Toplak et al., 2013). In individuals with PSU, the aspect of the EF that may be affected would be the reflexive system but not the algorithmic one. In fact, the participants with PSU in our study performed better on some of the laboratory tasks than the group of non-problematic smartphone users, although this difference was not statistically significant. This is in line with the studies that found beneficial effects of an efficient smartphone use on certain processes, such as working memory, shifting, attention and inhibition

(Liebherr et al., 2020; Toh et al., 2021; Wilmer et al., 2017), and constitutes evidence suggesting that it may not be appropriate to assess PSU with the same symptoms of substance addictions (Billieux et al., 2015). Our study did not find EF difficulties in people with PSU, such as those exhibited by substance abusers (Gustavson et al., 2017; Thoma et al., 2011; Verdejo-García & Pérez-García, 2007). This difference found in EF may be because of EF impairment, in addition to being a risk factor for both disorders, is a consequence of the neuromodulation of the frontal circuits produced by substance abuse (Gustavson et al., 2017; Piechatzek et al., 2009).

Although the present study contributes to enrich the understanding of the cognitive profile of PSU, several limitations should be considered in the interpretation of these results. First, an important limitation is the generalizability due to the non-probability sampling technique and the characteristics of the sample. Because of the participants in our study were limited to adolescents from two provinces in Spain, sample homogeneity may bias EF performance patterns. Therefore, the sample representativeness cannot be reached out to for other populations, and future research might examine the generalization of these results among individuals from different cultures and regions. In addition, more demographic data, such as parental education and socioeconomic status, should be considered as moderating variables. Although the literature supporting the effect of the demographic variables on PSU is scarce, they may have a potential moderating effect. Almeida et al. (2025) found that participants with higher socioeconomic status were less likely to show PSU. On the other hand, a review by Fischer-Grote et al. (2019) revealed that going to a private school was a predictor for excessive mobile phone use. Second, our results require cautious interpretation regarding the effect size of the results. We obtained small-to-moderate effect sizes ($d \approx 0.53$ for the significant differences between groups) and, since the effects our design is sensitive enough to detect with our sample are $d \approx 0.63$, smaller effects may have gone undetected.

Another limitation of this study is that the assessment of the PSU grade has been based only on a self-administered questionnaire, which has a potential risk of social desirability or distortion. These measures should be complemented with objective quantitative parameters of smartphone usage, such as screen time, used applications, usage frequency and received notifications; since it has been shown that these parameters may have different relationship with specific aspects of EF. Toh et al. (2021) found that smartphone screen time was related to better shifting and working memory abilities, whereas frequent smartphone checking was associated with better shifting ability but poorer common EF. Moreover, smartphone use patterns and type of apps used are likely to have specific effects on PSU and EF. A literature review by Chan et al. (2023) revealed that smartphone use patterns differ significantly in their relationship with problematic use. For example, evidence from the studies included in this review revealed that watching videos, chatting, and making calls predicted PSU, but gaming and social media use yielded inconsistent results. On the other hand, Reed (2023) performed a series of experiments examining social media addiction and EF They demonstrated a relationship between social media addiction and impulse control problems rather than between social media addiction and attentional issues. In addition, future studies should consider the presence of the smartphone while participants complete EF tasks, since it has been shown that performance results are different depending on whether the smartphone is present. In the study by Schwaiger and Tahir (2022), participants experienced fewer difficulties performing a complex attentional task when their smartphone was in another room.

Finally, this study cannot draw conclusions about causality between PSU and EF. Impaired EF may be the consequence of smartphone overuse, or reduced EF could lead individuals to become dependent to this device. Therefore, future longitudinal studies should be conducted to assess the relationship between these variables progressively over time and more complex statistical methods could help to clarify the complex nature of causality in this relationship. The EF system should be evaluated within a model in which its relationship with other variables is studied. Several studies have provided theoretical models regarding the role of EF in the development of addictive behaviours such as PSU (Fabio et al., 2022; Kim-Spoon et al., 2017). These behaviours are assumed to result from an imbalance between two systems: the impulsive system, which allows quick and emotional responses to achieve immediate gratification, and the reflective system, which is related to executive functions and is responsible for the control of impulsive behaviours (Wegmann et al., 2020). Similarly, Kim-Spoon et al. (2017) also proposed two main systems involved in the regulation of substance use behaviours: the reactive system, represented by sensitivity to reward and punishment, and the regulatory system, which refers to EF processes. Therefore, substance abuse can be viewed as an inability to inhibit reward-seeking behaviours as well as behaviours that are likely to result in punishment. Nevertheless, further behavioural and neurobiological research is needed to broaden our understanding of the moderating role of EF in the development and maintenance of PSU.

In conclusion, the results of the present study confirmed the hypothesis for the parent-report measures but not for the performance-based outcomes. As expected, according to the evaluation of the parents through the BRIEF-2 questionnaire, participants from the group of problematic smartphone users showed greater difficulties in EF related to the emotional regulation needed to solve everyday problems compared to those from the group of non-problematic smartphone users. Conversely, no differences were found between groups in cognitive regulation and the performance of the EF tasks. These results indicate that some aspects of EF related to acting in accordance with the beliefs and goals of the individual may be reduced in PSU but without impairments in EF competence, which involves cognitive abilities. This means that adolescents with a higher level of PSU may have greater difficulties in regulating their own behaviour and emotional responses, but they can manage their cognitive processes and solve problems effectively, unlike the results found in frequent substance users. Therefore, the neurocognitive profile of PSU differs from that of substance addictions. While both involve difficulties in impulse control, PSU may be characterized by deficits related to emotional regulation, without the direct neurological changes in the reward pathway that a substance causes. However, this does not mean that PSU is not a major social concern, since it has been shown that it can lead to negative consequences in academic performance, social relationships as well as mental and physical health; and is related to low emotional regulation, which is a symptom that requires attention.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

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