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The relationship between autistic traits and problematic smartphone use in adolescents: The serial mediating role of anxiety and executive dysfunction

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Background Based on the Interaction of Person-Affect-Cognition-Execution (I-PACE) model, this study aimed to explore the relationship between autistic traits and problematic smartphone use (PSU) among Chinese adolescents and to examine the serial mediation effect of anxiety and executive dysfunction in the association between autistic traits and PSU.

Methods The Autism-Spectrum Quotient, Smartphone Addiction Scale, the trait version of the State–Trait Anxiety Inventory, and Dysexecutive Questionnaire were administered to a sample comprising 412 senior high school students (average age = 17.05 years, *SD* = 0.65). Structural equation models were utilized to explore the simple and serial mediating role of anxiety and executive dysfunction played in the association between autistic traits and PSU.

Results This study found that social rather than non-social autistic traits were positively associated with anxiety, executive dysfunction, and PSU. Furthermore, after controlling for gender, anxiety and executive dysfunction acted as sequential mediators in the connection between social autistic trait and PSU. However, non-social autistic trait did not predict anxiety, executive dysfunction, or PSU.

Conclusion This study supports the I-PACE model and deepens understanding of PSU formation. Furthermore, the findings underscore the importance of addressing social challenges faced by adolescents with high autistic traits, providing a viable potential intervention pathway to promote healthy smartphone use in this population.

Keywords Autistic traits, Problematic smartphone use, Anxiety, Executive dysfunction, Serial mediation, Structural equation models

Introduction

As of June 2024, the number of smartphone Internet users in China mainland has reached 1.096 billion, which is nearly 75.9% of the Chinese population [1]. Despite of convenience of smartphones [2], a growing number of studies find the adverse effects of excessive smartphone use [3]. Excessive smartphone use is linked to social anxiety [4, 5], poor communication skills [6], social relationship and loneliness [7], lower mindfulness [8], poor emotion regulation [9], sleep problems [10, 11], and more psychological distress [12].

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Some scholars have described excessive smartphone use as "mobile phone addiction" or "smartphone addiction", highlighting features of behavioral addiction like salience, withdrawal, and tolerance [5, 13]. However, others have argued that labeling frequent smartphone use alongside substances like cocaine or alcohol may diminish the severity of true addiction and overpathologize typical behavior [14]. Therefore, the more appropriate terminology "problematic smartphone use" was used in this study.

In light of the aforementioned adverse consequences of PSU, and considering that adolescents have lower impulse control than adults and are more susceptible to the adverse effects of PSU [15], research on predictors of PSU among adolescents and the underlying mechanisms is essential for improving the understanding of PSU among adolescents and development of effective interventions.

Although the Interaction of Person-Affect-Cognition-Execution (I-PACE) model was originally proposed to explain development and maintenance of Internet use disorders [16, 17], it has also been applied to understanding PSU [18]. This model was applied to test factors that could contribute to PSU in this study. Autistic traits, as personality traits, were tested as an antecedent of PSU; anxiety and executive dysfunction, as affective and cognitive factors, respectively, were tested as intervening variables that would mediate this association. Following the I-PACE model, the current study would address how autistic traits influence PSU.

The relationship between autistic traits and PSU

Autism spectrum disorder (ASD) is a group of neurodevelopmental disorders charactered by poor social skills, damaged communications, and restricted and repetitive behaviors and interests (RRBIs) [19]. These traits not only exist in clinical samples, but also in the general population with a continuous distribution [20, 21]. According to the continuum theory of autism, autistic traits are a subclinical set of characteristics that are milder but qualitatively similar to the diagnosed autism phenotype [22, 23]. Higher levels of autistic traits are associated with increased sensitivity, attention to detail, and intense focus on specific tasks, and also associated with poorer affect recognition, impaired social interactions, decreased fantasy life, and poorer communication skills [23, 24]. These social challenges may lead individuals with higher autistic traits to seek out alternative means of communication that are less demanding than face-to-face interactions. Online communication could represent a more accessible form of interaction for such individuals, as the Internet can reduce the constraints they might experience in offline social settings [25]. Previous studies have investigated the relationship between autistic traits and Internet addiction and found a significant correlation [26–28]. PSU was considered as a specific form of internet addiction [29, 30]. The convenience of online communication with smartphones, which are an easily accessible online medium, makes them potentially highly attractive to individuals with high autistic traits. Additionally, a recent review showed that autistic traits and behavior addiction share some common characteristics, such as extreme preoccupations and rigid habits [31], which has found a positive correlation between autistic traits and behavior addiction in both clinical and general population. Thus, it seems that different aspects of autistic traits are relevant to PSU, including characteristics in social and non-social domains [30]. However, few studies have investigated the relationship between autistic traits and PSU. To the best of our knowledge, only one study among college students found a significant association between autistic traits and PSU [4]. Furthermore, this association was mediated by the social interaction characteristics of autistic traits (social anxiety and loneliness). It is still unclear whether other characteristics of autistic traits are relevant to PSU.

Most prior studies have investigated autistic traits as a unitary construct, while growing data reveals the dissociation of social and non-social autistic traits in both clinical and general population. This dissociation is observed at the behavioral [32–35], genetic [36, 37], cognitive [38, 39], and neural levels [38]. Social and non-social traits are thought to represent different processes, as social traits are conceptualized by deficits in social abilities, communication, and recognition of social cues, while non-social traits are mainly conceptualized by systemizing [33]. In sum, the understanding of the relationship between autistic traits and PSU is limited, and it is necessary to fractionate social and non-social autistic traits in the current study, which could deepen our understanding of the relationship between autistic traits and PSU.

The mediating role of anxiety between autistic traits and PSU

Anxiety is one of the most common comorbidities of ASD in children [40, 41], adolescents [41, 42], and adults [35, 43]. Comorbid anxiety disorders have been reported in approximately 40% of ASD individuals [44]. A recent review has revealed that higher trait anxiety scores in autism compared to control groups [45]. Individuals with higher level of autistic traits seem likely not only lack social skills and social knowledge, but also lack the initiative to engage in interpersonal interaction [44], which may be associated with anxiety [46–50]. This supports

the idea of a close relation between autistic traits and anxiety.

Additionally, previous research has found that individuals with high anxiety typically use their smartphones more excessively [51–55]. This is also in line with Brand et al.'s (2016) I-PACE Model, which is a theoretical model that suggests that a number of core characteristics of an individual are susceptibility factors of PSU, such as personality traits, biological factors, and psychopathological traits (e.g., anxiety, depression), which play an important role in the early developmental stages of PSU [16]. Individuals with higher levels of anxiety may tend to use smartphones to fulfil the need to interact in a less direct way than in real-life interactions [56]. Using smartphone can reduce an individual's anxiety when interacting with others because it provides more opportunity to think about each response in a dialogue [57]. A recent review on the relationship between anxiety, including trait anxiety, social anxiety, and generalized anxiety, with smartphone addiction, reveled a small to moderate correlation between anxiety and smartphone addiction [58]. Moreover, existing studies have revealed that social autistic traits are strongly positively correlated with anxiety and other psychiatric conditions, while non-social autistic traits are irrelevant to these variables [44, 59]. Therefore, anxiety may be a mediator in the relation between autistic traits and PSU.

The mediating role of executive dysfunction between autistic traits and PSU

Executive function is a cognitive control system responsible for integration and coordination of information in the service of goal-oriented behaviors [60]. This umbrella term is consisted of three core domains: working memory, inhibition control, and switching [60, 61]. Executive dysfunction theory of ASD advocated that autism is usually associated with deficits in executive function [39, 62]. Executive dysfunction underlies characteristic symptomatology of ASD, both in the social and non-social domains. Further, executive function deficits are found in non-clinical sample high in autistic traits. A growing body of research has revealed a link between autistic traits and executive dysfunction among general individuals [63–65].

Additionally, RRBIs in ASD individuals have been hypothesized to be linked with executive dysfunction [38]. Research has demonstrated that RRBIs are related to three core executive function (i.e., cognitive flexibility, inhibition, and working memory) impairments [66]. Contrarily, some research found that social autistic traits but not RRBIs are associated with executive dysfunction [67, 68]. Another research showed that both social autistic traits and RRBIs are associated with executive dysfunction [69]. Few studies have examined the association between autistic traits and executive dysfunction with distinguishing between social and non-social traits in the general population.

In addition, executive dysfunction is a robust predictor of PSU [16, 17]. Following the Interaction of Person-Affect-Cognition-Execution (I-PACE) model, executive dysfunction is crucially involved in the development and maintenance of PSU [16, 17]. Existing empirical studies indicated that executive dysfunction is correlated with PSU [70–73]. Therefore, executive dysfunction may be another mediator in the relation between autistic traits and PSU.

The serial mediating effect of anxiety and executive dysfunction

It has been shown that high level of anxiety can lead to impaired executive function (i.e., executive dysfunction) [37, 62, 74–76]. The attentional control theory (ACT) [74] proposed that anxiety impairs inhibition and shifting (two core components of executive function). This can be explained as anxiety exhausting cognitive resources and leading to executive dysfunction [74, 77].

Previous studies have examined the mediation mechanism in the relation between anxiety and PSU. The mediators examined include distress tolerance [53], mindfulness [53], rumination [51, 52], fear of missing out [51, 54, 55], and boredom proneness [52, 54]. However, few empirical studies explored the mediation role of executive dysfunction between them, which is an essential factor contributing to the development of PSU [78]. A study found a mediating role of executive dysfunction between anxiety and PSU in college students [72].

Therefore, individuals with higher autistic traits may have more anxiety, which could be associated to greater executive dysfunction, in turn relating to the tendency to engage in PSU. In other words, anxiety and executive dysfunction serially mediate the association between autistic traits and PSU.

The present study

This study explored the potential mediation mechanisms underlying the relationship between autistic traits and PSU [16, 17]. According to the I-PACE model, some core characteristics of individuals, such as personality traits, are susceptibility factors for PSU, while affective and cognitive factors mediate the association between these core characteristics and PSU. Individuals with higher levels of autistic traits are more likely to lack social stimulation and social skills, and may feel uncomfortable interacting with others face-to-face, which may cause them to feel anxious in social situations [44], and this anxiety can in turn exacerbate executive dysfunction [37, 62, 74–76].

Thus, in order to cope with negative emotions and stress, individuals experiencing anxiety and executive dysfunction may turn to increased smartphone use as a coping way to enhance comfort or entertainment while socialising. Based on this, we proposed that the relationship between autistic traits and PSU would be serially mediated by anxiety and executive dysfunction.

To the best of our knowledge, this is the first study to investigate the relationship between social and non-social autistic traits and PSU in adolescents and to explore the mediation role of anxiety and executive dysfunction in this relationship. Based on the aforementioned literature review, we established a hypothesized model presented in Fig. 1, and tested the following hypotheses: (1) Autistic traits are positively correlated with PSU among adolescents. (2) Anxiety acts as a simple mediator between autistic traits and PSU. (3) Executive dysfunction acts as a simple mediator between autistic traits and PSU. (4) Autistic traits exacerbate PSU through the serial mediation role of anxiety and executive dysfunction. Furthermore, based on previous studies, social autistic traits may be more predictive of PSU than non-social autistic traits due to their inherent social nature.

Method

Participants

Using a convenient sampling method, a total of 470 senior high school students in Sichuan, Chongqing and Hunan province in China completed the online questionnaires (Survey Star, www.wjx.cn) during the July–August 2023. Data from 58 participants were excluded due to short response times, regular responses, or incorrect answers to lie detector questions. Since participants were asked to make forced choices for each question, there were no missing values. The data provided by a total of 412 participants were thus included in subsequent analyses, for a response rate of 87.7%. The age distribution of the subjects was 15–19 years old, with an average age of 17.05 ± 0.65. Among them 111 were male and 301 were female. This study was approved by the local Ethics. All participants provided written informed consent. The participants were fully informed about the purpose and procedures of the study. The consent form clearly indicated their right to withdraw from the study at any time without facing any negative consequences. Participants' privacy and confidentiality were protected. The researchers assured the participants that their personal information would remain confidential and that the data would be anonymized.

Measurement

Autistic traits

The Autism-Spectrum Quotient (AQ) is a self-report, 50-item questionnaire designed to measure autistic traits in the general population [20] and assessing five different areas (10 items each): social skills, attention to details, attention switching, communication, and imagination. Each item is scored on a four-point scale: "definitely disagree", "slightly disagree", "slightly agree", and "definitely agree". The AQ total score ranges from 50 to 200, with a higher AQ score meaning greater autistic traits for an individual. The Chinese version of the AQ has been confirmed to have good internal consistency (Cronbach $\alpha = 0.81$) [79]. In this study, the Cronbach's α for the AQ total scale was 0.66.

To assess both social and non-social autistic traits, we utilized the two-factor model of the Autism Spectrum Quotient [20]. Specifically, we distinguished between a "Social Interaction" factor (representing AQ social traits) and an "Attention to Detail" factor (representing AQ non-social traits). Higher scores on these factors indicate greater challenges in social interaction and a stronger inclination towards attention to detail, respectively [33].

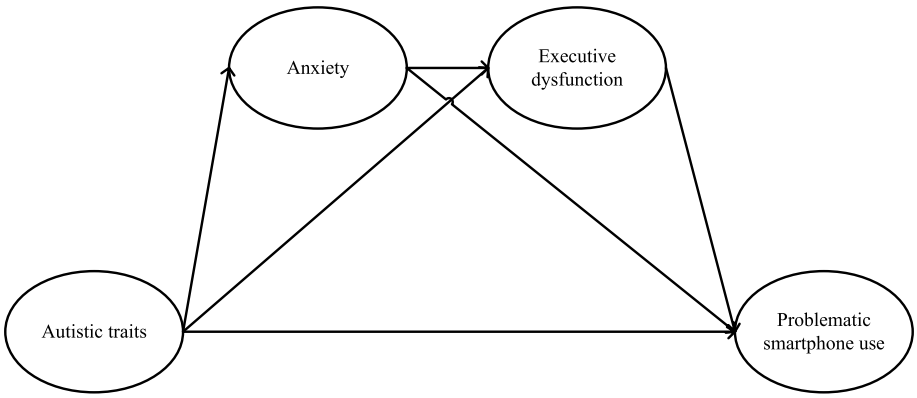

Fig. 1 The hypothesized serial mediation model

The Cronbach's α for the AQ social traits subscale was 0.76, while AQ non-social traits subscale was 0.60.

Problematic smartphone use

Problematic smartphone use was measured by the Smartphone Addiction Scale (SAS) [2] which consists of 33 items. The scale includes six components: daily life, disturbance, positive anticipation, withdrawal, cyberspace-oriented relationship, overuse, and tolerance. Each item is rated on a six-point Likert scale, ranging from 1 ("strongly disagree") to 6 ("strongly agree"). A higher score indicates a more severe PSU. The Chinese version of the SAS was used in this study, and the scale had a good reliability with Cronbach's α coefficient of 0.91 [80]. The Cronbach's α coefficient of the SAS in this study was 0.95.

Anxiety

Anxiety was measured using the trait version of the State–Trait Anxiety Inventory [81]. The questionnaire consists of 20 items. Each item was rated on a 4-point scale ranging from 1 (not at all) to 4 (always), higher scores indicate higher anxiety. The Chinese version of the STAI-T was used in this study, and the scale had a good reliability with a Cronbach's α of 0.89 in the general population [82]. In the current study, Cronbach's α of the STAI-T was 0.90.

Executive dysfunction

Executive dysfunction was measured by the Dysexecutive Questionnaire (DEX) [83]. This questionnaire consists of 20 items and includes five subscales: inhibition, intention, executive memory, positive affect, and negative affect. Each item in this scale was rated on a 5-point scale ranging from 0 (never) to 4 (very often). A higher score indicates a more impaired executive function. The Chinese version of the DEX was used in this study, which has been confirmed to be a reliable measurement for both clinical and non-clinical Chinese population [84, 85]. The Cronbach's α coefficient of the DEX in this study was 0.93.

Data analysis

This study utilized SPSS 15.0 and Mplus 7.4 software for data analysis. We performed a descriptive statistics analysis to identify the distribution of all variables and Pearson's correlation analysis to estimate the correlation coefficients between all study variables. Subsequently, a Harman single-factor test was carried out to examine potential common method bias [86]. Finally, based on previous studies [87], all variables were standardized, and then serial mediating effect analysis was conducted under the control of gender and age with structural equation modeling technology. In this model, 5000 bootstrap samples and 95% bias-corrected confidence intervals (CIs) were implemented. The goodness of fit was assessed using various indices, including the χ^2 test statistic, root mean square error of approximation (RMSEA), standardized root mean square residual (SRMR), comparative fit index (CFI) and Tucker-Lewis index (TLI).

Autistic traits (both social and non-social traits) were independent variables (X); PSU was dependent variable (Y); anxiety was considered the first mediated variable (M1); and executive dysfunction was the second mediator (M2). An effect is considered significant when 95% CI does not contain zero.

Results

Common method bias test

Since all study variables were measured by self-reported questionnaires, it is necessary to evaluate the extent of common method bias [86]. A Harman single-factor test was conducted. Specifically, all items of each questionnaire were included in a factor analysis adopting principal component analysis method to extract factors. The unrotated exploratory factor analysis extracted a total of 29 factors with an eigenvalue > 1, the first factor explained only 18.37% of the total variance, which is less than the critical standard of 40%. Therefore, common method bias was not a major problem in this study. In addition, this study also examined the common method bias by controlling for the effects of an unmeasured latent methods factor, which showed that after controlling for the common method variance factor, the change in each of the fit indicators did not exceed 0.05, thus indicating that there is no serious problem of common method bias in this study [88].

Descriptive statistics and correlation analysis

The means and standard deviations of study variables and the correlations among them are presented in Table 1. All study variables were significantly correlated each other. Moreover, the correlation coefficients between social and non-social autistic trait with anxiety, executive dysfunction, as well as PSU were calculated. Results revealed that social autistic trait was positively and significantly correlated with anxiety, executive dysfunction, as well as PSU, while non-social autistic trait exhibited a negative correlation with these variables. Additionally, the correlation coefficient of social and non-social autistic traits was −0.331 ($p < 0.001$). Further details are given in Table 1.

Serial mediation analysis

Firstly, we examined the serial mediation with the overall autistic traits. Figure 2 presents the path coefficients of

Table 1 Descriptive statistics and correlation coefficient matrix of all study variables

Variables	*M*	*SD*	1	2	3	4	5	6
1. Autistic traits	119.91	8.62	1					
2. Social autistic trait	93.07	9.00	0.920***	1				
3. Non-social autistic trait	24.78	3.37	0.051	−0.331***	1			
4. Anxiety	45.38	8.97	0.496***	0.515***	−0.100*	1		
5. Executive dysfunction	36.17	14.46	0.445***	0.475***	−0.122*	0.581***	1	
6. Problematic smartphone use	85.36	21.85	0.262***	0.298***	−0.119*	0.470***	0.537***	1

N = 412. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

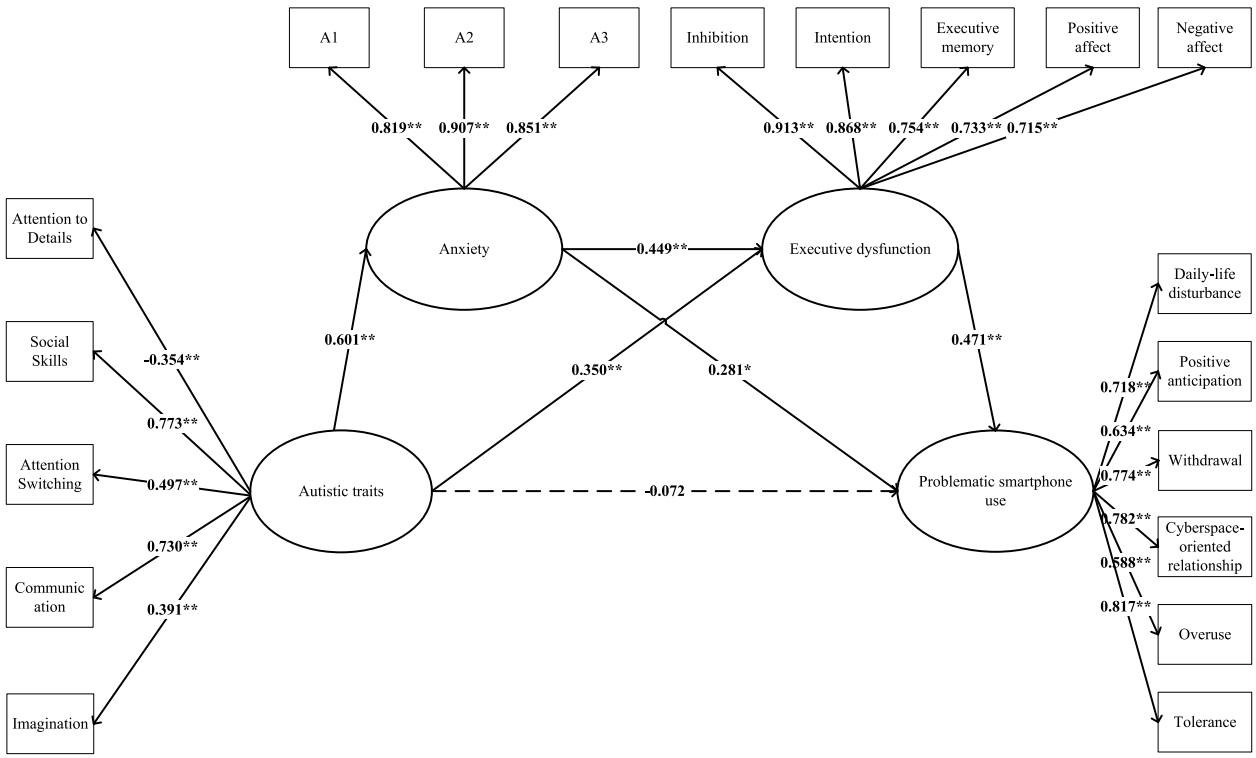

Fig. 2 Serial mediation model of the relationship between autistic traits and problematic smartphone use. Solid lines mean significant pathways. Dotted line means non-significant pathway. ** $p < 0.01$. *** $p < 0.001$

the mediation analysis. The total effect of autistic traits on PSU is $c = 0.389$, $p < 0.001$. The mediation effect analysis was carried out according to the hypothesized model and the model fit indices are listed as follows: $\chi^2/df = 2.57$, RMSEA = 0.065, CFI = 0.932, TLI = 0.916, SRMR = 0.060. According to Hu and Bentler (1995)'s recommendation, if $\chi^2/df < 3$, RMSEA < 0.08, SRMR < 0.10, and TLI and CFI > 0.90, the model is acceptable. When anxiety and executive dysfunction were included, the direct effect of autistic traits on smartphone addiction was not significant ($c' = -0.072$, $p = 0.329$). Thus, anxiety and executive dysfunction exerted a completely mediated effect in the relationship between autistic traits and PSU. The total mediation effect was significant ($ab = 0.461$, 95% CI = [0.358,0.580], see Table 2). The simple mediation effect of anxiety ($a1b1 = 0.169$, 95% CI = [0.056,0.303]) and executive dysfunction ($a2b2 = 0.209$, 95% CI = [0.086,0.251]) was significant. The serial mediation effect of anxiety and executive dysfunction was also significant ($a1db2 = 0.127$, 95% CI = [0.065,0.200]).

Then, social and non-social autistic trait were divided and included in the hypothesized model. The total effect of social autistic trait on PSU is $c1 = 0.401$, $p < 0.001$, while non-social autistic trait had no significant effect on PSU, $c2 = -0.032$, $p = 0.638$. Therefore, the following mediation analysis excluded non-social autistic trait.

Table 2 Serial mediation analysis results of the relationship between autistic traits and problematic smartphone use

		Effect	BootSE	95% CI	
				Lower	Upper
c	**Autistic traits → problematic smartphone use (total effect)**	**0.389**	**0.057**	**0.272**	**0.492**
c'	Autistic traits → problematic smartphone use (direct effect)	−0.072	0.074	−0.215	0.072
ab	Total indirect effect	0.461	0.042	0.358	0.251
a1b1	Autistic traits → anxiety → problematic smartphone use	0.169	0.064	0.056	0.303
a2b2	Autistic traits → executive dysfunction → problematic smartphone use	0.165	0.042	0.056	0.303
a1db2	Autistic traits → anxiety → executive dysfunction → problematic smartphone use	0.127	0.065	0.200	0.269

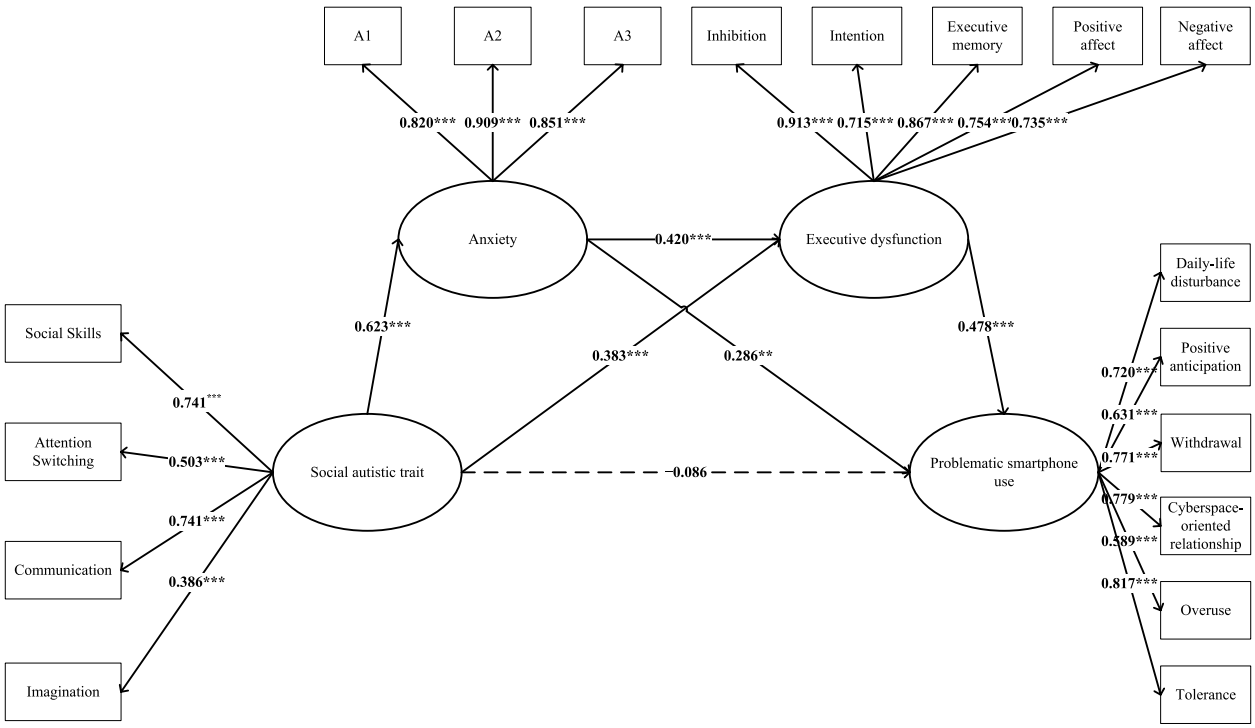

Fig. 3 Serial mediation model of the relationship between social autistic trait and problematic smartphone use. Solid lines mean significant pathways. Dotted line means non-significant pathway. ** $p < 0.01$. *** $p < 0.001$

Figure 3 presents the path coefficients of the mediation analysis with social autistic trait. The results of social autistic trait model are analogical to the overall autistic traits model and the model fit indices are listed as follows: $\chi^2/df = 2.64$, RMSEA = 0.063, CFI = 0.941, TLI = 0.926, SRMR = 0.057. When anxiety and executive dysfunction were included, the direct effect of social autistic trait on PSU was not significant ($c1' = -0.086$, $p = 0.267$). Thus, anxiety and executive dysfunction exerted a completely mediated effect in the relationship between social autistic trait and PSU. The total mediation effect was significant ($ab = 0.487$, 95% CI = [0.378,0.618], see Table 3). The simple mediation effect of anxiety ($a1b1 = 0.178$, 95% CI = [0.058,0.314]) and executive dysfunction ($a2b2 = 0.183$, 95% CI = [0.101,0.289]) was significant. The serial mediation effect of anxiety and executive dysfunction was also significant ($a1db2 = 0.125$, 95% CI = [0.069,0.209]).

Discussion

This study extends the application of the Interaction of Person-Affect-Cognition-Execution (I-PACE) model by examining its relation to PSU among adolescents. Notably, our research differentiates between social and non-social autistic traits, revealing their distinct relationships with PSU. Specifically, we found that

Table 3 Serial mediation analysis results of the relationship between social autistic trait and problematic smartphone use

		Effect	BootSE	95% CI	
				Lower	Upper
c1	**Social autistic trait → problematic smartphone use (total effect)**	**0.401**	**0.057**	**0.282**	**0.503**
c1′	Social autistic trait → problematic smartphone use (direct effect)	−0.086	0.077	−0.230	0.072
ab	Total indirect effect	0.487	0.061	0.378	0.618
a1b1	Social autistic trait → anxiety → problematic smartphone use	0.178	0.066	0.058	0.314
a2b2	Social autistic trait → executive dysfunction → problematic smartphone use	0.183	0.047	0.101	0.289
a1db2	Social autistic trait → anxiety → executive dysfunction → problematic smartphone use	0.125	0.035	0.069	0.209

social autistic traits were significantly and positively correlated with PSU, anxiety, and executive dysfunction, while non-social autistic traits showed no such association. Results from the mediation model indicated that anxiety and executive dysfunction played a serial mediating role in the relationship between social autistic traits and PSU. Social autistic traits indirectly increased PSU through three pathways: anxiety, executive dysfunction, and the anxiety–executive dysfunction serial path. In contrast, non-social traits had no effect on PSU, anxiety, or executive dysfunction. These findings demonstrate the complexity of PSU, provide insights into how social autistic traits drive PSU and suggest pathways for targeted interventions.

In summary, this research advances the field by offering new insights into the relationship between autistic traits and PSU, and provide implications for future studies. These findings have important implications for developing interventions that address the social challenges faced by adolescents with high autistic traits and promote healthy smartphone use habits in this population.

The relationship between autistic traits and problematic smartphone use

The findings of this study reveal a significantly positive correlation between autistic traits and PSU. Particularly, social autistic traits show a stronger association with PSU. This finding is consistent with previous research, indicating that individuals with high autistic traits may be more inclined to use smartphones as a means to avoid the discomfort of social interactions, as digital communication reduces the constraints they might experience in offline social settings [25]. This may be why social autistic trait has a higher correlation with PSU. That is, social autistic trait focuses on the characteristic of difficulty in social interaction.

However, it is noteworthy that non-social autistic traits show no prediction to PSU. This may suggest that while non-social autistic traits are associated with executive dysfunction, it may not be sufficient to lead to PSU. It may also imply that different dimensions of autistic traits may have varying impacts on PSU, with social autistic traits potentially playing a larger role in PSU.

These findings underscore the importance to address social challenges for adolescents high in autistic traits, and provide viable intervention pathways to promote healthy smartphone use habits for this population. Future research can further explore how different dimensions of autistic traits independently or collectively affect PSU and how to design targeted prevention and intervention measures to reduce PSU among adolescents with high autistic traits.

The simple mediating role of anxiety

Results confirm that anxiety is a simple mediator between autistic traits and PSU in adolescents. Consistent with previous studies [44, 45, 49, 59, 79], this study observed that individuals with high autistic traits tend to experience higher level of anxiety. According to the compensatory internet use theory, individuals may excessively rely on smartphones to alleviate their anxiety, thus leading to PSU [89]. This finding coincides with prior research on college students [51–55]. Therefore, it is reasonable to conclude that adolescents with high levels of autistic traits are more susceptible to developing PSU due to elevated anxiety.

In parallel with prior research [44, 59], results support the notion that social rather than non-social autistic trait is associated with anxiety within the general population. Because of their poor social skills and difficulties in communication, individuals with high autistic traits may experience feelings of embarrassment in social situations [49] as well as heightened loneliness [90]. These deficits in social ability may explain why people with high autistic traits are more inclined to choose non-face-to-face interactions [4]. Smartphone and online communication give them the opportunities to get rid of embarrassing occasions. This is consistent with the positive correlation

between autistic traits and social anxiety in general student samples [4, 91, 92].

The simple mediating role of executive dysfunction

Moreover, results confirmed that executive dysfunction plays a simple mediating role between autistic traits and smartphone addiction in adolescents. This finding is in line with prior studies which have robustly demonstrated the association between executive dysfunction and smartphone addiction [71–73]. The result that autistic traits were positively linked with executive dysfunction is consistent with the executive dysfunction theory of ASD [39, 62]. Previous studies revealed that individuals with high autistic traits have inferior attentional shifting compared to their counterparts with low autistic traits [63, 92]. Working memory and attentional control have also been demonstrated to be decreased in individuals with high autistic traits [63, 93]. Additionally, executive dysfunction is a shared feature in ASD and internet addiction [94], executive dysfunction could aggravate the development of internet addiction [95–97]. Individuals with worser working memory capacity and lower attentional control may suffer more distraction from digital media such as the Internet and mobile phones [98]. It is therefore reasonable to conclude that adolescents with high autistic traits are prone to develop PSU due to their executive dysfunction.

It would be worth noting that social but not non-social autistic traits predicted executive dysfunction. It is inconsistent with the hypothesis that executive dysfunction underlies RRBIs [38]. Non-social autistic trait did not predict executive dysfunction may be because the "Attention Switching" subscale was classified into social autistic trait in this study. This subscale is conceived a non-social feature of ASD in previous studies. However, Palme and coworkers [99] argued that attention switching is a trait that benefits social behavior. The dual properties of "Attention Switching" may underestimate the relationship between non-social autistic trait and other study variables (e.g., executive dysfunction, anxiety).

The serial mediating role of anxiety and executive dysfunction

More importantly, this study found that anxiety and executive dysfunction exerts a serial mediating role in the association between autistic traits and PSU in adolescents. Prior studies on the mediation mechanism in the relationship between anxiety and smartphone addiction mainly focused on the mediated role of FoMO, rumination and boredom proneness [58, 100, 101]. The finding that anxiety predicted executive dysfunction is consistent with the attention control theory [74]. Prior studies have found that anxiety impairs executive function across all aspects [62, 75, 76]. Indeed, a recent study has already found executive dysfunction madidates the relationship between anxiety and PSU [72]. According to the I-PACE model [16, 17], poor executive function could aggravate the development of addiction behavior. Hence, it is reasonable to conclude that individuals with high autistic traits have a strong tendency to develop PSU due to their impaired executive function caused by anxiety.

The relationship between social and non-social autistic traits within general population

Another noteworthy point to mention is that when autistic traits were divided into social and non-social autistic trait, social autistic trait showed positive correlations with other study variables, while non-social autistic trait showed weak though significant negative correlations. Moreover, these two factors had a moderately significant negative correlation. In past studies, the clinical individuals scored higher than the control group on all subscales of AQ [20, 102]. This suggests that the results cannot be interpreted as detail-orientation irrelevant to autistic traits. In contrast, these findings should support the notion that social and detail-oriented autistic trait do not tend to co-occur in the general population as revealed by prior cluster analysis [99]. Our results demonstrated that social autistic traits caused PSU, which is consistent with previous study [4]. Therefore, intervention program of PSU for individuals with high autistic traits should focus on their deficits and difficulties in social interaction.

Theoretical implications

This study advances the theoretical understanding of PSU by the Interaction of Person-Affect-Cognition-Execution (I-PACE) model in an adolescent sample. It builds on prior research by fractionating autistic traits into social and non-social domains, showing that social autistic traits are more strongly associated with PSU through the mediating role of anxiety and executive dysfunction. These findings support and expand the I-PACE model by demonstrating the interplay between personality traits (autistic traits), affect (anxiety), and cognition (executive dysfunction) in shaping PSU. This fractionation approach suggests that social difficulties rather than detail-oriented behaviors are the primary drivers of PSU in individuals with high autistic traits, offering a more refined theoretical understanding of the link between autistic traits and behavioral addictions. By highlighting the mediating mechanisms of anxiety and executive dysfunction, this study underscores the importance of considering affective and cognitive factors when studying technology addiction in specific populations.

Practical implications

Findings provide several practicable insights for reducing PSU among adolescents with high levels of social autistic traits. First, interventions aimed at mitigating PSU should prioritize addressing the social challenges faced by these individuals, as their preference to use smartphones may stem from difficulties in face-to-face social interactions. Targeted programs could focus on social skills, social anxiety, and alternative coping mechanisms for managing negative emotions. Additionally, improving executive functioning through cognitive training or mindfulness practices may be beneficial in reducing the reliance on smartphones, a maladaptive coping strategy. This research also informs educators and mental health professionals to provide tailored intervention programs that cater to specific needs of adolescents with high social autistic traits, ultimately promoting healthy digital habits in this vulnerable population.

Limitations of the study and further research

A few limitations of the current study should be acknowledged. Firstly, the sample in this study is Chinese adolescents.Future research could consider how cultural factors influence the expression of autistic traits and the development of PSU, as well as the potential impact of cultural backgrounds on anxiety and executive functioning.

Secondly, this is a cross-sectional study and thus cannot uncover causal relation. To address this limitation, future research should adopt longitudinal studies to track changes over time and establish causal relationships between autistic traits, anxiety, executive dysfunction, and PSU. Longitudinal designs could allow researchers to observe how these variables influence each other over time and provide stronger evidence for the direction of these relationships. Finally, this study did not explore which core aspects of executive function are related to PSU. This study utilized only self-report questionnaire to measure executive function and attention to detail subscale to represent non-social autistic trait which makes results limited. Future research should examine which specific core aspects of executive function—such as working memory, inhibitory control, or cognitive flexibility—are most closely related to PSU. This could be achieved by incorporating more comprehensive and objective measures of executive functioning, such as behavioral tasks or neuropsychological assessments. Additionally, using a more detailed approach to assess non-social autistic traits, beyond attention to detail, could provide a clearer understanding of their role in PSU development.

Conclusion

Anxiety and executive dysfunction acted as sequential mediators in the connection between social autistic trait and smartphone addiction. However, non-social autistic trait did not predict anxiety, executive dysfunction, or smartphone addiction. Our results confirmed that social autistic traits are of greater concern than non-social autistic traits in PSU, provided implications for PSU interventions among individuals with high autistic traits.

Abbreviations

PSU	Problematic smartphone use
I-PACE	Person-Affect-Cognition-Execution model
ASD	Autism spectrum disorder
RRBIS	Restricted and repetitive behaviors and interests
ACT	Attentional control theory
AQ	Autism Spectrum Quotient
SAS	Smartphone Addiction Scale
DEX	Dysexecutive Questionnaire
SD	Standardized deviation
Boot SE	The standard error of 95% Bootstrap confidence interval
RMSEA	Root mean square error of approximation
SRMR	Standardized root mean square residual
CFI	Comparative fit index
TLI	Tucker-Lewis index

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Authors' contributions

ZSY conducted data collection and analysis under the supervision of YL and completed the first draft of the thesis. YL has revised the first draft and gave many valuable suggestions. CZP did most of the critical work in the revision process. All authors reviewed the manuscript.

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Data availability

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Declarations

Ethics approval and consent to participate

The design of this study followed the guidelines and regulations of the Declaration of Helsinki and has been approved by the local research Ethics Committee of Chongqing Normal University (May 30, 2023; CNU-EDU-20230530–002). All participants signed informed consent. Written informed consent to participate in this study was provided by the participants.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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