Self-regulation profiles in addictive behaviors among adolescents : a transdiagnostic approach

Self-Regulation Profiles in Addictive Behaviors among Adolescents:

A Transdiagnostic Approach

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Abstract

Dual-pathway models suggest that poor self-regulation (immature regulatory combined with strong reactive processes) is an important factor underlying addictive behaviors among adolescents. This study examined whether there are different self-regulation profiles among community adolescents, and how these profiles are related to the presence, severity and comorbidity of different addictive behaviors. A community sample of 341 adolescents (54.5% female; 13-17 years) was recruited. Participants self-reported on regulatory (inhibitory control) and reactive (reward and punishment sensitivity) processes, as well as on different addictive behaviors (binge eating, tobacco-, cannabis- and alcohol use, gaming, gambling and pathological buying). A model-based clustering analysis found evidence for three meaningful profiles: 'impulsive/under-controlled', 'anxious' and 'protective'. The 'impulsive/under-controlled' profile was characterized by the highest prevalence and severity of cannabis use and the most severe alcohol use. The 'impulsive/under-controlled' and 'protective' profiles demonstrated the highest prevalence and severity of tobacco use, whereas the 'impulsive/under-controlled' and 'anxious' profiles showed the highest binge eating scores. Adolescents who reported more than three types of addictive behaviors generally belonged to the 'impulsive/under-controlled' profile. The profiles did not differ for gaming, gambling and pathological buying. The 'impulsive/under-controlled' profile emerged as the most vulnerable profile in the context of addictive behaviors (especially for binge eating and substance use).

Keywords: adolescents; addictive behaviors; transdiagnostic; self-regulation; dual-pathway perspective.

Introduction

Addictive behaviors among adolescents

Addictive behaviors, defined as behaviors that are marked by the experience of loss of control and the continuation of these behaviors despite their negative consequences, are prevalent among adolescents (Gray & Squeglia, 2018; Schulte, Grilo, & Gearhardt, 2016). Addictive behaviors can be considered as an umbrella term for different types of behaviors. For example, adolescents can experience loss of control over their eating behavior, which is often referred to as *binge eating*. Recent prevalence rates show that binge eating is reported by one in three adolescents (He, Cai, & Fan, 2016; Van Malderen, Goossens, Verbeken, Boelens, & Kemps, 2019). Another area in which adolescents may experience loss of control is the experimentation with *substance use*. Adolescence is the peak period for the start of substance use, with tobacco and alcohol use frequently preceding the use of illicit substances (Degenhardt, Stockings, Patton, Hall, & Lynskey, 2016). The average lifetime prevalence of the use of these substances among adolescents is striking, with 46% for tobacco, 80% for alcohol and 18% for illicit substances (Kraus & Nociar, 2016). Recently, there has also been increased interest in *non-substance related addictive behaviors*. The most salient examples are gaming, gambling and pathological buying with prevalence rates up to 10% among adolescents in the general community (Jorgenson, Hsiao, & Yen, 2016).

Importantly, there is a high *comorbidity rate* between different types of addictive behaviors in adolescents. For example, a recent study found that adolescents with binge eating are 20-40% more likely to report substance abuse compared to adolescents without binge eating (Kirkpatrick et al., 2019). Indeed, researchers have emphasized the substantial *phenotypic overlap* between addictive behaviors (Escrivá-Martínez et al., 2020; Schulte et al., 2016). Specifically, it has been found that addictive behaviors share a number of characteristics (e.g., associated negative consequences, certain personality dimensions) (Escrivá-Martínez et al.,

2020). This finding highlights the importance of investigating these behaviors together (i.e., transdiagnostically) in order to discover shared underlying mechanisms, leading to interventions targeting multiple behaviors and preventing symptom shifts (García-Escalera et al., 2016). Because a central element of addictive behaviors is an inability to stop or regulate one's behavior, *self-regulation* seems to be a promising transdiagnostic candidate as a shared mechanism underlying different types of addictive behaviors (Freis et al., 2022; Romer, Hariri, & Strauman, 2021). Also neurobiologically, different addictive behaviors have shown to exhibit the same self-regulation impairments, strengthening the idea of self-regulation as a shared underlying mechanism (for example see Nigg, 2017).

A dual-pathway perspective on self-regulation

A suitable theoretical framework for operationalizing self-regulation is the *dual-pathway model* (e.g., Nigg, 2017; Strack & Deutsch, 2004). This model proposes that self-regulation is governed by two interacting systems: *regulatory processes* and *reactive processes*[1]. Regulatory processes are slow and deliberate and enable engagement in goal-directed behavior (top-down, cold system). An important regulatory process is *inhibitory control*, which can be described as the ability to inhibit a dominant impulse in order to attain higher-order goals (Barkley, 1997; Nigg, 2000). Importantly, everyday behavior is not only driven by rational regulatory processes; it is also emotionally driven because of the constant influence from external reward-related stimuli in the environment (e.g., palatable food and drinks, attractive games). These influences occur fast and effortless and can be conceptualized as reactive processes (bottom-up, hot system). Two important and related reactive processes are *reward sensitivity* (i.e., sensitivity to appealing stimuli and engagement in approach

[1] The dual-pathway model considers self-regulation *broadly* as an outcome of the interaction between regulatory and reactive processes. This theoretical view differs slightly from other, temperament-based theoretical models (e.g., Gray & Hinde, 1987; Rothbart & Posner, 2006), which define self-regulation more *narrowly* as the regulatory component of temperament (often referred to as 'effortful control') and distinguish it from the reactive component of temperament (which is similar to the definition of reactive processes in the dual-pathway model).

behavior) and *punishment sensitivity* (i.e., sensitivity to punishment and engagement in avoidance behavior) (Gray, 1970). According to the dual-pathway perspective, regulatory and reactive processes need to be in balance to ensure adequate control over everyday behavior. Conversely, impaired self-regulation can be reflected in an imbalance between immature regulatory processes coupled with strong reactive processes (e.g., Nigg, 2017; Strack & Deutsch, 2004). Importantly, adolescence is a period characterized by a developmental asynchrony between two brain systems: an easily aroused affective system (i.e., intense affective experiences which increase sensation seeking behavior) and a slower maturing cognitive system (i.e., capacities needed to control the affective experiences) (Crone, van Duijvenvoorde, & Peper, 2016; Steinberg et al., 2018). Consequently, self-regulation skills are crucial during adolescence, making this an important developmental period to investigate.

There has been increased research interest into the role of regulatory processes (i.e., inhibitory control) and reactive processes (i.e., reward and punishment sensitivity) in the context of addictive behaviors among adolescents in the general community. Specifically, for *binge eating*, several studies point to a contribution of low inhibitory control (e.g., Ames et al., 2014; Bartholdy et al., 2019; Van Malderen, Goossens, Verbeken, & Kemps, 2018), high reward sensitivity (e.g., Bodell et al., 2018; Byrne, LeMay-Russell, & Tanofsky-Kraff, 2019; Kidd & Loxton, 2021) and high punishment sensitivity (e.g., Bijttebier, Beck, Claes, & Vandereycken, 2009; Hasking, 2006; Wilson, Loxton, & O'Donovan, 2021).

Likewise, with regard to *substance use*, the influence of both types of processes has been reported. In line with evidence on binge eating, research has clearly shown that substance use in adolescents can be explained by low inhibitory control (e.g., López-Caneda, Rodríguez Holguín, Cadaveira, Corral, & Doallo, 2013; McNeill et al., 2021; Quach et al., 2020; Riggs & Pentz, 2016; Roberts et al., 2014) and high reward sensitivity (e.g., Scott-Parker & Weston, 2017; Urošević et al., 2015; van Hemel-Ruiter, de Jong, Ostafin, & Wiers, 2015). However, to

date, the contribution of punishment sensitivity seems to be less clear, and most studies have been conducted in adult samples. In particular, while some studies have found an association between low punishment sensitivity and substance use (Franken & Muris, 2006; Simons, Dvorak, & Batien, 2008; White, Young, Morris, & Lawford, 2011), others have shown a contributing role for high punishment sensitivity (Lopez-Vergara et al., 2012; Rádosi et al., 2021; Taylor, Reeves, James, & Bobadilla, 2006), and yet other studies have failed to find any significant contribution (O'Connor, Stewart, & Watt, 2009; Willem, Bijttebier, & Claes, 2010).

Recently, the role of regulatory and reactive processes has also been investigated in *non-substance related addictive behaviors* (for example see Antons, Brand, & Potenza, 2020). In particular, low inhibitory control has been linked to gaming (Nie, Zhang, Chen, & Li, 2016; Wang, Tian, Zheng, Li, & Liu, 2020) and gambling (Betancourt et al., 2012; Ioannidis, Hook, Wickham, Grant, & Chamberlain, 2019) in adolescents, whereas such evidence in the context of pathological buying is only available in adult samples (Harnish & Roster, 2019; Heffernan, Hamilton, & Neave, 2021). Likewise, high reward sensitivity has been shown to consistently account for gaming (Deng et al., 2021; Hu, Zhen, Yu, Zhang, & Zhang, 2017) and gambling (Dussault, Brendgen, Vitaro, Wanner, & Tremblay, 2011; Reardon, Wang, Neighbors, & Tackett, 2019) in adolescents, with such evidence for pathological buying again reported only in adult samples (Claes et al., 2010; Davenport, Houston, & Griffiths, 2012; Fenton-O'Creevy, Dibb, & Furnham, 2018). In line with research on substance use, the role of punishment sensitivity is less clear and has mostly been investigated in adult samples. For gaming, some studies have found a contributing role for high punishment sensitivity (Meerkerk, van den Eijnden, Franken, & Garretsen, 2010; Park et al., 2013), whereas others did so for low punishment sensitivity (Giles & Price, 2008; He et al., 2017; Yen et al., 2012), or found no significant association (Jeong et al., 2020). Similarly, both high punishment sensitivity (Atkinson, Sharp, Schmitz, & Yaroslavsky, 2012; MacKillop et al., 2014) and low punishment

sensitivity (Navas et al., 2015; Vitaro & Wanner, 2011) have been linked to gambling, with some studies failing to find significant associations (Eitle & Taylor, 2010; van Leeuwen, Creemers, Verhulst, Ormel, & Huizink, 2011). For pathological buying, some studies have reported a role for high punishment sensitivity (Mueller et al., 2011; Raemen et al., 2020), but others have not (Lawrence, Ciorciari, & Kyrios, 2014; Voth et al., 2014).

Collectively, these findings point to poor self-regulation as a common factor underlying different types of addictive behaviors (binge eating, substance use, gaming, gambling and pathological buying) among adolescents. Specifically, the contributing roles of low inhibitory control and high reward sensitivity have been well established, in line with the dual-pathway perspective. The role of punishment sensitivity, however, is less clear; both high as well as low levels have previously been found in relation to addictive behaviors, as well as no association at all. Some researchers have suggested that there may be two distinct pathways to addictive behaviors (Bijttebier et al., 2009; Kim-Spoon et al., 2017). For some individuals, addictive behaviors seem to be driven mainly by low levels of inhibitory control combined with high levels of reward sensitivity ('impulsive/under-controlled' pathway) while for others, addictive behaviors seem to be characterized predominantly by high levels of punishment sensitivity ('anxious' pathway). These findings extend the dual-pathway perspective in that there may be two different constellations of regulatory and reactive processes in the explanation of addictive behaviors. Moreover, this emphasizes the need to investigate whether different profiles of regulatory and reactive processes can account for the co-occurrence of addictive behaviors.

Importantly, although the dual-pathway perspective proposes that regulatory and reactive processes interact in explaining addictive behaviors, the majority of studies to date have exclusively examined the role of either regulatory or reactive processes. Only a handful of studies have focused on investigating the interactions between these two processes in relation to addictive behaviors (e.g., Li et al., 2020; Peeters, Oldehinkel, & Vollebergh, 2017; Van

Malderen, Goossens, Verbeken, & Kemps, 2020; Willem et al., 2010; Wills et al., 2013). Additionally, previous research has largely been focused on specific types of addictive behaviors as outcomes, and thus a transdiagnostic focus is lacking (Insel et al., 2010). To our knowledge, no study has yet examined the transdiagnostic role of poor self-regulation, conceptualized as the combination of immature regulatory and strong reactive processes, across a wide range of addictive behaviors in a single adolescent community sample.

Current study

The aim of the current study was to gain further insight into the role of poor self-regulation (conceptualized as immature regulatory processes combined with strong reactive processes) as an underlying factor in addictive behaviors among adolescents. Importantly, this study had a transdiagnostic focus by examining several types of addictive behaviors within a single community sample. Investigating these behaviors together (i.e., transdiagnostically) with the main goal to discover shared underlying mechanisms, has the advantage that it may lead to the development of transdiagnostic interventions targeting multiple behaviors and preventing symptom shifts (García-Escalera et al., 2016). Two research questions were addressed.

First, it was investigated whether there are naturally occurring profiles based on regulatory and reactive processes among adolescents in the general community. Because of the theory-driven nature of the current study, the hypotheses were based on theory as well as available empirical evidence. Specifically, guided by the theoretical dual-pathway perspective (Strack & Deutsch, 2004) and empirical evidence (Bijttebier et al., 2009; Freis et al., 2022; Romer et al., 2021), we predicted three distinct profiles based on the observed combinations of regulatory and reactive processes. In particular, we predicted two so-called 'vulnerable' profiles: an 'impulsive/under-controlled' profile (low inhibitory control, high reward sensitivity, low punishment sensitivity) and an 'anxious' profile (moderate inhibitory control,

low reward sensitivity, high punishment sensitivity), as well as a third more 'protective' profile (moderate inhibitory control, moderate reward sensitivity, moderate punishment sensitivity).

Second, it was examined whether these profiles are related to the presence, severity and comorbidity of different addictive behaviors. It was hypothesized that adolescents in either of the 'vulnerable' profiles would report a higher prevalence, severity and comorbidity of addictive behaviors compared to adolescents in the 'protective' profile (for example see Bartholdy et al., 2019; Bijttebier et al., 2009; Deng et al., 2021; Fenton-O'Creevy et al., 2018; Heffernan et al., 2021; Ioannidis et al., 2019; Kidd & Loxton, 2021; Kim-Spoon et al., 2017; Quach et al., 2020; Reardon et al., 2019; Scott-Parker & Weston, 2017; Wang et al., 2020). Furthermore, because research is largely inconclusive about the role of reactive processes (specifically for punishment sensitivity), we explored whether the two 'vulnerable' profiles ('impulsive/under-controlled' and 'anxious' profile) differed from one another in terms of the presence, severity and comorbidity of addictive behaviors (Santens et al., 2018; Turner et al., 2014).

Method

Participants and procedure

The sample consisted of 341 adolescents from the community (54.5% female; 13-17 years). Participants were recruited through secondary schools. Active informed consents, which provided information about the study, were signed by the schools, the parents and the adolescents. Data collection consisted of filling out several online self-report questionnaires at school, for which all participants received a personal code to ensure pseudonymization. Total duration for completing the questionnaires was approximately 50 minutes (which was equivalent to one class hour). During data collection, the primary researcher was available in case there were questions. The study protocol was approved by the Ethics Committee of the Faculty of XXX at XXX (masked for review).

Materials

Self-regulation. Participants reported their levels of regulatory processing (inhibitory control) and reactive processing (reward and punishment sensitivity).

Regulatory processing was assessed by the Dutch translation of the adolescent version of the 'Behavior Rating of Executive Function' (BRIEF; Gioia, Isquith, Guy, & Kenworthy, 2000). This self-report questionnaire consists of 68 items which are responded to on a 3-point scale ranging from 1 (never) to 3 (often). Higher scores indicate more problems with regulatory processing. While the BRIEF captures different regulatory processes, the current study focused specifically on *inhibitory control*, measured by the 'Inhibitory Control' subscale (12 items; e.g., 'I have trouble waiting for my turn'). The BRIEF is known to be a reliable and valid measure of inhibitory control (Gioia, Isquith, Retzlaff, & Espy, 2002; Lee, 2005). Internal consistency of the 'Inhibitory Control' subscale in the present study was good ($\alpha = .83$).

Reactive processing was assessed by means of the Dutch translation of the 'Behavioral Inhibition/Activation Scales' (BISBAS) (Carver & White, 1994), a self-report questionnaire containing 24 items (including four distractor items). In line with previous research (e.g., Matton, Goossens, Braet, & Vervaet, 2013; Van Malderen et al., 2020), reward sensitivity is captured by the 'BAS' subscale (13 items; e.g., 'If I want something, I usually do everything to get it') and punishment sensitivity is operationalized by the 'BIS' subscale (7 items; e.g., 'I am worried about making mistakes'). All items are responded on a 4-point scale ranging from 1 (not at all true) to 4 (all true). Higher scores indicate higher reward/punishment sensitivity. The psychometric properties of the BIS/BAS scale are good (Cooper, Gomez, & Aucote, 2007; Vandeweghe et al., 2016), as were the internal consistency coefficients in the present study ($\alpha = .86$ for 'BAS' and $\alpha = .79$ for 'BIS').

Addictive behaviors. Participants reported on seven types of addictive behaviors (binge eating, tobacco-, cannabis- and alcohol use, gaming, gambling and pathological buying) during the last 12 months.

First, participants were asked about the *presence* of the addictive behaviors during the past 12 months (0 = no, 1 = yes) (e.g., "Have you consumed alcohol during the past year?"; "Have you played games (PlayStation, Xbox, games on the computer) during the past year?"). Participants were also asked about the experience of *loss of control* over the addictive behaviors during the past 12-months (0 = no, 1 = yes) (e.g., "During the past year, did you experience that you were not able to stop smoking once you had started?"; "During the past year, did you experience that you were not able to stop gambling once you had started?")[2].

Second, participants reported the severity of each addictive behavior they had experienced over the past 12 months. A different questionnaire was used for each specific type of addictive behavior (see Adamson et al., 2010; Ferris & Wynne, 2001; Latner, Mond, Kelly, Haynes, & Hay, 2014; Lemmens, Valkenburg, & Peter, 2009; Müller, Trotzke, Mitchell, de Zwaan, & Brand, 2015; Prokhorov et al., 2000; Saunders, Aasland, Babor, De la Fuente, & Grant, 1993). An overview of these questionnaires and their characteristics can be found in Table 1. All questionnaires were responded by using a continuous scale, where higher scores are indicative of greater severity. All questionnaires have good psychometric properties and have been found suitable for use in adolescent samples (Estévez et al., 2021; Hanss et al., 2015; Lemmens et al., 2009; López-Pelayo, Batalla, Balcells, Colom, & Gual, 2015; Prokhorov et al., 2000; Santis, Garmendia, Acuña, Alvarado, & Arteaga, 2009; Vannucci & Ohannessian, 2018). Moreover, internal consistency coefficients of the separate questionnaires were excellent (ranged from $\alpha = .92$ to $\alpha = .99$).

[2] Importantly, for binge eating and pathological buying, only the experience of loss of control was questioned because this experience is inherently present in this behavior.

Lastly, a *comorbidity score* (with three distinct categories) was calculated based on the number of different types of addictive behaviors a participant reported: none or one type of addictive behavior (category 1), two or three types of addictive behaviors (category 2), and more than three types of addictive behaviors (category 3). The criterion for having reported an addictive behavior was the *presence* of this behavior (for tobacco use, cannabis use, alcohol use, gaming and gambling) or the experience of *loss of control* over this behavior (for binge eating and pathological buying).

Statistical analysis

To determine profiles (i.e., clusters) of adolescents based on their levels of self-regulation (regulatory and reactive processes), model-based clustering (MBC) was used (Fraley & Raftery, 2002), conducted with the R package *mclust* (Scrucca, Fop, Murphy, & Raftery, 2016). The purpose of this type of analysis is to detect – previously unknown – homogeneous and theoretically meaningful clusters or subgroups of subjects in the data. To this end, MBC, which is very similar but a bit more flexible than Latent Profile Analysis (LPA), considers the data as coming from a mixture of (an unknown number of) multivariate normal distributions, with each mixture component corresponding to a different subject cluster (i.e., the data of each subject cluster separately is assumed to come from a different multivariate normal distribution). Note that a mixture of (multivariate) normal distributions (i.e., when taking the data of all subjects of all clusters together) is often a distribution that is completely not (multivariate) normal (for more information see McLachlan, Lee, & Rathnayake, 2019). By placing certain restrictions on the covariance matrix within each cluster and these matrices between clusters (i.e., the different model options in *mclust* e.g., VII, EII, VVI), MBC models the data in a flexible way (for more information, see Fraley & Raftery, 2002). These restrictions determine the type of clusters found in the data (e.g., from restricted to circles with an equal variance within and between clusters up to tilted ellipses with unequal variances that can vary within and

between clusters). As such, MBC is able to model data in which the variables (in the full sample/across clusters) do not follow a (multivariate) normal distribution, which exempts the researcher from normality checking.

Note that, in addition to the best model (e.g., VII, EII, VVI), the optimal number of profiles (i.e., clusters) also needs to be determined. Therefore, we fitted MBC with 14 models and from 1 up to 9 profiles to standardized data (i.e., z-scores) of three variables: regulatory processes (BRIEF 'Inhibitory Control' subscale) and reactive processes ('BAS' and 'BIS' subscale). A total of 10 participants were removed for this analysis because of missing values on at least one of these variables. The best model and the appropriate number of profiles were selected by balancing theoretical considerations (i.e., interpretability and clinically meaningfulness of the retained profiles) against statistical considerations (i.e., model fit and the Bayesian Information Criterion or BIC).

After determining the optimal model and number of profiles, the profiles of the retained solution were interpreted by comparing the standardized means of each profile. Next, the distributions of age and gender were explored across the profiles[3]. Lastly, the associations between the obtained profiles and the presence, severity and comorbidity of addictive behaviors (binge eating, tobacco-, cannabis- and alcohol use, gaming, gambling and pathological buying) were investigated in three separate analyses. First, Chi-Square Tests were conducted to examine whether the profiles differed in terms of the *presence* of each addictive behavior (except for binge eating and pathological buying, for which only the experience of loss of control was reported). Next, univariate (between) analyses of variance (ANOVA) were conducted to investigate whether the *severity* of each addictive behavior differed across the profiles. Specifically, profile memberships was entered as a fixed (between) factor and the severity score

[3] Because the relationship between the profiles and addictive behaviors in terms of age and/or gender was not investigated as a separate research question, and to guard against a decrease in power by testing a more complex model, these variables were not included as covariates in the subsequent analyses.

of a specific addictive behavior as the dependent variable. Lastly, a Chi-Square Test was conducted to examine whether the profiles differed in terms of their level of *comorbidity*. For these analyses, a Bonferroni-correction for multiple testing was used to determine significance. In the event of an overall difference, post-hoc tests (which were also Bonferroni-corrected) were used to explore differences between the individual profiles (e.g., Scheffé and z-post-hoc tests).

Results

Descriptive statistics

Participants were between 13 and 17 years old (M = 14.77, SD = .91) and 54.5% of the sample was female. Scores ranged from 12 to 36 (M = 20.24, SD = 4.55) for the BRIEF 'Inhibitory Control' subscale, from 1 to 4 (M = 2.53, SD = .52) for the 'BAS' subscale, and from 1.14 to 4.14 (M = 2.69, SD = .68) for the 'BIS' subscale.

Table 2 presents the descriptive statistics for the seven addictive behaviors (binge eating, tobacco-, cannabis and alcohol use, gaming, gambling and pathological buying). The presence of each of the addictive behaviors varied widely, ranging from 5.3% for gambling to 62.6% for gaming. Loss of control also showed a large degree of variability, ranging from .09% for cannabis use to 41.1% for gaming. The comorbidity score, which can only take on one of three values, is also displayed in Table 2. Overall, almost half of the participants (46.7%) reported no or one type of addictive behavior, a nearly equal number of participants (47%) reported two or three types of addictive behaviors, and a small proportion (6.3%) reported more than three types of addictive behaviors. Spearman correlations between all study variables are displayed in Table 3.

Model based cluster analysis

Selecting the optimal model and number of profiles. According to the BIC, the EEE model with 2 profiles fits the data the best. However, when looking at the profile centers

(variable means), this solution seems limited in variability (i.e., a large group of subjects scoring below average and a smaller group scoring above average on all variables). Therefore, in order to test the theory-driven hypotheses, we also investigated the best model with three profiles, which is also an EEE model[4]. Table 4 compares the two- and three-profile EEE solutions in terms of profile sizes and model fit. We opted for the three-profile solution for further analyses as this solution optimally balances statistical (i.e., model fit and BIC) and theoretical considerations (i.e., interpretability and clinical meaningfulness). Nevertheless, because the difference in BIC between the two- and three-profile solutions is rather substantial (> 10), which provides relatively strong evidence for the two-profile solution from a statistical point of view (Kass & Raftery, 1995), we have also provided the results with the two-profile solution in Supplementary Materials[5].

Interpretation of the profiles. The standardized variable means (centers) of the profiles for the three-profile EEE solution can be found in Table 5. Note that these centers should be interpreted as z-scores (i.e., number of standard deviations above or below the mean). Univariate ANOVA analyses revealed that all profile means differed significantly from one another for all variables. Standardized means of each profile were interpreted in comparison to the other profile(s).

When inspecting the three-profile solution (see Figure 1), profile 1 was interpreted as the 'impulsive/under-controlled' profile (N = 27). In this profile, scores on the BRIEF

[4] In fact, there were 4 other models that had a better fit than the EEE model with three profiles (BIC of -2787.82) but a poorer fit than EEE with two profiles (BIC of -2765.91): EEI with four profiles (BIC of -2776.74), EEV with two profiles (-2778.61), VEV with two profiles (-2782.90) and EEI with five profiles (-2782.98). As the two solutions with two profiles gave almost identical results (in terms of profile sizes and variable means) to the EEE with two profiles, we did not take these two solutions into account. Further, the four and five profile solutions had some unstable profiles containing only a small number of subjects. Therefore, we also discarded these two solutions.

[5] It is important to note that the interpretation of the two- and three-profile solution is largely similar. Specifically, both solutions have one profile which is characterized by low inhibitory control and high reward sensitivity (i.e., vulnerable profile; referring to profile 1 in both the two- and three-profile solutions), and a profile which is characterized by high inhibitory control and low reward- and punishment sensitivity (i.e., protective profile; referring to profile 2 in both the two- and three-profile solutions). Importantly, the three-profile solution further refines the two-profile solution by adding a third profile which is predominantly characterized by high levels of punishment sensitivity.

'Inhibitory Control' subscale and the 'BAS' subscale were significantly higher compared to profiles 2 and 3, suggesting that adolescents from profile 1 had more problems with inhibitory control and higher reward sensitivity compared to those from profiles 2 and 3. Moreover, scores on the BRIEF 'Inhibitory Control' subscale and the 'BAS' subscale can be considered very high (> 1.5 standard deviations above the mean) and above average (> .5 standard deviations above the mean), respectively. In this profile, the score on the 'BIS' subscale can be considered moderate (i.e., around the mean); this score was significantly higher compared to that of profile 2, but significantly lower than that of profile 3.

Profile 2 was labelled as the 'protective' profile (N = 201). This profile had the lowest scores on the BRIEF 'Inhibitory Control' subscale as well as on the 'BAS' and 'BIS' subscales. This means that adolescents in this profile are characterized by fewer problems with inhibitory control and lower reward and punishment sensitivity compared to those in profiles 1 and 3. Moreover, this profile has moderate scores on the BRIEF 'Inhibitory Control' and the 'BAS' subscales (i.e., around the mean), and a below average score on the 'BIS' subscale (> .5 standard deviations below the mean).

Profile 3 was interpreted as the 'anxious' profile (N = 103). In this profile, scores on the BRIEF 'Inhibitory Control' subscale and the 'BAS' subscale can be considered moderate (i.e., around the mean); these were significantly higher compared to those of profile 2 but significantly lower than those of profile 1. The score on the 'BIS' subscale was significantly higher compared to that of profiles 1 and 2, resulting in profile 3 having higher punishment sensitivity compared to profiles 1 and 2 (this score can be considered high as the score is > 1 standard deviation above the mean).

Distribution of age and gender. There were no significant age differences between the profiles ($F(2,328) = .89$, $p = .413$). However, there were significant differences between the profiles with respect to gender ($\chi^2(2) = 23.89$, $p \leq .001$). The 'impulsive/under-controlled' and

'protective' profiles were relatively gender-balanced (48% girls – 52% boys and 47% girls – 53% boys, respectively), whereas the 'anxious' profile consisted of mostly girls (76%).

Associations between profiles and addictive behaviors

Presence of addictive behaviors (see Table 6). Chi-Square tests revealed significant differences between the profiles for tobacco use ($\chi^2(2) = 14.53$, $p \leq .001$) and cannabis use ($\chi^2(2) = 9.95$, $p = .007$). Specifically, as can be seen in Figure 2, the tobacco use was more prevalent in the 'impulsive/under-controlled' profile (19%) and the 'protective' profile (9%) compared to the 'anxious' profile (0%). Cannabis use was most prevalent in the 'impulsive/under-controlled' profile (22%) as compared to the 'protective' (8%) and 'anxious' profiles (4%). After Bonferroni-correction, there was no significant association between profile membership and alcohol use ($\chi^2(2) = 4.99$, $p = .082$), gaming ($\chi^2(2) = 7.40$, $p = .025$) or gambling ($\chi^2(2) = 6.47$, $p = .039$).

Severity of addictive behaviors (see Table 7). Univariate (between) analyses of variance (ANOVAs) indicated that there were significant differences in severity scores between the profiles for binge eating ($F(2,328) = 10.74$, $p \leq .001$), tobacco use ($F(2,328) = 5.68$, $p = .004$), cannabis use ($F(2,328) = 6.09$, $p = .003$) and alcohol use ($F(2,326) = 5.56$, $p = .004$). As shown in Figure 3, for binge eating, scores were the lowest (i.e., least severe) in the 'protective' profile as compared to the 'impulsive/under-controlled' and 'anxious' profiles, which were not significantly different from one another. Tobacco use was least severe (i.e., lowest scores) in the 'anxious' profile as compared to the 'impulsive/under-controlled' and 'protective' profiles, which did not significantly differ from one another. Lastly, the 'impulsive/under-controlled' profile showed the highest scores (i.e., most severe) for cannabis and alcohol use as compared to the 'protective' and 'anxious' profiles, which were not significantly different from one another. After Bonferroni-correction, there was no significant difference in severity scores

between the profiles for gaming ($F(2,323) = 2.24$, $p = .109$), gambling ($F(2,318) = 4.71$, $p = .010$) and pathological buying ($F(2,316) = 2.45$, $p = .088$).

Comorbidity of addictive behaviors (see Table 8). There was a significant association between the level of comorbidity of addictive behaviors and profile membership ($\chi^2(4) = 11.52$, $p = .021$). As shown in Figure 4, post-hoc tests revealed no significant differences between the profiles for adolescents who reported no or only one type of addictive behavior, nor for adolescents who reported two or three types of addictive behaviors. However, the 'impulsive/under-controlled' profile contained more adolescents who reported three or more types of addictive behaviors (19% of the sample) than the 'protective' (6% of the sample) and 'anxious' profiles (3% of the sample).

Discussion

The present study aimed to examine the contribution of *poor self-regulation* (conceptualized as immature regulatory combined with strong reactive processes) to addictive behaviors among adolescents.–This study took a *transdiagnostic focus* (i.e., investigating a broad range of addictive behaviors within a single sample) rather than a traditional *problem-specific focus* (i.e., investigating a specific type of addictive behavior). Overall, there were three meaningful self-regulation profiles based on the contribution of regulatory and reactive processes. Moreover, these profiles were related to the presence, severity and comorbidity of different addictive behaviors.

Self-regulation profiles

The first aim was to investigate whether there are naturally occurring *profiles* in adolescents from the general community based on their levels of regulatory and reactive processing. In line with theoretical and empirical predictions (Bijttebier et al., 2009; Freis et al., 2022; Romer et al., 2021; Strack & Deutsch, 2004), there were three distinct profiles: (1) an *'impulsive/under-controlled'* profile characterized by low inhibitory control, high reward

sensitivity and moderate punishment sensitivity, (2) an *'anxious'* profile characterized by moderate inhibitory control and reward sensitivity but high punishment sensitivity, and (3) a *'protective'* profile characterized by moderate inhibitory control, moderate reward sensitivity and lowered punishment sensitivity.

The *'impulsive/under-controlled'* profile (8% of the sample) fits with the dual-pathway perspective in terms of vulnerability (i.e., combination of immature regulatory processes and strong reactive processes).

The *'anxious'* profile, which consisted of 31% of the sample, was primarily driven by *high levels of punishment sensitivity*. This seems to indicate that, besides a profile characterized by dual-pathway vulnerability, there is a distinct vulnerable profile which is characterized specifically by higher levels of punishment sensitivity. This is very informative as to date, the role of punishment sensitivity in the context of addictive behaviors has been ambiguous (see below for a discussion of the relationships between this profile and addictive behaviors).

Interestingly, levels of *reward and punishment sensitivity* were either *high or moderate* in the two vulnerable profiles. Specifically, the 'impulsive/under-controlled' profile was characterized by moderate (and not low) levels of punishment sensitivity, whereas the 'anxious' profile was characterized by moderate (and not low) levels of reward sensitivity. This suggests that, in the vulnerable profiles, when one reactive process is elevated (e.g., reward sensitivity) the other (e.g., punishment sensitivity) is not lowered, but rather is moderate. Consequently, the vulnerable profiles in the presents study seem to be primarily defined by the presence of one dominant reactive process and not the additional absence of the other reactive process. This also seems to suggest that both aspects of reactive processing vary in the same direction, indicating a general reactivity in both vulnerable profiles.

The results also provide evidence for a *'protective'* profile, which corresponds to 61% of the sample. This profile was characterized by moderate levels of inhibitory control and

reward sensitivity, but lowered levels of punishment sensitivity. The latter was unexpected because previous research has shown that low levels of punishment sensitivity might be a risk factor for the development of several types of psychopathology such as behavioral problems and psychopathy (Byrd, Hawes, Burke, Loeber, & Pardini, 2018; Morgan, Bowen, Moore, & Van Goozen, 2014). However, in the current study, it was particularly the combination of lowered levels of punishment sensitivity with moderate levels of inhibitory control and reward sensitivity that determined the protective character of this profile (also see Malmberg et al., 2012; Matton et al., 2013).

Interestingly, the profiles differed significantly by *gender*. Specifically, the 'impulsive/under-controlled' and 'protective' profiles were relatively gender-balanced, whereas there were more girls in the 'anxious' profile. This latter corresponds with previous evidence in both adults and adolescents, which have also demonstrated evidence for higher (likelihood of) anxiety in girls/women (for example see Matton et al., 2013; Ohannessian et al., 2017; Santens et al., 2018). With respect to impulsivity, the findings in the current study align with the leading perspective to date that gender differences are most consistently reported in children prior to the onset of puberty (i.e., below the age range of this study), and later in life gender differences are minimal or absent (Weinstein & Dannon, 2015). However, regarding the protective profile, our findings are at odds with previous evidence indicating that females are found to be more resilient compared to males (e.g., Ferreira et al., 2019; Vinayak & Judge, 2018).

There were no significant differences between the profiles with respect to *age*. Although this is in line with previous findings in adolescents (Matton et al., 2013), it is somewhat surprising from a developmental perspective. Research has shown that adolescence is characterized by a developmental imbalance between a rapidly peaking *affective system* (i.e., intense emotional experiences) and a slower developing *cognitive system* (i.e., cognitive

capacities necessary to control these intense emotional experiences) (Crone, van Duijvenvoorde, & Peper, 2016; Peeters et al., 2017; Steinberg, 2010). This imbalance is often invoked to explain the increase of psychopathology during this developmental period (Peeters et al., 2017; Wiers et al., 2007). The discrepancy is gradually restored from early to late adolescence, and consequently it could be expected that adolescents in the 'protective' profile were older. However, the age range in the current study was possibly too small (10 – 17 years) to capture significant age differences. Another possible explanation for the fact that older adolescents were not more 'protective' may be because they are mature in terms of cognitive regulation but not emotional reactivity (Silvers et al., 2012; Theurel & Gentaz, 2018).

Self-regulation profiles and addictive behaviors

The second aim of the present study was to determine how the self-regulation profiles are related to the presence, severity and comorbidity of different addictive behaviors. First, the '*impulsive/under-controlled'* profile was characterized by the highest prevalence and severity of cannabis use and the most severe alcohol use. Moreover, adolescents who reported more than three types of addictive behaviors were most prevalent in the 'impulsive/under-controlled' profile as compared to the other two profiles. These findings clearly emphasize the vulnerable nature of the 'impulsive/under-controlled' profile, which is in line with the dual-pathway perspective (Strack & Deutsch, 2004) and empirical evidence (Quach et al., 2020; van Hemel-Ruiter et al., 2015).

Second, compared to the 'anxious' profile, the 'impulsive/under-controlled' and 'protective' profiles demonstrated the highest prevalence and severity of *tobacco use*. This indicates that tobacco use is clearly less prevalent and less severe in the 'anxious' profile. It further suggests that tobacco use is characterized less by high levels of punishment sensitivity which was typical of the 'anxious' profile. However, this finding contradicts some previous research that has shown an association between high punishment sensitivity and tobacco use in

adolescents (e.g., Rádosi et al., 2021), but is in line with other research that has shown a role for low punishment sensitivity in tobacco use among adolescents (e.g., White et al., 2011). The latter suggests that the contribution of low punishment sensitivity in tobacco use may be understood as a reduced sensitivity to the negative (physical and psychosocial) effects of smoking. This finding also fits within harm avoidance theory, which suggests that individuals high in punishment sensitivity (and thus anxiety) may be less likely to endorse substance use (Milivojevic et al., 2012).

Importantly, *binge eating* was equally prevalent in the two vulnerable profiles (i.e., 'impulsive/under-controlled' and 'anxious') and these two profiles were both related to more severe binge eating than the 'protective' profile. This is in line with empirical evidence showing a role for low inhibitory control (e.g., Bartholdy et al., 2019), high reward sensitivity (e.g., Bodell et al., 2018) and high punishment sensitivity (e.g., Wilson et al., 2021) in the context of binge eating among adolescents. This finding also accords with previous studies that have investigated the affective components in binge eating among adolescents. Specifically, these have demonstrated an underlying emotional dysregulation whereby both positive affectivity (which is more related to reward sensitivity) and negative affectivity (which is more related to punishment sensitivity) contribute to binge eating (Haedt-Matt & Keel, 2011; Van Malderen et al., 2019).

Taken together, the current study provided evidence for two different vulnerable profiles in the context of addictive behaviors among adolescents: one characterized by low inhibitory control and high reward sensitivity (i.e., 'impulsive/under-controlled' profile) and one characterized by high punishment sensitivity (i.e., 'anxious' profile). However, both profiles also differed substantially from one another in terms of their specific relationships with particular addictive behaviors. Overall, the 'impulsive/under-controlled' emerged as the most vulnerable profile. This finding corresponds with the theoretical model of Koob and Volkow

(2016) which proposes that addictive behaviors are mainly reward-driven at first (i.e., when anticipating the rewarding effects), but after a while these behaviors become more punishment-driven (i.e., trying to avoid the negative consequences of the addictive behaviors) as a result of the habituation of dopamine (reward) receptors (Koob & Volkow, 2016). In line with this theoretical framework, it could be expected that the 'impulsive/under-controlled' profile would be related to the starting phase of experimenting with addictive behaviors (in community samples), while the 'anxious' profile would be related to more clinical levels of addictive behaviors or even addictive disorders (in clinical samples). Thus, examining the same research questions in a clinical sample might result in a higher explanatory value for the 'anxious' profile.

Another valuable framework to look at the differences between the 'impulsive/under-controlled' and the 'anxious' profiles in relation to addictive behaviors, is the revised version of the Reinforcement Sensitivity Theory (Gray & McNaughton, 2000). In this revised theory, three instead of two neurobehavioral systems are distinguished: behavioral inhibition (BIS), behavioral activation (BAS) and the fight-flight-freeze system (FFFS). Heym et al. (2008) subsequently suggested dividing the construct of behavioral inhibition (BIS) into two constructs: BIS-Anxiety and FFFS-Fear. They reasoned that the construct of FFFS-Fear may be more similar to the original construct of BIS and thus avoidance, while the construct of BIS-Anxiety may be more related to the regulatory construct of inhibitory control. Consequently, it may be that the interactions between regulatory processes (inhibitory control) and reactive processes (reward and punishment sensitivity) may differ depending on which specific BIS-construct is considered. Therefore, distinguishing between those two underlying BIS-components in future research may help to shed a light on the complexity of the findings in the current study (also see Gullo & Dawe, 2008).

Finally, it appears that addictive behaviors in the context of *eating* and *substance use* were particularly related to the profiles, while this was not the case for the *non-substance related addictive behaviors* of gaming, gambling and pathological buying. A possible explanation may be that these behaviors were either less prevalent in the present sample (gambling was only present in 5.3% of the sample) or conversely highly prevalent in the present sample (62.6% for gaming and 32.9% for pathological buying). For addictive behaviors that were less prevalent (i.e., gambling), it may be that associations with the profiles will emerge in adult samples (where the prevalence may be higher) or in clinical samples (where they are more severe). On the other hand, addictive behaviors that were highly prevalent in the current sample (i.e., gaming and pathological buying), may be considered normative. For example, it is possible that the normative variant of these behaviors was assessed rather than the variant that might be associated with negative long-term consequences (the one that is expected to be related to the self-regulation profiles). Consequently, this suggests that different measures might be needed to assess these behaviors. Moreover, gaming and shopping are often seen as pleasant and popular activities by adolescents, which are associated with positive outcomes (e.g., entertainment and making friends when gaming, social interaction during shopping). Therefore, the *function* of these behaviors rather than their presence or severity may be related to the profiles. For example, one might expect that gaming and/or pathological buying in response to an impulsive urge ('impulsive/under-controlled' profile) or to alleviate negative affect ('anxious' profile) would be more pathological than doing it for entertainment or for social reasons. A final possible explanation for the lack of associations between the profiles and non-substance related behaviors may be that, despite some common underlying factors, these behaviors are very diverse and thus may also have some important unique underlying factors.

Strengths, limitations and directions for future research

The present study has several important strengths. First, it was conducted in an adolescent sample. Adolescence is known to be a challenging developmental period in which there is a high prevalence of addictive behaviors, and thus a particularly important period to investigate. Second, while previous research has often examined the role of self-regulation in one specific type of addictive behaviors (e.g., binge eating or alcohol use), the current study used a *transdiagnostic focus* by including a wide range of addictive behaviors. Moreover, the types of addictive behaviors are situated within different domains (i.e., eating, substances and non-substance related addictive behaviors). The inclusion of non-substance related addictive behaviors such as gaming, gambling and pathological buying was particularly innovative.

Some limitations and suggestions for future research should also be mentioned. First, despite the relatively large sample size overall, the sample size of the 'impulsive/under-controlled' profile was small (N = 27 or 8% of the total sample). While this subgroup exceeds the minimum sample size as recommended by recent statistical guidelines (Dalmaijer, Nord, & Astle, 2022), it is possible that the current results are driven by a small proportion of adolescents who belong to this specific profile and thus endorse addictive behavior symptomatology. Thus future research might investigate the self-regulation profiles in a *larger population* (e.g., nationwide samples), which may help to improve the generalizability of the findings. Relatedly, the results of the current study were derived from a community sample, which is particularly informative in terms of prevention and screening efforts. However, our measure of interest primarily captured addictive behavior symptomatology. Given that adolescence is a developmental period characterized by the *onset* of particular behaviors (e.g., substance use), it is not surprising that the rates of symptomatology of these behaviors are quite low. Consequently, in the context of intervention efforts, addressing the same research questions in

a *clinical sample* using the actual diagnostic criteria for these behaviors would be very informative.

Next, although the focus of the present study was transdiagnostic, the severity of each type of addictive behavior was necessarily assessed using a different questionnaire. Consequently, each addictive behavior was considered separately in the analyses, and nuances emerged across the different types of behaviors. The development of a novel questionnaire that captures these types of addictive behaviors together could provide a *composite score*, and thus further extend the transdiagnostic focus in this field of research. Relatedly, there was no previous research available to guide us on the operationalization of the comorbidity score in the current study, and therefore this approach has no proven validity or reliability. Thus, it will be important for future research to include valid and reliable operationalizations of the variables once they are available.

Also, the current study relied on self-report questionnaires to assess the variables of interest. It is possible that adolescents may not be sufficiently able to accurately rate themselves on the presence, severity and loss of control over addictive behaviors, as well as on their levels of inhibitory control, reward sensitivity and punishment sensitivity. Therefore, a challenge for future research will be to include multiple assessment methods (i.e., multi-method) and informants (i.e., multi-informant) to capture the relevant variables.

Lastly, it is important to mention that the current study was based on the original Reinforcement Sensitivity Theory (Gray 1970), which distinguished two neurobehavioral systems underlying human personality: behavioral inhibition (BIS) and behavioral activation (BAS). However, the most recent version of this theory postulates three such systems: BIS, BAS and the fight-flight-freeze system (FFFS) (Gray & McNaughton, 2000). Consequently, there are also more recent measures designed to operationalize these systems, for example the 'Reinforcement Sensitivity Theory of Personality Questionnaire' (RST-PQ) (Corr & Cooper,

2016), instead of questionnaires which operationalize the original theory, such as the BISBAS questionnaire (Carver & White, 1994) which was used in the current study. Thus future research could usefully investigate the research questions of the current study using the most recent version of the Reinforcement Sensitivity Theory and its corresponding measurements.

Theoretical and clinical implications

The present study has some preliminary but meaningful implications. Theoretically, the findings show that *poor self-regulation* appears to play an important role in understanding the presence, severity and comorbidity of addictive behaviors among adolescents. Furthermore, the findings further strengthen the dual-pathway perspective on self-regulation but also extend it by showing that there appear to be *three distinct self-regulation profiles* among adolescents in the general community based on their levels of regulatory and reactive processing. Together, these results may further refine explanatory models in the domain of addictive behaviors (for example see Wiers et al., 2007).

From a clinical perspective, there seem to be *two separate but vulnerable profiles* in the context of addictive behaviors among adolescents, one that is characterized by low inhibitory control and high reward sensitivity and another which is predominantly driven by high levels of punishment sensitivity. The results underscore the importance of the 'impulsive/under-controlled' profile in particular in the context of binge eating and substance use. This knowledge may be important for prevention and screening efforts in these addictive domains. For example, it could be valuable to screen adolescents for low levels of inhibitory control and high levels of reward sensitivity because they may be particularly at risk of engaging in binge eating and different forms of substance use. Consequently, intervention efforts could focus on increasing inhibitory control (e.g., by means of a modified go/no-go task which is designed to increase the ability to inhibit dominant responses in daily live such as resisting a substance because of the long term goal to pursue a healthy lifestyle) and/or decreasing the impact of

reward sensitivity (e.g., by means of a modified dot probe task to train adolescents to shift their attention away from tempting substances). Importantly, the 'protective' profile is also clinically meaningful, as evidence shows that specific protective factors may provide transdiagnostic protection against adversity on the development of psychopathology (Masten et al., 2021). Specifically in this study, adolescents with moderate levels of inhibitory control combined with moderate levels of reward sensitivity can be considered to be protected against the development of addictive behaviors.

Conclusion

The present study investigated whether there are naturally occurring self-regulation profiles among adolescents in the general community, based on their levels of regulatory and reactive processing. A further aim was to examine the relationship between these profiles and the presence, severity and comorbidity of a wide range of addictive behaviors among adolescents (binge eating, tobacco, cannabis and alcohol use, gaming, gambling and pathological buying). There were three meaningful self-regulation profiles: an 'impulsive/under-controlled' profile, an 'anxious' profile and a 'protective' profile. Overall, the three profiles were related to the presence and severity of different addictive behaviors. The 'impulsive/under-controlled' profile emerged as the most vulnerable in the context of addictive behaviors (especially in the context of binge eating and substance use).

Data accessibility statement

The study materials, data and analysis scripts used for this article will be accessible after publication upon request.

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Contributors

All authors contributed to the design, protocol and writing up of the study. EVM was responsible for data collection, under the supervision of LG. EVM and TW conducted the statistical analyses and EVM wrote the first draft of the manuscript. TW focused specifically on writing up the analytical techniques. All other authors edited subsequent drafts of the manuscript, and have approved the final manuscript.

Conflicts of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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