Reward sensitivity, attentional bias, and executive control in early adolescent alcohol use

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Reward sensitivity, attentional bias, and executive control in early adolescent alcohol use

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HIGHLIGHTS

- Higher reward sensitivity was related to heavier adolescent alcohol use.
- Alcohol attentional bias was positively related to adolescent alcohol use.
- Executive control was negatively related to young adolescent alcohol use.
- Attentional bias predicted alcohol use only in weak executive control adolescents.

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ABSTRACT

This study examined whether attentional bias for alcohol stimuli was associated with alcohol use in young adolescents, and whether the frequently demonstrated relationship between reward sensitivity and adolescent alcohol use would be partly mediated by attentional bias for alcohol cues. In addition, this study investigated the potential moderating role of executive control (EC), and tested whether the relationship between alcohol-related attentional bias and alcohol use was especially present in young adolescents with weak EC. Participants were 86 adolescents (mean age = 14.86), who completed a Visual Probe Task (VPT) as an index of attentional bias, a flanker-task based Attention Network Task (ANT) as an index of EC, the sensitivity of punishment and sensitivity of reward questionnaire (SPSRQ) as an index of reward sensitivity, and an alcohol use questionnaire. High reward sensitivity, high alcohol-related attentional bias, and weak EC were all related to alcohol use. The relationship between reward sensitivity and alcohol use was not mediated by alcohol-related attentional bias. As hypothesized, attentional bias was only associated with alcohol use in participants with weak EC. Together, the present findings are consistent with the view that high reward sensitivity and low EC may be considered as risk factors for adolescent alcohol use. The independent contribution of reward sensitivity and attentional bias might suggest that adolescents who are highly reward sensitive and display an attentional bias for alcohol cues are at even higher risk for excessive alcohol use and developing alcohol abuse problems. Future research using a longitudinal approach would allow an examination of these risk factors on subsequent alcohol use. Treatment implications are discussed, including the importance of strengthening EC and reducing the rewarding value of alcohol use.

1. Introduction

There is considerable evidence supporting the view that alcohol-related stimuli capture the attention of people who use or abuse alcohol (see for review, Field & Cox, 2008). Using the Visual Probe Task (VPT), previous studies have demonstrated an alcohol-related attentional bias in heavy users of alcohol when picture pairs were presented for a longer period of time, such as 500–2000 ms (e.g., Field, Mogg, Zetteler, & Bradley, 2004; Miller & Fillmore, 2010; Townshend & Duka, 2001). In addition, recent studies have found that controlled executive processes (e.g., Executive Control, EC) moderate the relationship between automatic appetitive processes (e.g., attentional bias) and alcohol use. These findings suggest that relatively weak executive functioning increases the influence of appetitive processes on alcohol use, and that especially people with weak EC are at risk to develop excessive alcohol use (Farris, Ostafin, & Palfai, 2010; Friese, Bargas-Avila, Hofmann, & Wiers, 2010; Houben & Wiers, 2009; Peeters et al., 2012, 2013; Thush et al., 2008). However, not much is known about the role of attentional bias and the possible moderating influence of EC in (early) adolescent alcohol use.

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It has been hypothesized that an alcohol-related attentional bias develops by the process of classical conditioning. That is, by repeated experience of the rewarding effects of drug-taking, alcohol-related cues would become associated with these rewarding effects and would consequently acquire the ability to grab the user's attention (e.g., Franken, 2003; Robinson & Berridge, 1993, 2001). Following this perspective, adolescents with high reward sensitivity could be especially at risk for developing attentional bias for alcohol cues. Germane to this, it has been argued that people's responding to appetitive cues in the environment depends on their trait reward sensitivity (Gray, 1970, 1982). People high on reward sensitivity are sensitive to stimuli that signal unconditioned reward and the relief from punishment. In the development of early adolescent alcohol use this would imply that the initial responses to alcohol-related cues would vary as a function of adolescents' reward sensitivity, whereas the repeated experience of the effects of alcohol use would subsequently shape the development of alcohol-related attentional bias. In line with this view, previous research has found a consistent link between adolescent substance use and high reward sensitivity (Knyazev, 2004; Lopez-Vergara et al., 2012; O'Connor & Colder, 2005; Pardo, Aguilar, Molinuevo, & Torrubia, 2007; van Hemel-Ruiter, de Jong, Oldehinkel, & Ostafin, 2013). Moreover, reward sensitivity has been found to be a significant predictor of reactivity to alcohol cues (Glautier, Bankart, & Williams, 2000; Kambouropoulos & Staiger, 2001, 2004; Zisserson & Palfai, 2007). Of the few studies that have examined attentional bias for alcohol cues in adolescents, none have included measures of reward sensitivity. Thus it remains to be tested whether individuals with high reward sensitivity also show stronger alcohol attentional bias and whether the previous findings of a relationship between reward sensitivity and alcohol use might be (partly) mediated by attentional bias for alcohol cues. Therefore, the first aim of this study was to test further the interrelationships between reward sensitivity, attentional bias for alcohol cues, and early adolescent alcohol use.

The few studies that have examined attentional bias for alcohol cues in adolescent samples found evidence for an attentional bias in heavy drinking adolescents (16–18 years: Field, Christiansen, Cole, & Goudie, 2007), and high-risk adolescents (12–16 years: Pieters et al., 2011; 15–20 years: Zetteler, Stollery, Weinstein, & Lingford-Hughes, 2006), but not in an unselected group of adolescents (15–21 years: Willem, Vasey, Beckers, Claes, & Bijttebier, 2013). The results of the latter study showed a moderating role for self-reported attentional control in the relationship between attentional bias and alcohol use such that the relation between attentional bias and alcohol use was significant for participants with strong attentional control but not for those with weak attentional control. The direction of this finding was unexpected and is difficult to explain. Given the debate regarding whether self-report methods are adequate assessments of EC capacity (cf., Reinholdt-Dunne, Mogg, & Bradley, 2009; Wiers, Ames, Hofmann, Krank, & Stacy, 2010), the present study used a performance measure of EC to test further if EC moderates the relationship between attentional bias for alcohol cues and common adolescent alcohol use. Based on previous research investigating the moderating role of EC processes on automatic processes (Farris et al., 2010; Friese et al., 2010; Houben & Wiers, 2009; Peeters et al., 2012, 2013; Thush et al., 2008) we expected that especially adolescents with weak EC capacity would show a relationship between alcohol attentional bias and alcohol use. Thus the present study extends previous research in two important ways. First, this study examines the relationship between reward sensitivity and alcohol attentional bias and tests whether the previously reported relationship between reward sensitivity and adolescent alcohol use is mediated by attentional bias. Second, the study investigates the potential moderating role of EC on the relationship between alcohol-related attentional bias and alcohol use in (young) adolescents by using a performance measure instead of a self-report (subjective) index of EC.

In short the present study tested if i) reward sensitivity would be positively related to adolescent alcohol use, ii) this relationship would be mediated by attentional bias for alcohol pictures, and iii) EC moderates the relationship between attentional bias for alcohol pictures and alcohol use, such that the relation is demonstrated in individuals with weak (but not strong) EC.

2. Method

2.1. Participants and recruitment

Participants were recruited from two different Dutch secondary schools. A total of 88 adolescents in between 12 and 18 years of age agreed to participate and returned the signed informed consent forms. One participant was excluded because of more than 25% missing on the SPSRQ, and one because of more than 25% errors on the ANT. This resulted in a total of 86 participants (37 male and 49 female; mean age = 14.86, SD = 1.37). Descriptive statistics are presented in Table 1.

2.2. Assessments and outcome measures

2.2.1. Questionnaire measures

2.2.1.1. Self-reported alcohol use. Alcohol use was measured using a substance use questionnaire developed by TRAILS (Tracking Adolescents' Individual Lives Survey, see van Hemel-Ruiter et al., 2013). Alcohol use was calculated as an aggregate of the standardized scores of the eight quantity and frequency items (e.g., "At how many of the weekdays do you normally drink alcohol?"; Cronbach's alpha = 0.91). As the aggregate alcohol use variable demonstrated a non-normal distribution, a log10 transformation was conducted. The statistical significance of the results did not differ when the analyses were conducted with either the raw or the transformed variables. For ease of interpretation, we report the results based on the raw scores.

2.2.1.2. Reward sensitivity and punishment sensitivity. The Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ, Torrubia, Ávila, Moltó, & Caseras, 2001) is a self-report measure of reward sensitivity (RS; 24 items, e.g., "Do you often do things to get praised?") and punishment sensitivity (PS; 24 items, e.g., "Do you often refrain from doing something because you are afraid of it being illegal?"). Participants can respond to these questions with either yes or no. RS and PS are calculated by summing the 24 questions of which participant answered yes. The total score can thus range from 0 to 24, and a higher score reflects a higher reward sensitivity or punishment sensitivity. Cronbach's alpha for reward sensitivity = 0.77, for punishment sensitivity = 0.86.

2.2.2. Computerized measures

2.2.2.1. Attentional bias. Attentional bias was assessed with a VPT (MacLeod, Mathews, & Tata, 1986). In this task we used pictures of three different categories: alcohol, tobacco, and cannabis. For the purpose of the current study only the alcohol trials are relevant. Each category consisted of ten different picture pairs, which were composed of a substance-related picture and a neutral picture. The neutral pictures were matched on composition and brightness. Another eight pairs of neutral pictures were used as practice trials at the beginning of the

Table 1
Sample characteristics (N = 86).

Variable	Mean (SD) or percentage
Female gender	57%
Age	14.86 (1.37)
Servings of alcohol/week over previous month[a]	3.84 (5.20)
Lifetime Abstainer of alcohol	15.1%

[a] One serving of alcohol contains approximately 11 ml of pure alcohol.

task, and as buffer trials in between the switch between different categories of substances. All pictures were 95 mm high and 95 mm wide.

Each trial started with a fixation cross which was presented for 500 ms in the middle of the screen. Participants were instructed to attend to the fixation cross. Next, the cross disappeared and two pictures were presented (a substance-related and a neutral picture), each on one side of the screen, for a period of 500 or 1250 ms. After disappearance of the pictures a small arrow (probe) pointing upward or downward was presented at the location of either one of the pictures. Participants had to respond to the arrow direction by pressing the corresponding button on the keyboard as quickly and accurately as possible. The next trial started 500 or 1250 ms after each response. The probe was presented equally often on the right and on the left side, and was presented equally often upward and downward. Substance-related pictures were presented equally often on the right as on the left side, and for half of the trials the picture pairs were presented for 500 ms and half for 1250 ms.

The VPT started with 16 practice trials, in which participants received feedback about their accuracy, followed by two blocks of 120 critical trials. Each block was preceded by 2 buffer trials with substance–neutral picture pairs that were not presented during the critical trials. Within each block, each picture pair was presented four times. The alcohol, tobacco, and cannabis trials were randomly distributed and the 500 ms and 1250 ms presentation time trials were intermixed in each block. Both response time and accuracy were recorded.

2.2.2.2. Executive control. The Attention Network Task (ANT, Fan, McCandliss, Sommer, Raz, & Posner, 2002) is a task designed to measure the alerting, orienting, and executive function of spatial attention, and is a combination of the cued reaction time (Posner, 1980) and the flanker task (Eriksen & Eriksen, 1974). Each trial started with a fixation cross which was presented for 400 ms in the middle of the screen. Participants were told to attend to the fixation cross. Next, a row of five horizontal black lines (one central arrow plus four flankers) was presented above or below the fixation cross, with arrowheads pointing left or right. The target is a left or right-facing arrowhead at the center. The target was "flanked" on either side by two arrows in the same direction (congruent condition), the opposite direction (incongruent condition) or by two horizontal lines (neutral condition). Participants had to respond to the target by pressing the corresponding button on the response box as quickly and accurately as possible. Before the target appeared, a warning cue was presented to signal the upcoming target. There were four warning conditions: a center cue, which was presented at the center location (replacing the fixation cross), a double cue, which were two asterisks presented above and below the fixation cross, or a spatial cue which was an asterisk presented at the exact location of the upcoming target, or no cue at all.

The ANT started with 24 practice trials in which participants received feedback about their mean response time and accuracy, followed by three blocks of 96 critical trials each. Trials were presented in random order, with all types of warning cue and types of flankers presented evenly frequently, and as many target arrows left as right.

2.3. Procedure

Participants were tested in a quiet room at school. Two laptop computers were set up for computer-based assessments in separate corners of one room, in order to be able to test two participants at one time. The measures as discussed in this article were part of a larger assessment of five computerized tasks and four questionnaires. The measures were administered in a set order: first, the VPT, and three other computer tasks, then the ANT, and finally the paper-and-pencil questionnaires including the demographic questionnaire, substance use questionnaire, and the SPSRQ. Computer tasks were presented at a 14-inch Acer laptop computer with a 60 Hz screen (1024 × 768 resolution) using E-prime software version 2.0 (Psychology Software Tools Inc., Pittsburgh, Pennsylvania). Participants were seated 50 cm away from the screen and responses were collected on the keyboard. The entire assessment took about 75 min.

Table 2
Mean reaction times for alcohol and neutral stimuli during the VPT 500 ms and VPT 1250 ms.

	Alcohol stimuli		Neutral stimuli	
	M	(SD)	M	(SD)
VPT 500 ms	659	(99)	665	(97)
VPT 1250 ms	649	(98)	653	(103)

2.4. Data reduction and analysis

VPT trials with an incorrect response (4.5%) or with reaction times 3 SD below (probable anticipations) or above (probable distractions) the mean (1.5%) were removed. Mean reaction times for correct responses are reported in Table 2. We computed attentional bias (AB) scores by subtracting the mean reaction time on alcohol trials from the mean reaction times on corresponding neutral trials. This resulted in two attentional bias scores: for alcohol pictures that were presented 500 ms or 1250 ms. A higher AB score means a stronger attentional bias toward alcohol-related pictures compared to neutral pictures.

ANT trials with reaction times 3 SD below (probable anticipations) or above (probable distractions) the mean (2.0%), or with an incorrect response (5.4%) were removed. Mean reaction times for correct responses for congruent and incongruent trials are reported in Table 3. The EC effect was calculated by subtracting the mean RT of all congruent flanking conditions, summed across cue types, from the mean RT of incongruent flanking conditions (see Fan et al., 2002). A higher score on EC therefore reflects a weaker EC function.

Missing value analysis on the questionnaires showed that 0.7% of the items were not completed. We imputed the single items of the alcohol questionnaire and the SPSRQ by conducting mean substitution.

3. Results

3.1. Bivariate analyses

First, we performed a bivariate correlation analysis to explore the relationship between age, gender, RS and PS, alcohol attentional bias, EC and alcohol use. Table 4 shows that alcohol use was positively correlated with age, and RS, and negatively with gender and PS. It further shows that AB was unrelated to RS and PS. Thus the present findings were inconsistent with the hypothesis that a relationship between reward sensitivity and alcohol use would be mediated by alcohol attentional bias. In addition, there was no evidence for a direct relationship between alcohol use and AB or EC. To investigate the hypothesized moderating role of EC on the relationship between AB and alcohol use, we performed a regression analysis.

3.2. The relationship between adolescent alcohol use, reward sensitivity, attentional bias, and executive control

To investigate the hypothesized relationship between adolescent alcohol use and reward sensitivity (RS), alcohol attentional bias (AB500 ms and AB1250 ms) and the interaction between attentional bias and EC, we performed a hierarchical regression analysis. We also

Table 3
Mean reaction times for congruent and incongruent trials during the ANT.

	Congruent trials		Incongruent trials	
	M	(SD)	M	(SD)
ANT	533	(73)	644	(97)

Table 4
Bivariate correlations among measures SPSRQ (SR and SP), alcohol attentional bias and EC, as well as age and gender.

	1	2	3	4	5	6	7	8
1 Age	–							
2 Gender[a]	−0.07	–						
3 Alcohol use	0.48**	−0.23*	–					
4 Reward sensitivity	0.22*	−0.25*	0.40**	–				
5 Punishment sensitivity	−0.16	0.19	−0.27*	−0.15	–			
6 Alcohol attentional bias 500 ms	0.11	0.07	0.12	0.16	−0.08	–		
7 Alcohol attentional bias 1250 ms	0.06	0.08	0.20	0.01	−0.16	0.04	–	
8 Executive control	0.27*	−0.06	0.00	0.22*	0.05	−0.04	−0.03	–

[a] Male = 1, female = 2.
* $p < 0.05$ (two tailed).
** $p < 0.01$ (two tailed).

included punishment sensitivity as the correlation analysis showed a significant negative association between punishment sensitivity and alcohol use. Because gender and age correlated strongly with alcohol use, they were included in the model as covariates. This is especially relevant regarding the positive relation between age and EC, and age and alcohol use, and the expectation that alcohol use would be explained by weaker EC. Therefore, in the first step we included age and gender as control variables. In step 2 we included RS, PS, AB500 ms, AB1250 ms, and EC and in step 3 the interaction-effects of AB500 ms × EC, and AB1250 ms × EC. This model (Table 5) explained 43% (R^2 adj = 0.37, $F(9,85) = 6.45$, $p < 0.001$) of the variance in adolescent alcohol use, with age and RS being significant, and gender, EC and the interaction AB1250 ms × EC approaching significance.

We subsequently trimmed the model, leaving only the predictors that were significant or approached significance. This trimmed model (Table 6) explained 42% (R^2 adj = 0.38, $F(6,85) = 9.51$, $p < 0.001$) of the variance in adolescent alcohol use. The results of step 2 show that older age, stronger reward sensitivity, stronger AB for cues presented for 1250 ms and weaker EC were associated with higher levels of alcohol use. However, when the interaction of AB 1250 ms × EC was entered in step 3, the main effects of both AB 1250 ms and EC did not reach significance anymore. Further, the interaction effect between attentional bias and EC was not significantly related to alcohol use.

Although the corresponding interaction was not significant, we exploratory tested our a priori hypothesis that only in adolescents with weak EC, AB and alcohol use would be related. We calculated simple slopes separately for adolescents with weak and strong EC. A visual representation of the interaction effect is presented in Fig. 1. The simple slopes for attentional bias at weak EC ($\beta = 0.20$, $p = 0.03$) and strong EC ($\beta = 0.05$, $p = 0.73$) show that only for adolescents with weak EC, AB 1250 ms was significantly related to alcohol use. That is, in adolescents with weak EC, a stronger attentional bias for alcohol cues that were presented for 1250 ms was related to a higher level of alcohol use.

3.3. Post-hoc analyses: are there specific roles for gender and age?

The finding that gender correlated with RS as well as alcohol use, gives rise to the idea that gender might be a moderating factor in the relation between RS and alcohol use. We explored the possibility of a moderating influence of gender by means of a hierarchical linear regression moderator analysis. After centering all variables, we entered gender and RS in the first step and the gender × RS interaction variable in the second. A moderating effect expresses when the moderator variable is not significant in explaining variance in the dependent variable, but the interaction with the independent variable is. The final model showed that indeed gender was not significant in explaining variance

Table 5
Hierarchical regression model for variables explaining alcohol use (N = 86).

Variable	Beta	*t*	*p*-Value	R^2 change
Step 1				
(Constant)		1.94	0.06	
Gender	−0.19	−2.03*	0.05	
Age	0.47	4.93**	<0.001	0.27
Step 2				
(Constant)		1.35	0.18	
Gender	−0.13	−1.41	0.16	
Age	0.43	4.64**	<0.001	
Reward sensitivity	0.29	3.07**	<0.01	
Punishment sensitivity	−0.09	−1.01	0.32	
Attentional bias 500 ms	0.06	0.62	0.54	
Attentional bias 1250 ms	0.17	1.90	0.06	
Executive control	−0.18	−1.92	0.06	0.15
Step 3				
(Constant)		1.46	0.15	
Gender	−0.14	−1.53	0.13	
Age	0.44	4.70**	<0.001	
Reward sensitivity	0.26	2.70**	0.01	
Punishment sensitivity	−0.11	−1.14	0.26	
Attentional bias 500 ms	0.05	0.59	0.56	
Attentional bias 1250 ms	0.10	1.01	0.32	
Executive control	−0.16	−1.69	0.10	
AB500 ms*EC	−0.01	−0.09	0.93	
AB1250 ms*EC	−0.15	−1.48	0.14	0.02

Note: R^2 final model = 0.43**, Adjusted R^2 = 0.37.
IV's were centered before analysis.
* $p < 0.05$.
** $p < 0.01$.

Table 6
Trimmed hierarchical regression model for variables explaining alcohol use (N = 86).

Variable	Beta	*t*	*p*-Value	R^2 change
Step 1				
(Constant)		1.94	0.06	
Gender	−0.19	−2.03*	0.05	
Age	0.47	4.93**	<0.001	0.27
Step 2				
(Constant)		1.50	0.14	
Gender	−0.14	−1.56	0.12	
Age	0.44	4.85**	<0.001	
Reward sensitivity	0.31	3.36**	<0.01	
Attentional bias 1250 ms	0.19	2.14*	0.04	
Executive control	−0.19	−2.10*	0.04	0.14
Step 3				
(Constant)		1.63	0.11	
Gender	−0.15	−1.71	0.09	
Age	0.45	4.98**	<0/001	
Reward sensitivity	0.28	3.03**	<0.01	
Attentional bias 1250 ms	0.13	1.30	0.20	
Executive control	−0.18	−1.94	0.06	
AB1250 ms*EC	−0.14	−1.39	0.17	0.01

Note: R^2 final model = 0.42**, Adjusted R^2 = 0.38.
IV's were centered before analysis.
* $p < 0.05$.
** $p < 0.01$.

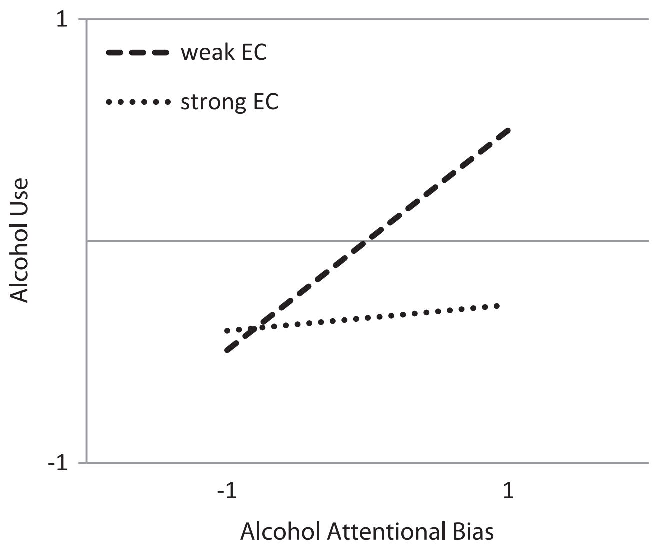

Fig. 1. Alcohol use as a function of low versus high attentional bias (respectively 1 SD below and above mean score) and low and high EC (respectively 1 SD below and above mean score). A higher attentional bias score reflects a more positive attentional bias for alcohol cues.

in alcohol use ($t = -1.32$, $p = 0.19$), but also the interaction effect was not significant ($t = 1.05$, $p = 0.30$). Only RS was a significant independent contributor to the explanation of alcohol use ($t = 3.68$, $p < 0.01$). Thus, RS was strongly related to adolescent alcohol use, and this was not different for boys and girls.

The correlation analysis further showed that age correlated positively with RS. Although age was included as a covariate in the linear regression analysis, we post-hoc built a mediation model in which we included RS as a mediator for the relation between age and alcohol use. That is, we tested whether the relation between age and alcohol use could be explained by RS. Therefore, according to Baron and Kenny (1986), we first carried out three regression analyses in which we tested whether 1) age was predictive for RS, 2) age was predictive for alcohol use, 3) RS had a significant unique effect on alcohol use, and 4) the contribution of age to the explanation of alcohol use shrinked when RS was added to the equation. The results showed that age was significantly related to alcohol use ($B = 0.275$, $p < 0.001$), and RS ($B = 0.72$, $p = 0.04$). RS contributed uniquely to the explanation of alcohol use when age was in the model ($B = 0.05$, $p < 0.01$). In the full model also age remained a significant contributor in the explanation of alcohol use ($B = 0.\ 24$, $p < 0.001$). The Sobel test (Baron & Kenny, 1986) showed that the indirect effect of age via RS was different from zero ($p < 0.01$). Therefore, the mediation analysis showed that RS partly mediated the relation between age and alcohol use.

4. Discussion

This study examined the relation between alcohol use, EC and attentional biases toward alcohol cues. The major results can be summarized as follows: (i) alcohol use was related to strong reward sensitivity, ii) among the predictor variables, reward sensitivity predicted unique variance of alcohol use, (iii) attentional bias toward alcohol cues was not related to reward sensitivity, and (iv) alcohol attentional bias and drinking were related in participants with weak EC but not in those with strong EC.

The current finding that adolescents with higher reward sensitivity reported higher levels of alcohol use is in line with previous research among adolescents (Colder et al., 2013; Jonker, Ostafin, Glashouwer, van Hemel-Ruiter, & de Jong, 2014; Knyazev, 2004; Lopez-Vergara et al., 2012; O'Connor & Colder, 2005; Pardo et al., 2007). These results suggest that in the early stages, reward sensitivity may promote adolescent alcohol use. Consistent with such view, recent research using performance measures of reward and punishment sensitivity showed that reactivity to rewarding cues was positively related to concurrent (Colder & O'Connor, 2002; van Hemel-Ruiter et al., 2013) and prospective adolescent alcohol use (van Hemel-Ruiter, de Jong, Ostafin, & Oldehinkel, submitted for publication), and that the increase in reward sensitivity over two years was a significant predictor of increase in young adolescent alcohol use over these years (Colder et al., 2013).

We expected that the relationship between alcohol use and reward sensitivity would be partly mediated by alcohol-related attentional bias. The findings did not support this hypothesis, as reward did not show a meaningful relationship with attentional bias. Thus the present findings did not substantiate the view that high reward sensitivity would set adolescents at risk for developing attentional bias for alcohol cues.

The post-hoc analysis of a possible moderating role of gender in the relationship between reward sensitivity and alcohol use showed that this relation did not differ between boys and girls. Thus, although boys showed stronger reward sensitivity than girls, this difference could not explain the higher alcohol consumption of boys, related to girls. Therefore, while research has shown that some of the risk factors related to problematic alcohol use during adolescence apply only to boys or girls (see e.g., Schulte, Ramo, & Brown, 2009; Weichold, Wiesner, & Silbereisen, 2014), this study gives no indication that the role of reward sensitivity in adolescent alcohol use is different for boys and girls.

Further, the post-hoc mediation analysis showed that the relation between age and alcohol use was partly mediated by reward sensitivity. That is, part of the relation between age and alcohol use could be explained by the increase of reward sensitivity when adolescents grow older. This finding is in line with recent research showing that reward sensitivity increased during adolescence and that increases in reward sensitivity were related to increases in substance use (Colder et al., 2013). However, due to the correlational nature of this study is it not possible to conclude about individual growth trajectories on the basis of the present findings.

Although alcohol use was related to punishment sensitivity, (a) the bivariate correlation was weaker than between alcohol use and reward sensitivity and (b) the regression analysis showed that punishment sensitivity did not continue to predict variance of alcohol use when reward sensitivity was included. These findings suggest that the negative consequences of alcohol consumption might be less critical in motivating behavior than the rewarding consequences (cf. Bijttebier, Beck, Claes, & Vandereycken, 2009).

Extending previous research on the role of attentional bias and executive control in adolescent alcohol use (Farris et al., 2010; Field et al., 2007; Friese et al., 2010; Houben & Wiers, 2009; Peeters et al., 2012, 2013; Pieters et al., 2011; Thush et al., 2008; Willem et al., 2013; Zetteler et al., 2006) the current study showed that young adolescents who demonstrated a stronger attentional bias toward alcohol cues reported a higher level of alcohol use. Although EC did not significantly moderate the relationship between attentional bias and alcohol use, the exploratory analysis showed that alcohol-related attentional bias was only related to alcohol use in adolescents with weak EC. In this regard it seems relevant to consider that in the present sample the experience with alcohol use was limited and as a group the current participants reported only a low level of substance use. Together with the notion that participants were relatively young, this might suggest that in the present sample the attentional bias might not have come to large effects yet (cf., van Hemel-Ruiter, de Jong, & Wiers, 2011). Therefore, the difference in attentional bias as well as alcohol use between weak and strong EC adolescents might have been too small for the moderation effect to reach the level of significance. The additional finding that weak EC per se was associated with higher levels of alcohol use (although this relationship was only marginally significant after entering the interaction of attentional bias and attentional control) is in line with previous studies which showed that controlled executive processes (e.g., EC) were associated with the development and maintenance of alcohol use disorders (e.g., Finn & Hall, 2004; Gunn & Finn, 2013; Nigg et al., 2006). Although further research is needed on this topic, these findings might suggest that executive functioning is a risk factor in both a direct and an indirect way. That is, adolescents with weak EC might have trouble controlling their alcohol intake as well as resisting the attentional capture of alcohol-related cues.

The finding that only in the 1250 ms condition AB was related to alcohol use in adolescents with weaker EC can be explained by the fact that with a longer stimulus presentation time there is more time for cognitive processes to influence participants' responding. Therefore, for those with stronger EC it will be easier to counter the automatic influence of alcohol cues on behavior. Further, these results are in line with previous studies which have consistently demonstrated that heavy substance users showed an attentional bias for stimuli that were presented for longer stimulus presentation times (i.e., 2000 ms), but found mixed results with shorter stimulus duration times (i.e., 200 ms or 500 ms) (Bradley, Field, Mogg, & Houwer, 2004; Bradley, Mogg, Wright, & Field, 2003; Field, Eastwood, Bradley, & Mogg, 2006; Field et al., 2004; Townshend & Duka, 2001).

Together, the present findings are consistent with the view that high reward sensitivity and low EC may be considered as risk factors for adolescent alcohol use. For those with high reward sensitivity, the positive effects of alcohol may have more impact than for those with low reward sensitivity and may therefore lower the threshold for future use. In the same vein, it seems reasonable to assume that for those who have difficulty to disengage their attention from alcohol cues, the threshold for developing craving will be lowered which in turn may promote actual alcohol consumption. The independent contribution of reward sensitivity and attentional bias might implicate that people who are highly reward sensitive and display an attentional bias for alcohol cues are at even higher risk for excessive alcohol use and developing alcohol abuse problems.

It should be acknowledged, however, that the cross-sectional design precludes inferences regarding the direction of the relationship between reward sensitivity, EC, and alcohol use. Future research using a longitudinal approach would allow an examination of the risk factors of reward sensitivity and EC on subsequent alcohol use. To the extent that reward sensitivity and EC prove to be risk factors for heavy alcohol use, interventions should focus on these variables. First, interventions could target the rewarding valence of alcohol. Related to this, recent studies have demonstrated a decrease in alcohol consumption after evaluative conditioning (Houben, Havermans, & Wiers, 2010; Houben, Schoenmakers, & Wiers, 2010) and pairing rewarding stimuli with situational cues signaling that approach is unwanted (Houben, Havermans, Nederkoorn, & Jansen, 2012). Second, interventions could focus on increasing EC. In line with this, preliminary results demonstrated that increasing working memory capacity indeed resulted in a decrease in alcohol intake (Houben, Wiers, & Jansen, 2011). Further, due to the limited sample size of this study we were not able to compare gender differences for all variables, while there are clues that the role of automatic and controlled processes in adolescent substance use may differ for boys and girls (see e.g., Pieters et al., 2011; Willem et al., 2013).

Finally, other aspects of the study limit the inferences that can be made from the results. First, because participation was voluntary, some form of selection bias might have influenced the results. Adolescents who used higher levels of substances might have refused to participate because they did not want anyone to know how much they used. In addition, participants might not be entirely honest in reporting their alcohol use, because most of them had not yet reached the legal age of sixteen[1] to use alcohol in The Netherlands (Brener, Billy, & Grady, 2003). However, self-report measures of substance use have been found to be valid and reliable as long as confidentiality and anonymity is guaranteed (Del Boca & Darkes, 2003). Further, because the present study was part of a larger study on cognitive biases in substance use, the VPT contained alcohol, tobacco, and cannabis pictures. As a consequence, the number of critical alcohol-related pictures in each presentation time (i.e., 500 ms and 1250 ms) was rather low (40), which might have had a negative impact on the sensitivity of the current task. Finally, the ANT was the last computer task in a series of five. This might have influenced the results, for example due to fatigue.

In sum, the present study showed that higher reward sensitivity and lower EC was related to early adolescent alcohol use. In addition, it demonstrated that stronger attentional bias for alcohol-related pictures was related to higher levels of alcohol use, but only in adolescents with weak attentional control. The results suggest that high reward sensitivity and weak EC might be seen as potential risk factors for adolescent alcohol use.

[1] Recently the legal age has been raised to eighteen, but at the time of the present study it was still sixteen.

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Contributors

The first, second and fourth author contributed to the design of the study. The first author took the lead in data collection and statistical analysis and wrote the first draft of the manuscript. All authors contributed to and have approved the final manuscript.

Conflict of interest

All authors declare that they have no conflicts of interest.

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