



Weaknesses in executive functioning predict the initiating of adolescents' alcohol use



Margot Peeters^{a,*}, Tim Janssen^b, Karin Monshouwer^{a,c}, Wouter Boendermaker^b, Thomas Pronk^b, Reinout Wiers^b, Wilma Vollebergh^a

^a Utrecht University, Utrecht, The Netherlands

^b University of Amsterdam, The Netherlands

^c Trimbos Institute, The Netherlands

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ABSTRACT

Recently, it has been suggested that impairments in executive functioning might be risk factors for the onset of alcohol use rather than a result of heavy alcohol use. In the present study, we examined whether two aspects of executive functioning, working memory and response inhibition, predicted the first alcoholic drink and first binge drinking episode in young adolescents using discrete survival analyses. Adolescents were selected from several Dutch secondary schools including both mainstream and special education (externalizing behavioral problems). Participants were 534 adolescents between 12 and 14 years at baseline. Executive functioning and alcohol use were assessed four times over a period of two years. Working memory uniquely predicted the onset of first drink ($p = .01$) and first binge drinking episode ($p = .04$) while response inhibition only uniquely predicted the initiating of the first drink ($p = .01$). These results suggest that the association of executive functioning and alcohol consumption found in former studies cannot simply be interpreted as an effect of alcohol consumption, as weaknesses in executive functioning, found in alcohol naïve adolescents, predict the initiating of (binge) drinking. Though, prolonged and heavy alcohol use might further weaken already existing deficiencies.

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1. Introduction

Recent studies have demonstrated associations between cognitive deficits and (heavy) drinking in adolescents (Fernie et al., 2013; Hanson et al., 2011; Khurana et al., 2012; Nigg et al., 2006; Squeglia et al., 2009; Tapert et al., 2002). Especially binge drinking seems to be associated with cognitive deficits in adolescents and young adults (Hermens et al., 2013; Peeters et al., 2014). An important question that arises from these findings is whether these deficits are present prior to and predict the onset of drinking or whether the (heavy) use of alcohol induces these deficits. Although this relationship has been investigated in several studies (Fernie et al., 2013; Hanson et al., 2011; Khurana et al., 2012; Nigg et al., 2006; Squeglia et al., 2009; Tapert et al., 2002), none of these studies have included alcohol-naïve adolescents at baseline, which clearly limits the interpretation of the associations found. In the present study we therefore examined whether the relative weaknesses in

executive functions (i.e., working memory and response inhibition) predict the initiation of the first alcoholic drink and the first binge drinking episode in young adolescents.

1.1. Cognitive development in adolescence

During adolescence several important cognitive functions mature and develop. Executive functions such as working memory, attention and response inhibition, continue to mature until late adolescence (Blakemore and Choudhury, 2006; Casey et al., 2008). These functions are important for the planning, organization and coordination of other cognitive processes (Baddeley, 1983; Miyake et al., 2000), and involve neural networks including different areas in the prefrontal cortex. In contrast to other brain regions (e.g., the visual cortex), the prefrontal cortex undergoes changes until late adolescence (Blakemore and Choudhury, 2006). Working memory, in particular, continues to mature until late adolescence (18–21 years; Luna et al., 2004). In addition, basic levels of response inhibition are already present in early childhood; young children already able to inhibit responses, however, improvement of this function continues into adolescence (Luna et al., 2004). Both working memory and response inhibition are important for cognitive control; the

* Corresponding author at: Utrecht University, Heidelberglaan 1, 3584 CS Utrecht, The Netherlands. Tel.: +31 30 2533056.

E-mail address: m.peeters1@uu.nl (M. Peeters).

ability to suppress thoughts and impulses in order to achieve long-term goals (Bunge and Wright, 2007; Luna et al., 2004; Steinberg, 2007). Cognitive control has often been related to risk behavior (Casey et al., 2008; Steinberg, 2007). It has been argued that the slower maturation of the prefrontal cortex, and the accompanying gradual development of cognitive control, might underlie the often observed increases in risky behaviors during adolescence, including binge drinking (Casey et al., 2008; Steinberg, 2007). A different line of research has suggested that the increase in risk-taking behavior is a motivational issue (Crone and Dahl, 2012). It is more rewarding, and thus more motivating, for adolescents than it is for adults to engage in risky behaviors because of factors such as peer acceptance or popularity, which might explain the increased risk-taking behavior during adolescence (Crone and Dahl, 2012). The delayed development of the prefrontal cortex and associated cognitive control skills in adolescents might therefore not represent a “deficit” or immature functioning, but rather a highly flexible and adaptive development, tuned to the social demands adolescents encounter (for a detailed description see Crone and Dahl, 2012). Nevertheless, in both lines of research, the development of cognitive control in late adolescence plays an important role in explaining risk-taking behaviors in adolescents.

1.2. Executive functioning and alcohol use

Working memory (i.e., keeping information active) and response inhibition are two important executive functions often examined in relation to alcohol use (Khurana et al., 2012; Nigg et al., 2006; Verdejo-Garcia et al., 2008; Wiers et al., 2007). Deficits in response inhibition and working memory appear to increase automatic and impulsive response in such a way that behavioral responses in relation to alcohol stimuli are more likely directed by immediate satisfaction of needs than pursuance of long-term goals (Grenard et al., 2008; Thush et al., 2008; Peeters et al., 2012, 2013; Wiers et al., 2007). In other words, deficits in executive functioning limit individuals to respond in a controlled and planned manner to alcohol stimuli, leading to more impulsive and automatic responses which have been associated with increased alcohol use (Grenard et al., 2008; Thush et al., 2008; Peeters et al., 2012).

Several longitudinal studies have examined the direct effect of relatively poor executive functioning on drinking behavior in adolescence. Nigg and colleagues (2006), for instance, found that poor inhibition skills in early adolescents (12–14 years, $N=498$) predicted later (15–17 years) problematic alcohol use. Likewise, Khurana and colleagues (2012) found that relatively poor working memory predicted growth in the frequency of alcohol use in a community sample of adolescents ($N=358$). Moreover, the authors found that the effect of working memory on alcohol use was mediated by impulsivity suggesting that poor working memory functioning might increase impulsive behavior which subsequently increases alcohol use among adolescents. In addition, Fernie and colleagues (2013) found that several measures of impulsivity (i.e., delay discounting, risk taking and response inhibition) predicted increase in alcohol use among young adolescents (12–13 years, $N=287$). The question remains, however, whether these deficits precede and predict the onset of adolescents’ drinking, since these studies have examined executive functioning after adolescents already consumed their first drink, thus leaving open the possibility that the impaired executive functioning was already the result of earlier drinking.

1.3. Current study

In the present study we examined the predictive effect of working memory and response inhibition, two executive functions under the heading of cognitive control, and frequently associated

with risk behavior, on the initiating of the first alcoholic drink in a sample of young adolescents (12–15 years, before the legal alcohol buying age of 16 – in the Netherlands at the time of the study). Although cognition involves many more aspects than executive functions, we decided to focus on these two cognitions, since particularly these functions are assumed to play a vital role in adolescent alcohol use as they continue to mature in adolescence (Verdejo-Garcia et al., 2008). Binge drinking is a common drinking pattern among young adolescents, and it has been linked to several (health) risk behaviors (Miller et al., 2007). We therefore also examined the predictive effect of executive functioning on the initiating of the first binge drinking episode (i.e., five or more glasses on a day). Both adolescents from mainstream as well as adolescents from special education (SE) were included in the study to ascertain variation in drinking behavior. Adolescents in SE schools have been found to drink more heavily (Kepper et al., 2011) compared to adolescents from mainstream education. Adolescents attend these SE schools when they have behavioral problems (e.g., conduct problems, hyperactivity, attention problems), although they may not necessarily be diagnosed with a behavioral disorder. These externalizing behavioral problems are associated with relatively weak WM functioning (Barkley, 1997; Pihl et al., 1990), and might place adolescents at risk for problematic alcohol use and later alcohol dependence.

We hypothesized that relatively weak working memory and response inhibition would predict the initiating of the first alcoholic drink and the first binge drinking episode in this sample. Discrete-time survival analyses was used to determine the initiating of the first drink and binge drink episode during the two-year follow-up of the study and to evaluate the predictive effect of executive functioning. Moreover, both functions have previously been associated with adolescent alcohol use and problem drinking (Khurana et al., 2012; Nigg et al., 2006), although their unique contribution to the initiating of drinking has not yet been examined simultaneously.

2. Materials and method

2.1. Participants

This study was part of a larger study in which we assessed self-reported and behavioral cognitions, and personality styles related to alcohol use and other risk behaviors. Participants were recruited from several mainstream and 17 SE schools in the Netherlands. Males were slightly overrepresented (69% boys versus 31% girls) because more boys than girls attend SE schools (Oswald et al., 2003). For both samples, informed consent of the child as well as passive parental consent was requested. In the mainstream sample, 37 parents declined participation of their child. For the SE sample, 15 parents and 7 students declined participation in this study. The mainstream sample included 250 adolescents (69% girls), selected from a national survey study, which was part of the International Health Behavior of School-aged Children-survey (HBSC, Zanotti et al., 2012). Adolescents who participated in the Dutch national study were contacted for additional assessments after the completion of the main survey. The SE sample included 374 adolescents (12% girls). For the purpose of this study, adolescents between 12 and 15 years were selected, resulting in a sample of 534 (371 boys, 163 girls) adolescents.

Data were collected at intervals of 6–8 months across four waves. At baseline, 525 adolescents participated in the study (98% of 534, note that some adolescents were absent during the first wave but participated in the following waves). Overall, 415 (78%) adolescents participated in wave 2, 399 (75%) adolescents participated in wave 3, and 425 (80%) adolescents participated in wave 4. Missing cases were imputed using a multiple imputation program

(i.e., multiple imputation by chained equations (MICE), which is explained below). The data over four waves were collected either via the Internet (in the case of mainstream education) or via a trained research assistant (in the case of SE education). Adolescents from SE completed the questionnaire with pen and paper followed by a computer session to assess the computer tasks. Five of the SE students completed only the computer tasks at baseline and did not complete the questionnaire. Since we used multiple imputation to handle missing cases, we included these adolescents in the study for further analysis.

2.2. Measures

2.2.1. Demographical measures

Sex, age and externalizing behavioral problems were assessed using a questionnaire. The Strength and Difficulties Questionnaire (Goodman, 1997) was used to assess externalizing behavior problems (hyperactivity and conduct problems). The scale includes 25 items, with three answering categories (i.e., not true, somewhat true or certainly true). For the purpose of this study we used the externalizing subscale of this questionnaire, which includes items such as “I am restless, overactive and cannot stay still for long” or “I often loose temper”.

2.2.2. Alcohol use

To determine the initiating of drinking and binge drinking (five or more glasses on a day), we asked participants to indicate, for weekend and weekdays separately, the number of glasses they consumed on an average single day (e.g., “When you consume alcohol on a week/weekend day how many glasses do you drink). For the purpose of the survival analysis, this continuous measure was recoded as dichotomous variable. The initiating of first alcoholic drink was defined as drinking at least one standard glass of alcohol (containing 12.5 ml of pure alcohol) on a week or weekend day. Participants received either a “one” or a “zero” on both variables, which served as an indicator of the occurrence of the event (i.e., initiating of drinking or binge drinking; “one” indicated that the event occurred).

2.2.3. Working memory

Working memory performance was assessed with the Self Ordered Pointing Task (SOPT; Petrides and Milner, 1982). Participants completed a concrete version of the SOPT. Pictures were simultaneously placed at different positions on screen, starting with a practice trial of 4 pictures followed by four trials with 6, 8, 10, and 12 pictures, respectively. The position of pictures on screen was randomly shuffled in a number of variations equal to the amount of pictures. Participants were asked to select each picture once throughout the variations, but not to select the same position twice in a row. Participants were encouraged to complete the task without any errors. Irrespective of the errors made, all participants received the feedback “well done” after each trial. With respect to the second instruction, the task was programmed not to allow selecting the same location twice in a row. For each test trial, a proportional error score was computed by dividing the number of correct responses by the number of total pictures within each trial to account for task difficulty (Cragg and Nation, 2007). The total SOPT score was calculated by taking the mean of the proportion of correct scores of the four trials. Higher scores indicated better working memory functioning.

2.2.4. Response inhibition

Response inhibition was assessed using the Stroop task (Stroop, 1935). The Stroop task, as a measure of response inhibition, has been used successfully as a moderator in previous studies (Houben and Wiers, 2009; Peeters et al., 2012). Participants were instructed

to indicate the color of the word (i.e., red, green, blue, or yellow) that appeared on the screen by pressing the corresponding key on the keyboard while ignoring the meaning of the word. Participants started with a practice block, which consisted of 40 trials with symbols (e.g., @@@@ or &&&&). The practice block was followed by a test block with 28 trials. Trials could be congruent (i.e., meaning of the word matches the color), neutral (i.e., colored symbols instead of words), or incongruent (i.e., meaning of the word differs from the color), and they were presented in random order between participants. Each trial was repeated until a correct answer was given. An error message, including a description of the keys used and their corresponding color, followed an incorrect response. A response inhibition score was calculated by subtracting the RTs on neutral trials from the RTs on incongruent trials, with higher RTs indicating more problems with control. For analytical purposes, RTs were divided by 1000.

2.3. Missing data

Because we wanted to determine whether a participant initiated drinking and/or binge drinking during study follow-up, it was necessary to have a data set that was as complete as possible. Missing data, especially when it involves a risk factor or event, is particularly problematic in survival analyses (van Buuren et al., 1999). Multiple imputation (MI) is a commonly used method to handle missing data. Previous results indicated that MI is a reliable and valid method (Sterne et al., 2009). However, to check whether this was also the case for the present sample, a simulation study was performed (performed on the high-risk sample, which had the largest number of missing data). To determine the best method to handle the missing data, several options were compared, including listwise deletion, manual fill in methods (e.g., looking at previous or subsequent wave/looking at majority/filling in zeros at each missing), and MI. We compared the five methods on two criteria that were relevant for our study: (1) percentage of onsets that would be identified by each method and (2) the predictive effect of two variables commonly associated with alcohol use, namely sensation seeking and impulsivity. The results revealed that multiple imputation was the optimal method to handle the missing data in the current study (paper submitted for publication, detailed description of the simulation study can be requested from the first author). We used the program MICE (R-package in R) to create five different imputation files, which were transported to Mplus version 7 (Muthén and Muthén, 1998–2010) for survival analyses. MICE replaces the missing information with plausible values by both minimizing the uncertainty and the bias of the model (van Buuren et al., 1999). Plausible values are imputed based on carefully chosen confounding variables that serve as predictors of the missing values. For the present study, we checked correlation matrices to determine the variables that should be used to predict missing data. Both covariates and the outcome measure were included in the imputation model, as recommended by the developers (van Buuren and Oudshoorn, 2000). For the binary variables, we chose the logistic regression method. For all other continuous covariates, we used the predictive mean matching method. Lifetime alcohol use, daily smoking, drug use (cannabis, ecstasy, cocaine, hallucinogens), gender, age, and personality (impulsivity, sensation seeking, anxiety, and hopelessness) were selected as predictors of missingness.

2.4. Analytical procedure

First, descriptives for demographical information, alcohol use and executive functioning were presented for the two samples separately (mainstream versus SE, Table 1) and for the onset and binge sample separately (Table 2). Second, the five imputed data files were prepared for discrete-time survival analysis. Since the aim

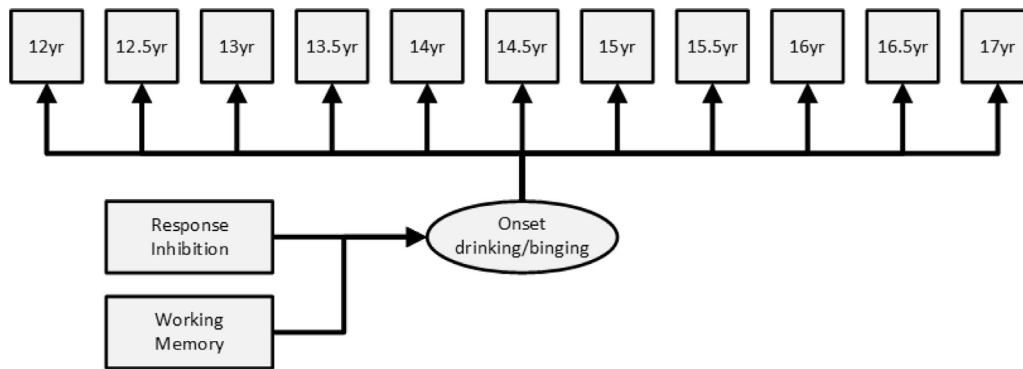


Fig. 1. Structural survival model with age indicators (12–17 years) and predictors (i.e., response inhibition and working memory) of the initiating of (binge) drinking.

Table 1
Descriptives for the two samples (mainstream versus special education) separately.

	Mainstream education	Special education	t-Test
Age	13.84 (.82)	13.70 (.73)	$t(532) = -1.93$
Sex (%boys)	39	88	
Hyperactivity problems (SDQ)	1.62 (.46)	1.93 (.48)	$t(501) = 10.94^*$
Conduct problems (SDQ)	1.26 (.23)	1.60 (.38)	$t(501) = 6.72^*$
Alcohol quantity baseline	.28 (1.52)	3.13 (7.66)	$t(503) = 4.81^*$
Working memory	.80 (.09)	.73 (.10)	$t(493) = -7.51^*$
Response inhibition	.07 (.22)	.21 (.35)	$t(492) = 4.89^*$

SDQ = Strength and Difficulties Questionnaire.

* $p < .05$.

Table 2
Descriptive statistics for the total sample, the onset sample and the binge drinking sample.

	Total (N = 534)		Onset (N = 336)		Binge (N = 458)	
	M	SD	M	SD	M	SD
Age baseline	13.75	.76	13.69	.77	13.73	.78
Alcohol use	2.19	6.45	0	0	.35	.83
Response inhibition	.16	.32	.13	.30	.14	.30
Working memory	.75	.11	.76	.10	.76	.11

Note: The total sample contains all participants from both sample origins (mainstream and special education). The onset sample contains only the part of the total sample that did not drink at baseline. The binge sample contains only the part of the total sample that did not binge at baseline.

of the study was to examine executive functioning as risk factor for initiating a first alcoholic drink, we excluded all adolescents who already consumed alcohol at baseline (for the onset sample) and all adolescents who already engaged in binge drinking (drinking five or more glasses) at baseline (for the binge sample). For each adolescent, the age of the onset and the age of the first binge drinking episode were assessed for every half a year (e.g., 12, 12.5, 13, . . . , 17), resulting in 11 possible time points at which the event could have occurred (see Fig. 1). Using Mplus for the discrete-survival analysis, a latent factor of the probability that an individual would experience the event at a certain time point (i.e., age) was estimated.

Survival analyses were conducted using Mplus version 7 (Muthén and Muthén, 1998–2010). The factor loadings assessing the probability of the event occurrence (see Fig. 1 onset/binge) were fixed at one (see Fig. 1 age indicators) to ascertain that the effect of executive functioning on the onset of alcohol use/binge drinking was the same for each age. Residual variances were fixed at zero. We tested for possible sex differences using multigroup analyses. We used the clustering option in Mplus to account for the effect of setting (home versus school assessment).

3. Results

3.1. Descriptives for separate groups (special education versus mainstream)

Table 1 represents the descriptive statistics for adolescents from mainstream and special education separately. As can be seen in Table 1, students in SE education significantly differed on sex, hyperactivity and conduct problems, executive functioning and alcohol use from mainstream students. Effect sizes for difference in working memory and response inhibition were of medium size (Cohen's d working memory = .53, response inhibition = .46).

3.2. Descriptives total group

Table 1 includes descriptive statistics of age and executive functioning at baseline for the total sample and the two analytical samples (i.e., onset and binge drinking) separately. Small differences for sum scores on the two executive functioning task emerged. We used t -tests to examine whether possible differences in executive functioning were found between the group who already engaged in drinking at baseline (excluded from the study) compared to alcohol naïve adolescents at baseline (included in the study). Significant differences on executive functioning at baseline emerged between the two groups with lower scores for working memory ($M = .72$ for drinkers and $M = .76$ for alcohol naïve adolescents) and higher scores for response inhibition (indicating relatively weaker executive functioning for the drinkers (working memory: $t = 3.26$, $p = .01$; response inhibition: $t = -2.36$, $p = .02$).

Figs. 2 and 3 represent the cumulative incidence rates of the initiating of first drink (Fig. 2) and first binge drinking episode (Fig. 3) for the total group and the non-(binge)drinking group at baseline.

3.3. Prediction of first drink and first binge drinking episode

Table 3 shows the results of the survival analysis with working memory and response inhibition as predictors of the first alcoholic drink and binge drinking episode. Multigroup analysis favored the model in which we constrained sex differences to be equal

Table 3
Odds ratio's and standardized regression coefficients for response inhibition and working memory predicting onset of drinking and binge drinking.

	Onset (N = 336)			Binge (N = 458)		
	Odds	β	p	Odds	β	p
Response inhibition	2.20	.80	.01	1.45	.37	.57
Working memory	.60	-.51	.01	.43	-.84	.04

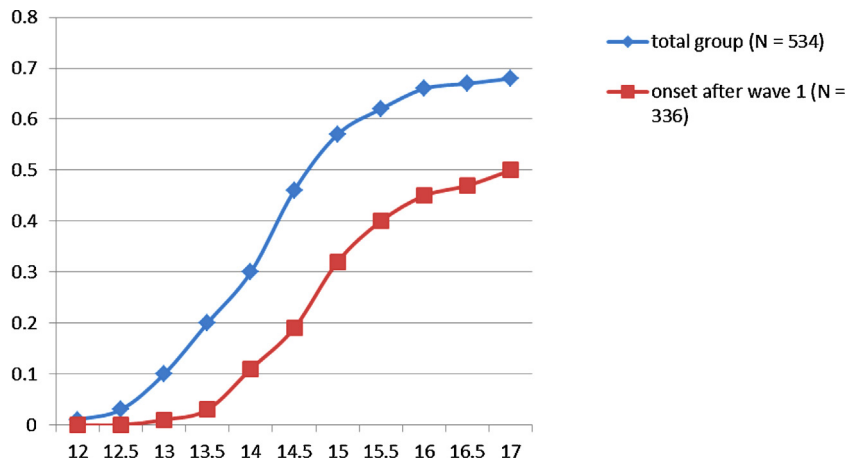


Fig. 2. Cumulative incidence rates of the age of onset for the total sample and the onset sample separately.

(BIC.constrained onset = 1338, BIC.unconstrained onset = 1347; BIC.constrained binge = 1645, BIC.unconstrained binge = 1696), suggesting no significant differences in the predictive effect of working memory and response inhibition on the initiating of (binge) drinking. Both executive functions were analyzed in a multivariate model to examine the unique influence of each function. Both working memory and response inhibition predicted the initiating of the first alcoholic drink. Weaker working memory ($\beta = -.51$, $OR = .15$, $p = .01$) and poorer response inhibition ($\beta = .80$, $OR = 3.12$, $p = .01$, higher scores indicate poorer response inhibition) increased the likelihood that adolescents would initiate drinking during study follow-up, indicating an earlier initiating of first drink and first binge drinking episode for those adolescents with relatively weaker executive functions.

Working memory, but not response inhibition predicted the initiating of a first binge drinking episode. Lower scores on working memory ($\beta = -.08$, $OR = .33$, $p = .04$) increased the likelihood that adolescents would initiate binge drinking during study follow-up.

4. Discussion

The present study was one of the first to examine the predictive effect of executive functioning on the initiating of the first alcoholic drink and binge drinking episode among young adolescents, and the first to examine adolescents who were alcohol-naïve at baseline. The results indicated that relatively weak working memory predicted both the initiating of the first alcoholic drink and the first binge drinking episode, beyond the effect of response inhibition. In

addition, relatively poor response inhibition predicted the initiating of drinking beyond the effect of working memory, however, no effect was found for the prediction of first binge drinking episode. Particularly adolescents from SE education revealed relatively poor working memory functioning and response inhibition, a finding supported by previous studies (Barkley, 1997; Pihl et al., 1990; Nigg et al., 2006). It seems likely that the a poorer level of executive functioning, observed in these adolescents, place them at risk for an early initiating of (binge) drinking which eventually might increase the risk for problematic alcohol use, later in adolescence (King and Chassin, 2007).

The findings of this study are in agreement with those of Khurana and colleagues (2012) who found that executive functioning, and more specifically working memory, predicted increase in frequency of drinking among young adolescents. Fernie and colleagues (2013) found similar results, revealing that response inhibition (and two other measures of impulsivity) predicted alcohol use six months later. Nigg and colleagues (2006) found that executive functioning predicted problem drinking behavior in high risk adolescents (adolescents from alcoholic families). In their study, poor response inhibition at age 12–14 predicted the onset of alcohol related problems at age 15–17. However, unlike Nigg et al. (2006), we did not find a predictive effect of response inhibition on binge drinking. A different sample, a different task, a different outcome variable and different analyzing techniques were used in the current study, which might explain the divergent results. It is possible that the Stroop task, used in this study to assess response inhibition, was less sensitive in detecting differences compared

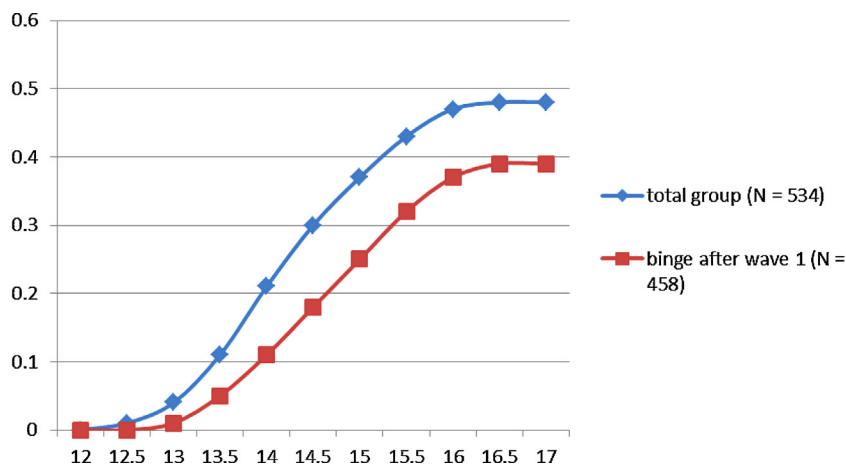


Fig. 3. Cumulative incidence rates of the onset age of binge drinking for the total sample and the onset sample separately.

to the working memory task, perhaps explaining why we did not find a unique effect of response inhibition on the initiating of the first binge drinking episode. In addition, results indicate that decision making is impaired after alcohol consumption. Good working memory functioning allows better decision making. It therefore might be possible that poorer working memory functioning impairs decision making resulting in more drinking/binge drinking (George et al., 2005).

Khurana and colleagues (2012) found that impulsivity fully mediated the effect of working memory on the drinking behavior of adolescents, suggesting that weaknesses in working memory affect behavior through disinhibition and impulsivity. Contrary to what Khurana and colleagues (2012) found, the results of the present study indicated that at least two executive functions *uniquely* contributed to the prediction of the initiating of drinking behavior. In addition, in the present study, working memory was a unique predictor of binge drinking in adolescents while disinhibition was not. The latter finding is in agreement with several studies that have found associations between binge drinking and working memory functioning (Stephens and Duka, 2008a; Crego et al., 2009; Squeglia et al., 2011). However, these cross-sectional studies (Crego et al., 2009; Squeglia et al., 2011) do not shed light on the direction of the relation. Although the results of the present study do not rule out a reverse effect of alcohol use on cognitive functioning (e.g., bidirectional effect cf. Peeters et al., 2014), the results do reveal that some weaknesses in executive functioning precede the initiating of drinking behavior. The continued use of alcohol may aggravate the pre-existing deficits (Khurana et al., 2012; Peeters et al., 2014), causing delay in development or even decline in the performance on executive functioning tasks.

4.1. Limitations

Besides the strengths of the study, such as the large sample size of young adolescents and the inclusion of a high-risk sample, some limitations should be considered. Although the exact same measures with the same instructions were used in the two different samples (mainstream and SE education), the assessment procedure was slightly different. Adolescents in the high-risk sample completed tasks under the guidance of a research assistant while adolescents in the mainstream sample completed assessment at home (i.e., online assessment). For that reason we adjusted for clustering effects due to differences in assessment setting. Furthermore, it is possible that the exclusion of drinkers at the study baseline limits the representativeness of the current sample compared to national averages. Though, adolescents who were excluded from the analysis revealed significant worse working memory functioning and poorer response inhibition, which is in line with our findings (an early initiating of alcohol use is predicted by relatively weak executive functioning). The generalizability of these results is restricted due to the specific characteristics the special education sample (e.g., externalizing behavioral problems). Unfortunately, we could not control for behavioral disorders in our analysis because information about DSM IV behavioral disorders was not collected (only general and limited information on externalizing behavior was available by means of the SDQ). Nevertheless, in the Dutch educational setting, approximately 5% of the students in secondary education attend a school for special education. Therefore, these students reflect an important part of the Dutch student population. Furthermore, multiple imputation has been criticized as method of handling missing data because it could add noise to the data (Rubin, 1996). This criticism appears to lose its value because recent sophisticated imputation methods are able to handle missing data better compared to older methods, such as list wise deletion (Rubin, 1996; Sterne et al., 2009). In addition, the simulation study in the present study supported this

critique. Moreover, in the present study binge drinking was defined as drinking five or more glasses on a day. Generally, binge drinking refers to drinking five or more glasses at one occasion (Wechsler and Nelson, 2001). However, it seems unlikely that adolescents of this age (12–16 years) regularly have the opportunity to drink in the afternoon as well as in the evening on weekend days. Moreover, binge drinkers consumed on average almost nine glasses on a binge drinking day, which can be interpreted as heavy drinking for such young adolescents. Nevertheless, it is possible that some of the adolescent binge drinkers in this study did not consume all five glasses in a row or at one occasion. A related possible limitation of the study is that alcohol use was assessed based on the participants' own indication, with no external corroboration from parents or friends. This potentially allowed participants to over report or underreport their alcohol use. Nevertheless, a study by Koning and colleagues (2010) revealed that self-report of alcohol use is a reliable method to assess alcohol consumption of adolescents. Lastly, recent studies suggest that repeated cycles of binge drinking are associated with executive dysfunction, and poor working memory performance in particular (Duka et al., 2004; Stephens and Duka, 2008b). Since we only examined the first episode of binge drinking we were not able to look at this relation. Future research could include number of binge episodes as important covariate in relation to executive functioning.

4.2. Implications and conclusion

The findings of the current study have implications for theory and for prevention. First, to the best of our knowledge this study is one of the first to demonstrate that deficits in executive functioning precede the initiating of drinking among adolescents. Previous studies have found strong indications for executive functioning being a risk factor for alcohol use among adolescents, however, the design of these studies prevented to derive strong inferences about deficits in executive functioning preceding the actual onset of drinking behavior (see Peeters et al., 2014, for an overview). Second, several clinical studies have found cognitive deficits after heavy and prolonged alcohol use (Hanson et al., 2011; Tapert et al., 2002). It is possible that some of these found deficits were already present before drinking behavior was initiated, and a magnified and biased effect of alcohol on adolescents' cognitive functioning may arise. It should be noted, however, that these studies excluded adolescents with an externalizing behavioral disorder (conduct disorder, ADHD), while the current study included adolescents with externalizing behavioral problems. In addition, deficits have been found for a wide range of cognitive functions (e.g., attention, visuospatial functioning), and alcohol might affect specific parts of the adolescent brain differently. Further research is needed to specify which cognitive functions are susceptible to heavy drinking and which functions are mainly of interest in predicting the drinking onset of adolescents.

With respect to prevention, the findings of the present study confirm the importance of early interventions. It has been demonstrated that executive functions moderate the effect of implicit cognitive motivational processes on alcohol and substance use in adolescents (Grenard et al., 2008; Peeters et al., 2012; Thush et al., 2008). As these processes get stronger with increased drinking, delay of the onset of drinking appears to be a good general strategy to prevent problematic alcohol use in adolescents (Koning et al., 2009, 2011). As some adolescents appear to be at a greater risk for an early onset of drinking, additional targeted prevention might be warranted as well (cf. Conrod et al., 2008). Recently several promising interventions have been introduced to increase response inhibition (Houben et al., 2011) and working memory (Klingberg et al., 2005; Dovis et al., 2012) in adolescents and young adults.

These training methods contribute to an increase in executive control, and they might eventually postpone the age of the onset.

The findings of this study demonstrate that pre-existing deficits in executive functioning predict the initiating of the first alcoholic drink and first binge drinking episode among young adolescents. The results suggest that relatively weak working memory and disinhibition are risk factors for the early initiating of drinking. Moreover, weak working memory functioning is a risk factor for binge drinking. A continued heavy drinking pattern might further worsen executive functioning (Squeglia et al., 2009; Tapert et al., 2002), beyond these pre-existing effects. Future research could benefit from disentangling cognitive deficits induced by alcohol use from cognitive deficits that predict alcohol use, with the current findings providing a first modest step.

Conflict of interest

The authors declare no conflict of interest.

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References

- Baddeley, A., 1983. Working memory. *Philos. Trans. R. Soc. B* 302, 311–324.
- Barkley, R.A., 1997. Behavioral inhibition, sustained attention, and executive functions: constructing a unifying theory of ADHD. *Psychol. Bull.* 121, 65–94.
- Blakemore, S.J., Choudhury, S., 2006. Development of the adolescent brain: implications for executive function and social cognition. *J. Child Psychol. Psychiatry* 47, 296–312.
- Bunge, S.A., Wright, S.B., 2007. Neurodevelopmental changes in working memory and cognitive control. *Curr. Opin. Neurobiol.* 17, 243–250.
- Casey, B., Jones, R.M., Hare, T.A., 2008. The adolescent brain. *Ann. N. Y. Acad. Sci.* 1124, 111–126.
- Conrod, P.J., Castellanos, N., Mackie, C., 2008. Personality-targeted interventions delay the growth of adolescent drinking and binge drinking. *J. Child Psychol. Psychiatry* 49, 181–190.
- Cragg, L., Nation, K., 2007. Self-ordered pointing as a test of working memory in typically developing children. *Memory* 15, 526–535.
- Crego, A., Holguín, S.R., Parada, M., Mota, N., Corral, M., Cadaveira, F., 2009. Binge drinking affects attentional and visual working memory processing in young university students. *Alcohol. Clin. Exp. Res.* 33, 1870–1879.
- Crone, E.A., Dahl, R.E., 2012. Understanding adolescence as a period of social-affective engagement and goal flexibility. *Nat. Rev. Neurosci.* 13, 636–650.
- Duka, T., Gentry, J., Malcolm, R., 2004. Consequences of multiple withdrawals from alcohol. *Alcohol. Clin. Exp. Res.* 28, 233–246.
- Dovis, S., Van der Oord, S., Wiers, R.W., Prins, P.J., 2012. Can motivation normalize working memory and task persistence in children with attention-deficit/hyperactivity disorder? The effects of money and computer-gaming. *J. Abnorm. Child Psychol.* 40, 669–681.
- Fernie, G., Peeters, M., Gullo, M.J., Christiansen, P., Cole, J.C., Sumnall, H., Field, M., 2013. Multiple behavioural impulsivity tasks predict prospective alcohol involvement in adolescents. *Addiction* 108, 1916–1923.
- George, S., Rogers, R.D., Duka, T., 2005. The acute effect of alcohol on decision making in social drinkers. *Psychopharmacology (Berl)* 182, 160–169.
- Goodman, R., 1997. The Strengths and Difficulties Questionnaire: a research note. *J. Child Psychol. Psychiatry* 38, 581–586.
- Grenard, J.L., Ames, S.L., Wiers, R.W., Thush, C., Sussman, S., Stacy, A.W., 2008. Working memory capacity moderates the predictive effects of drug-related associations on substance use. *Psychol. Addict. Behav.* 22, 426–432.
- Hanson, K.L., Medina, K.L., Padula, C.B., Tapert, S.F., Brown, S.A., 2011. Impact of adolescent alcohol and drug use on neuropsychological functioning in young adulthood: 10-year outcomes. *J. Child Adolesc. Subst. Abuse* 20, 135–154.
- Hermens, D.F., Lagopoulos, J., Tobias-Webb, J., De Regt, T., Dore, G., Juckes, L., Latt, N., Hickie, I.B., 2013. Pathways to alcohol-induced brain impairment in young people: a review. *Cortex* 49, 3–17.
- Houben, K., Wiers, R.W., Jansen, A., 2011. Getting a Grip on Drinking Behavior: training working memory to reduce alcohol abuse. *Psychol. Sci.* 22, 968–975.
- Houben, K., Wiers, R.W., 2009. Response inhibition moderates the relationship between implicit associations and drinking behavior. *Alcohol. Clin. Exp. Res.* 33, 626–633.
- Kepper, A., Monshouwer, K., Van Dorsselaer, S., Vollebergh, W., 2011. Substance use by adolescents in special education and residential youth care institutions. *Eur. Child. Adolesc. Psych.* 20, 311–319.
- Khurana, A., Romer, D., Betancourt, L.M., Brodsky, N.L., Giannetta, J.M., Hurt, H., 2012. Working memory ability predicts trajectories of early alcohol use in adolescents: the mediational role of impulsivity. *Addiction* 108, 506–515.
- King, K.M., Chassin, L., 2007. A prospective study of the effects of age of initiation of alcohol and drug use on young adult substance dependence. *J. Stud. Alcohol Drugs* 68 (2), 256–265.
- Klingberg, T., Fernell, E., Olesen, P.J., Johnson, M., Gustafsson, P., Dahlström, K., Gillberg, C.G., Forssberg, H., Westerberg, H., 2005. Computerized training of working memory in children with ADHD – a randomized, controlled trial. *J. Am. Acad. Child Psychiatry* 44, 177–186.
- Koning, I.M., Harakeh, Z., Engels, R.C.M.E., Vollebergh, W.A.M., 2010. A comparison of self-reported alcohol use measures by early adolescents: questionnaires versus diary. *J. Subst. Use* 15 (3), 166–173.
- Koning, I.M., Van den Eijnden, R.J., Verdurmen, J.E., Engels, R.C., Vollebergh, W.A., 2011. Long-term effects of a parent and student intervention on alcohol use in adolescents: a cluster randomized controlled trial. *Am. J. Prev. Med.* 40, 541–547.
- Koning, I.M., Vollebergh, W.A.M., Smit, F., Verdurmen, J.E., Van Den Eijnden, R.J.J.M., Ter Bogt, T.F.M., Stattin, H., Engels, R.C.M.E., 2009. Preventing heavy alcohol use in adolescents (PAS): cluster randomized trial of a parent and student intervention offered separately and simultaneously. *Addiction* 104, 1669–1678.
- Luna, B., Garver, K.E., Urban, T.A., Lazar, N.A., Sweeney, J.A., 2004. Maturation of cognitive processes from late childhood to adulthood. *Child Dev.* 75, 1357–1372.
- Miller, J.W., Naimi, T.S., Brewer, R.D., Jones, S.E., 2007. Binge drinking and associated health risk behaviors among high school students. *Pediatrics* 119, 76–85.
- Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., Howerter, A., Wager, T.D., 2000. The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: a latent variable analysis. *Cogn. Psychol.* 41, 49–100.
- Muthén, L.K., Muthén, B.O., 1998–2010. *Mplus User's Guide*, sixth ed. Muthén & Muthén, Los Angeles, CA.
- Nigg, J.T., Wong, M.M., Martel, M.M., Jester, J.M., Puttler, L.I., Glass, J.M., Adams, K.M., Fitzgerald, H.E., Zucker, R.A., 2006. Poor response inhibition as a predictor of problem drinking and illicit drug use in adolescents at risk for alcoholism and other substance use disorders. *J. Am. Acad. Child Adolesc. Psychiatry* 45, 468–475.
- Oswald, D.P., Best, A.M., Coutinho, M.J., Nagle, H.A.L., 2003. Trends in the special education identification rates of boys and girls: a call for research and change. *Exceptionality* 11, 223–237.
- Pihl, R.O., Peterson, J., Finn, P.R., 1990. Inherited predisposition to alcoholism: characteristics of sons of male alcoholics. *J. Abnorm. Psychol.* 99, 291–301.
- Peeters, M., Wiers, R., Monshouwer, K., van de Schoot, R.A.J.G., Janssen, T., Vollebergh, W., 2012. Automatic processes in at-risk adolescents: the role of alcohol-approach tendencies and response inhibition in drinking behavior. *Addiction* 107, 1339–1346.
- Peeters, M., Monshouwer, K., Schoot, R.A., Janssen, T., Vollebergh, W.A.M., Wiers, R.W., 2013. Automatic processes and the drinking behavior in early adolescence: a prospective study. *Alcohol. Clin. Exp. Res.* 37, 1737–1744.
- Peeters, M., Vollebergh, W.A.M., Wiers, R.W., Field, M., 2014. Psychological changes and cognitive impairments in adolescent heavy drinkers. *Alcohol Alcohol.* 49, 182–186.
- Petrides, M., Milner, B., 1982. Deficits on subject-ordered tasks after frontal- and temporal-lobe lesions in man. *Neuropsychologia* 20, 249–262.
- Rubin, D.B., 1996. Multiple imputation after 18 years. *J. Am. Stat. Assoc.* 91, 473–489.
- Stephens, D.N., Duka, T., 2008a. Cognitive and emotional consequences of binge drinking: role of amygdala and prefrontal cortex. *Philos. Trans. R. Soc.* 363, 3169–3179.
- Squeglia, L.M., Spadoni, A.D., Infante, M.A., Myers, M.G., Tapert, S.F., 2009. Initiating moderate to heavy alcohol use predicts changes in neuropsychological functioning for adolescent girls and boys. *Psychol. Addict. Behav.* 23, 715–722.
- Squeglia, L.M., Schweinsburg, A.D., Pulido, C., Tapert, S.F., 2011. Adolescent binge drinking linked to abnormal spatial working memory brain activation: differential gender effects. *Alcohol. Clin. Exp. Res.* 35, 1831–1841.
- Steinberg, L., 2007. Risk taking in adolescence new perspectives from brain and behavioral science. *Curr. Direct Psychol. Sci.* 16, 55–59.
- Stephens, D.N., Duka, T., 2008b. Cognitive and emotional consequences of binge drinking: role of amygdala and prefrontal cortex. *Philos. Trans. R. Soc. B* 363, 3169–3179.
- Sterne, J.A., White, I.R., Carlin, J.B., Spratt, M., Royston, P., Kenward, M.G., Wood, A.M., Carpenter, J.R., 2009. Multiple imputation for missing data in epidemiological and clinical research: potential and pitfalls. *Br. Med. J.* 338, b2393.
- Stroop, J.R., 1935. Studies of interference in verbal reactions. *J. Exp. Psychol.* 18, 643–662.
- Tapert, S.F., Granholm, E., Leedy, N.G., Brown, S.A., 2002. Substance use and withdrawal: neuropsychological functioning over 8 years in youth. *J. Int. Neuropsychol. Soc.* 8, 873–883.
- Thush, C., Wiers, R.W., Ames, S.L., Grenard, J.L., Sussman, S., Stacy, A.W., 2008. Interactions between implicit and explicit cognition and working memory capacity in the prediction of alcohol use in at-risk adolescents. *Drug Alcohol Depend.* 94, 116–124.
- van Buuren, S., Boshuizen, H.C., Knook, D.L., 1999. Multiple imputation of missing blood pressure covariates in survival analysis. *Stat. Med.* 18, 681–694.

- van Buuren, S., Oudshoorn, C., 2000. [Multivariate Imputation by Chained Equations. MICE V1.0 User's Manual](#). TNO Preventie en Gezondheid, Leiden.
- Verdejo-García, A., Lawrence, A.J., Clark, L., 2008. Impulsivity as a vulnerability marker for substance-use disorders: review of findings from high-risk research, problem gamblers and genetic association studies. *Neurosci. Biobehav. Rev.* 32, 777–810.
- Wechsler, H., Nelson, T.F., 2001. Binge drinking and the American college students: What's five drinks? *Psychol. Addict. Beh.* 15, 287–291.
- Wiers, R.W., Bartholow, B.D., van den Wildenberg, E., Thush, C., Engels, R.C., Sher, K.J., Grenard, J., Ames, S.L., Stacy, A.W., 2007. Automatic and controlled processes and the development of addictive behaviors in adolescents: a review and a model. *Pharmacol. Biochem. Behav.* 86, 263–283.
- Zanotti, C., Morgan, A., Currie, D., Looze, M.D., Roberts, C., Samdal, O., Smith, O.R.F., Barnekow, V., 2012. [Social Determinants of Health and Well-Being Among Young People](#). World Health Organization Regional Office for Europe.