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Executive Cognitive Functions and Impulsivity as Correlates of Risk Taking and Problem Behavior in Preadolescents

Daniel Romer,
University of Pennsylvania

Laura Betancourt,
The Children's Hospital of Philadelphia

Joan M. Giannetta,
The Children's Hospital of Philadelphia

Nancy L. Brodsky,
The Children's Hospital of Philadelphia

Martha Farah, and
University of Pennsylvania

Hallam Hurt
The Children's Hospital of Philadelphia

Abstract

Early initiation of drugs and other risk behaviors portends dysfunctional developmental outcomes. For example, youth who initiate drug use prior to age 14 exhibit the highest rates of lifetime drug use and substance use disorder (SUD) (Grant & Dawson, 1998). Early users of drugs also tend to engage in other externalizing behaviors, such as aggressive behavior and rule breaking that place them at risk for poor developmental trajectories (McGue, Iacono, & Krueger, 2006; Moffitt, 1993, 1996; Moffitt & Caspi, 2001). Early intervention may be able to alter these trajectories toward a healthier course. We examine and test neuropsychological explanations for these early manifestations of problem behavior to help identify potential points of intervention.

Hypotheses concerning the antecedent conditions and causes of youth drug abuse and other risk behaviors generally refer to one or more concepts related to what various researchers call self control, self regulation, behavior control, or impulsivity. There is the potential for confusion among these concepts, partly because of inconsistencies in terminology between laboratories, and partly because the concepts themselves have yet to be fully understood and differentiated from one another. In the present study, we distinguish between a set of mental abilities called executive cognitive functions (ECFs), on the one hand, and a set of self-reported personality traits broadly called impulsivity, on the other. ECFs include working memory, cognitive control, and reward processing, abilities that will be described in greater detail shortly. Impulsivity includes traits of sensation-seeking and the tendency to act without thinking or planning.

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One hypothesis put forth by Tarter and colleagues (Aytaclar, Tarter, Kirisci, & Lu, 1999; Tarter et al., 2003) points to a syndrome of early externalizing behaviors as well as poor ECF, a pattern they call “neurobehavioral disinhibition”, as the source of early risk taking. They find that youth with high levels of this pattern at ages 10 to 12 exhibit high levels of drug use in late adolescence (age 19). They place particular emphasis on ECF as one source of the risk (Aytaclar et al., 1999). Moffitt and colleagues also emphasize early neuropsychological deficits as the source of risk for development of a conduct-disordered trajectory that persists into adulthood. However, they also note the importance of impulsivity for this trajectory (Caspi, Henry, McGee, Moffitt, & Silva, 1995; White et al., 1994).

Despite evidence for a range of behavioral and cognitive deficits as the precursors of early drug use and risk taking, the precise nature of the deficit has not been isolated (see Zucker et al., 2008 and Zucker, 2006, for reviews). Indeed, poor ECF in preadolescence may not correlate with contemporaneous risk behavior. Aytaclar et al. (1999) found that some ECFs at ages 10 to 12 predicted drug use two years later. However, Tarter et al. (2003) found that ECF assessed at ages 10 to 12 did not predict subsequent drug use at age 16 or correlate with risk for drug use based on parental drug use history, while other indicators, such as externalizing behaviors, were much better predictors. It was not until age 19 that early ECF was a predictor of drug use and SUD. In neither of these studies was drug use assessed at the same time as ECF (ages 10 to 12), and in both cases the samples were drawn to contrast high versus lower risk youth rather than more general community populations.

Nigg et al. (2004) examined an extensive battery of ECFs in relation to drug use in boys ages 12 to 15. The ECFs that were studied did not appear to lie on a single dimension, and there was no evidence of relations between early drug use and the various ECF indices. A study of later drug use in the same sample of boys and a smaller sample of girls at ages 15 to 17 revealed a small correlation between performance on a response inhibition task (stop signal reaction time paradigm) and use of alcohol and other drugs (Nigg et al., 2006). However, the sample was drawn primarily from families with a history of drug abuse, and the ECF-drug use relation did not emerge until mid adolescence. It is not possible therefore to rule out the hypothesis that early drug use influences ECF rather than the other way around. Furthermore, the relation was only observed for one of many ECF tasks, making it difficult to determine the generality of the finding. Hence, little is known about the relation between ECF and risk taking in preadolescent community samples, and what evidence there is suggests that ECF is not strongly related to early initiation of risky behavior.

Other research has examined the relation between ECF and risk taking tendencies during childhood and adolescence (Crone & van der Molen, 2004; Hooper, Luciana, Conklin, & Yarger, 2004; Lamm, Zelazo, & Lewis, 2006; Overman et al., 2004). However, this research tends to use proxies for risk taking, such as the Iowa Gambling Task (IGT) (Bechara, Damasio, Damasio, & Anderson, 1994), rather than actual initiation of drug use or other risky behavior. This task as well as others test the ability to process and keep track of reward contingencies and are often treated as an index of ECF in itself. We refer to these tasks as measures of reward processing because they tend to be associated with orbitofrontal functioning (Fellows & Farah, 2005; Wallis, 2007). However, this research indicates that working memory as well as other aspects of ECF, such as ability to exert cognitive and behavioral control, is not related to reward processing in youth.

Research with adults has found that some components of ECF, working memory and reversal learning, are related to performance in the IGT (Bechara, Damasio, Tranel, & Anderson, 1998; Bechara & Martin, 2004). However, this relation has only been observed in persons who are drug dependent or who suffered brain lesions that affect decision making. Nevertheless, in commenting on these findings, Bechara and Martin (2004) noted that “the integrity of decision

making seems to be dependent on the intactness of working memory—that is, the participant's decision making is affected by having an abnormal working memory" (p. 160). In their research, Farah and Fellows (2005) found that both working memory capacity and reversal learning deficits may underlie performance on this task.

Other research with normal subjects has found evidence that working memory capacity influences performance on reward processing tasks. A study by Finn et al. (2002) found that working memory affected the performance of young adults on a task requiring learning of cues to reward. In addition, Hinson and colleagues (Hinson, Jameson, & Whitney, 2002, 2003) as well as Shamosh et al. (2008) find that reduced working memory capacity increases the tendency to choose smaller immediate rewards over larger but delayed rewards. Hence, there is some suggestion that weak working memory may interfere with optimal performance on reward processing tasks that involve the need to inhibit responses that previously led to reward or that currently lead to nonoptimal reward.

Role of Impulsivity

Another major correlate of risky behavior in adolescents is a set of relatively stable personality traits under the rubric of impulsivity (S. B. G. Eysenck & Eysenck, 1977, 1978; Patton, Stanford, & Barratt, 1995; Verdejo-Garcia, Lawrence, & Clark, 2008; Whiteside & Lynam, 2001; Zuckerman, 2006). These traits are regarded as under the control of both the prefrontal cortex (PFC) and the subcortical motivational systems to which it is linked (Chambers & Potenza, 2003; Chambers, Taylor, & Potenza, 2003; Cloninger, 1987, 1988; Zuckerman, 2006). Research in both humans and animals suggests that impulsivity is multidimensional (Evenden, 1999; Whiteside & Lynam, 2001) and that some of its manifestations grow in strength during adolescence (Casey, Getz, & Galvan, 2008; Chambers & Potenza, 2003; Chambers et al., 2003; Spear, 2000a). In particular, sensation seeking, the attraction to novel and exciting experiences peaks during adolescence (Romer & Hennessy, 2007; Zuckerman, 2006), likely reflecting enhanced dopamine release to the ventral striatum and prefrontal cortex (Chambers et al., 2003; Spear, 2000a, 2000b). Based on this increase, one would expect early risk takers to exhibit higher levels of sensation seeking, a pattern confirmed in one study of early drug use initiation (Crawford, Pentz, Chou, Li, & Dwyer, 2003).

Other forms of impulsivity may also correlate with early risk behavior. For example, tendencies to act without thinking have been studied under the rubric of poor behavioral control (Block, Block, & Keyes, 1988; Wong et al., 2006) or as part of novelty seeking in Cloninger's system (1988). This research indicates that early levels of poor behavioral control foreshadow later drug use, findings consistent with models put forth by Cloninger (1988), Tarter et al. (2003), and Moffitt (1993). Indeed, early manifestations of poor behavioral control might reflect the effects of the same mechanisms that underlie sensation seeking. However, less is known about how closely sensation seeking and poor behavioral control correlate during preadolescence when many risk behaviors first emerge.

Several theories of cortical and subcortical brain development focus on the relative imbalance between subcortical reward systems that mature more rapidly than slowly developing frontal control systems, resulting in poor control over impulsive behavior during adolescence (Casey et al., 2008; Nelson et al., 2002; Steinberg, 2008). These models base their predictions on structural brain imaging studies showing that dorsal and frontal brain areas exhibit a slower course of pruning and myelination than ventral and occipital areas (Gogtay, Giedd, Lusk, Hayashi, Greestein, Vaituzis, et al., 2004; Sowell, Peterson, Thompson, Welcome, Henkenius, Toga, 2003). Indeed, these studies indicate that complete maturation of these frontal areas does not occur until the third decade of life. Based on these models, one would expect that ECF would have only limited ability to control impulsive behavior tendencies in early adolescence.

Nevertheless, models of neurobehavioral risk for SUD (Moffit, 1993; Nigg et al., 2004; Tarter, et al. 2003) anticipate that ECF and impulsivity will be inversely related. Consistent with this expectation, an intervention to improve working memory ability in children ages 7 to 12 with ADHD found that the resulting improvements in ECF were accompanied by reductions in parent reports of impulsive tendencies (Klingberg, Fernell, Olesen, Johnson, Gustaffson, Dahlstrom, et al., 2005).

Impulsivity may also play a role in the manifestation of various types of externalizing problems that have also been associated with drug use and other risky behaviors in childhood and adolescence. Indeed, sensation seeking and poor behavioral control are major characteristics of externalizing behaviors (Caspi et al., 1995; White et al., 1994). In addition, externalizing problems tend to correlate moderately with internalizing symptoms in children and adolescents (Achenbach, 1991; Krueger, Caspi, Moffitt, & Silva, 1998), perhaps reflecting overlapping genetic influences (Kendler, Aggen, Jacobson, & Neale, 2003). Given that both externalizing and internalizing problems in childhood foreshadow later drug use in adolescence (Zucker, Donovan, Masten, Mattson, & Moss, 2008; Zuckerman, 2006), we anticipate that impulsivity would be an important source of those symptoms. Nevertheless, externalizing problems may be related to risk taking apart from their relation to impulsivity as suggested by models such as Tarter's neurobehavioral disinhibition approach.

Sensation seeking and poor behavioral control have been implicated in the initiation and continuation of a wide range of risky behaviors in adolescents (Verdejo-Garcia et al., 2008; Zuckerman, 2006). Indeed, risk behaviors tend to cluster in adolescents such that initiation of one behavior is related to initiation of others (Biglan & Cody, 2003; McGue et al., 2006). Hence, we expected that we would observe early initiation of several behaviors that place youth at risk for adverse outcomes. In particular, we have already reported the high rate of gambling for money that we have observed in the present cohort (Hurt, Giannetta, Brodsky, Shera, & Romer, 2008). Unlike most studies of ECF and other risk factors, we examined the general tendency to engage in risk taking using a variety of risky behaviors as markers of this pattern.

In this first wave of a prospective study, we examined a range of ECFs, forms of impulsivity, and externalizing and associated internalizing problems as correlates of general risk taking tendencies in a community sample of pre-adolescents ages 10 to 12. We also assessed a wide range of risky behaviors, including drug use, gambling, and fighting. Our interest in studying the inter-relationships among several different forms of ECF, impulsivity, externalizing behavior, and risk behavior led us to adopt structural equation modeling (SEM) as the analytic strategy (Kaplan, 2000). This approach permits one to measure factors common to different assessments that nevertheless reflect the same theoretic processes and to test hypothesized relationships between those factors. The method also permits tests of alternative models for explaining relationships between factors (see Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001, for a similar approach).

Based on theories of adolescent neurobiological vulnerability to drug use and dependence (Moffit, 1993; Tarter et al., 2003) as well as models of adolescent brain development (Casey et al., 2008; Chambers et al., 2003; Steinberg, 2008), we expected impulsivity as assessed by both sensation seeking and failure to act without thinking to be positively related to early initiation of risk behaviors and to externalizing and internalizing problems. We also expected ECFs, especially working memory ability and indicators of reward processing, to be inversely related to impulsivity, early initiation of risk behaviors, and externalizing/internalizing problems. In addition, based on Tarter's model, we expected externalizing problems to be related to risk taking apart from impulsivity.

Method

Participants in this multi-cohort longitudinal study were enrolled at ages 10 – 12 years. This report included data on the 387 youth who completed the first of four planned annual assessments. Seventy percent of the subjects attended 7 Philadelphia schools where onsite enrollment occurred. The remaining 30% attended other Philadelphia area schools and were recruited through flyers distributed at schools and posted in local venues such as libraries. Parental consent and youth assent were obtained in accordance with the protocol that was approved by the IRB of the Children's Hospital of Philadelphia. Youth were reimbursed for their time and travel.

The sample was predominantly non-Hispanic white (63%) and African American (27%) with nearly equal representation of boys (49%) and girls (51%). Mean age was 11.4 (SD = .9), at enrollment, with 10% in grade 4, 49% in grade 5, 26% in grade 6, and the rest (15%) in grade 7. Sixty-six percent of participants lived in households with married parents. Average household size was 4 individuals. Median years of parental education were 14. Hollingshead's Two-Factor Index of Social Status (reversed scored) (Hollingshead & Redlich, 1958, 2007) was 47.0 ± 15.8 corresponding to the lower range of middle-class.

Method of Assessment

Participants were tested one-on-one by examiners, who were carefully trained by project psychologists to administer all tasks in an efficient and standardized manner using scripted directions and prompts. Testing occurred in the school setting, research center testing rooms, and community libraries. Tasks were administered using pencil and paper, or on touch-screen laptops with either e-Prime (Schneider, Eschman, & Zuccolotto, 2002a, 2002b; Stahl, 2006) or Medialab (Jarvis, 2004) with the audio-computer assisted self-interviewing (ACASI) method of both visual and aural presentation. Use of ACASI served to maximize subjects' comfort in answering truthfully about their behaviors as they completed the questionnaire (Metzger et al., 2000) while also reducing differences that might result from reading a self-administered survey.

Assessment Batteries

Impulsivity—Two batteries were used to assess impulsivity. Both were administered via ACASI using MediaLab (Jarvis, 2004). Failure to think before acting and problems associated with this tendency was measured using 13 yes/no questions derived from the Junior Eysenck Impulsivity Scale (Eysenck, 1985; Eysenck & Eysenck, 1977; Kuo, Chih, Soong, Yang, & Chen, 2004). This scale is highly similar to the motor impulsivity subscale of the Barratt Impulsivity Scale (Patton, et al., 1995). Sensation seeking was assessed with 4 questions (e.g., I like to do frightening things) on a 4-point scale ranging from strongly agree to strongly disagree derived from Zuckerman's Sensation Seeking Scale (Hoyle, Stephenson, Palmgreen, Lorch, & Donohew, 2002). The four items were selected from a larger battery that had been identified to represent the four dimensions of the Zuckerman scale. Preliminary factor analyses revealed that the Eysenck scale was composed of two highly correlated components ($r = .52$), one reflecting the tendency to act without thinking (Eysenck 1, $\alpha = .74$) and the other the tendency to encounter problems when acting without thinking (Eysenck2, $\alpha = .51$). We treated these as alternative measures of a single form of poor behavioral control. The sensation seeking items formed a separate single factor ($\alpha = .74$). Total scores were calculated for each factor such that a higher score indicated more impulsive behavior.

Risk Behavior—Risk behaviors were also assessed by ACASI using questions derived from the CDC's Youth Risk Behavior Survey (YRBS), (Centers for Disease Control and Prevention, 2003) and NIDA's Monitoring the Future study (MTF) (Johnston, Bachman, & O'Malley,

2006; Johnston, O'Malley, & Bachman, 2003; Schulenberg, O'Malley, Bachman, Wadsworth, & Johnston, 1996). The YRBS and MTF have been used in national surveys of students (Kolbe, Kann, & Collins, 1993), and all questions were selected to be appropriate for participants in our cohort. Questions were screened to ensure that they were easily understood and used current slang terms for drugs and behaviors. The following categories of behaviors were surveyed: tobacco, alcohol, and other drug use; gambling for money; fighting; and, sexual behaviors that contribute to unintended pregnancy and sexually transmitted diseases. For substance use and gambling, questions asked about ever and recent use (past 30 days). For those who reported fighting, we asked about frequency of fighting in the past 12 months.

Many of the risk behaviors in the battery had very low prevalence rates. However, three behaviors were selected for further analysis that had high rates: alcohol use (17.4%), gambling (27.6%), and fighting (28.9%). Cigarette use (2.9%) was also selected despite its low prevalence in consideration of its long-term health risks. Because gambling and alcohol use had relatively wide variation in past 30-day activity, we scaled these behaviors using a 0 to 3 index, ranging from never having engaged in the behavior (0), having done so but not in the past 30 days (1), having done so in the past 30 days (2), to having done so very frequently in the past 30 days (3). Fighting was scaled as 1 if the participant reported engaging in the behavior in the past 12 months vs. 0 if he or she had not. Smoking was scaled as 1 if the participant reported having ever smoked and 0 otherwise.

Preliminary analysis revealed that the four risk behaviors were sufficiently inter-related to be described by a single underlying factor. The first principal component had an eigenvalue of 1.62 that accounted for over 40% of the variance. No other eigenvalue was greater than 1.0. This confirmed that our early initiation behaviors could serve as indicators of a general tendency toward risky behavior.

Demographics—A demographic questionnaire was completed by parents in a telephone interview that included questions regarding the child's grade in school, family composition, caregiver education, and employment.

Neurocognitive Battery

Using a battery of neurocognitive tasks, we assessed the following three prefrontally-mediated executive cognitive functions: Working Memory, Cognitive Control, and Reward Processing. Although these three functions are sufficiently distinct in their functions to merit the label "system," and can be assessed by separate sets of tasks, it is also true that they operate in concert (Duncan & Owen, 2000). Accordingly, the tasks included here were intended to place disproportionately heavy demands on a particular system, not to cleanly isolate that system (Huizinga, Dolan, & van der Molen, 2006; Miyake et al., 2000; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). All but one, the Digit Span subtest from the Wechsler Intelligence Scale for Children-IV, (Wechsler, 2003) were administered using laptop computers.

Working Memory—Working memory plays an essential role in many activities that are not tests of memory per se. The ability to hold the present context or goals of a complex task in mind requires working memory (Cohen, Cohen, & Ayache, 1992; Kimberg & Farah, 1993). More specifically, working memory is an underlying component of psychological self-regulation, which has been found to be deficient in children at risk for drug use (Tarter, Kirisci, Habeych, Reynolds, & Vanyukov, 2004). Working memory is most reliably associated with dorsolateral PFC (Mehta et al., 2000). We administered four tasks to assess this important function.

1) Corsi Block Tapping: This task is a nonverbal variant of the Digit Span task (Milner, 1971). The participant views a set of identical blocks that are spatially dispersed on the screen. The blocks are individually lit up in a random sequence. The participant is asked to tap each box in the *reverse* order of the sequence of lit boxes. This task is considered a task of spatial working memory as the sequence must be maintained and reversed in working memory in order to guide the subject's response. Performance on this task is dependent on right prefrontal brain regions (Banich, 2004). The Corsi Block Tapping total correct score was used as the dependent variable in analyses.

2) Letter Two-back: This task was adapted for children by Casey (Casey et al., 1995). It involves monitoring a series of letters for a repeat "two-back." Letters are presented for 500 msec each, separated by a 1 sec interval. Participants must continually update their working memory in order to compare the current letter to the letter shape presented two trials back. Imaging studies, including that of Casey, find lateral prefrontal activation with this task. The Letter Two Back total correct score was the dependent variable used in analyses.

3) Digit Span: This well-known task tests auditory-verbal working memory by having participants immediately repeat back sequences of digits to the experimenter. It was administered in standard form according to procedures listed in the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV) (Wechsler, 2003) manual. In functional imaging studies, this task reliably activates lateral prefrontal cortex (Owen, 2000). We used the WISC Digit Span total raw score as the dependent variable in our analyses.

4) Spatial Working Memory: This self-directed computerized task requires the subject to search for hidden tokens one at a time within sets of four to eight randomly positioned boxes. Tokens are hidden only once in each box. Working memory skills are tapped as the subject, while searching, must hold in working memory the locations already checked and, as tokens are found, they must remember and update the information about the locations of the found tokens (Elliott et al., 1997). In functional imaging studies, this specific task reliably activates dorsolateral prefrontal cortex (Owen, 1997a, 1997b; Owen, Doyon, Petrides, & Evans, 1996). The dependent variable for the Spatial Working Memory task was the between-search errors score.

Cognitive Control—An integral part of the ECFs of the PFC is a system that is sensitive to the need for allocation of attention under conditions of conflict. Evidence is accumulating that the medial PFC (which includes the anterior cingulate cortex (ACC)) plays this role, by monitoring for conflict between the individual's responses and the desired response (Botvinick, Braver, Barch, Carter, & Cohen, 2001). Errors are detected by this subsystem, which can then summon greater attention to facilitate performance. Deficiencies in medial PFC functioning have been related to a predisposition for drug use (Tarter et al., 2004). As with the other systems that are part of PFC proper, medial PFC function cannot be truly isolated, but it can be taxed disproportionately with proper task design. We administered two tasks to assess cognitive control.

1) Counting Stroop: This computerized adaptation of the Counting Stroop asks participants to sort cards according to one of two sorting conditions. One at a time a card is shown on the screen, each bearing between 1 and 5 instances of a digit from 1 to 5 (e.g., three "4's"). Throughout the task five blocks ('piles') numbered 1–5 are shown at the bottom of the screen. In the congruent condition, participants are timed as they sort the cards, as quickly as possible, according to the number (digit) shown on the card (e.g., three "4's" goes into the 4 pile). In the incongruent (conflict) condition, participants are timed as they do the same on the basis of the *number of digits* on the card (e.g., three "4's" goes into the 3 pile). The Stroop Effect is the

reaction time difference between the congruent and incongruent conditions. This task has the advantage over the classical color-naming Stroop in that it does not depend on skilled automatic reading (since poor readers will do paradoxically better on the classic Stroop). Functional neuroimaging studies have shown that for both Color and Counting Stroop, the incongruent condition activates the ACC relative to the congruent condition (Bush et al., 1998). For the Stroop task, the reaction time difference score (reaction time difference between incongruent and congruent conditions) was the dependent measure used in our analyses.

2) Flanker Task: In this task, developed by Eriksen (1974), subjects are asked to press a left-hand or right-hand response key depending on the direction indicated by a central arrow. The task is made challenging by flanking the central arrow with rows of other arrows, which can point in either the same direction (congruent) as the central arrow or in the opposite direction (incongruent condition) (Eriksen & Eriksen, 1974). The dependent measures in this task are the reaction time differences between congruent and incongruent trials. Opposite flankers cause response conflict and thus require cognitive control, the degree of which is correlated with activation of the ACC (Casey et al., 2000). For the reversal learning task, the final reaction time score (reaction time difference between incongruent and congruent conditions) was the dependent measure used for analyses.

Reward processing—An important aspect of executive function is the ability to resist the pull of reward stimuli, especially when they may lead to losses. This general concept has been operationalized in different laboratory tasks that pit the pull of a reward stimulus against the need to withhold or delay a response to avoid loss. Deficits in reward processing have been linked to impulse disorders in adolescents that are predisposing for drug abuse (Ernst et al., 2003) or to adults suffering from lesions to orbitofrontal regions (Fellows & Farah, 2005). We administered two tasks to assess reward processing.

1) Reversal Learning: Stimulus-reinforcement association learning and reversal learning are assessed by means of a simple computerized card game with play money stakes. Participants are shown two decks, one, mostly a winning deck (win: 6 times out of 7) and the other, mostly a losing deck (lose 6 times out of 7). The subject must choose a deck at each trial and feedback regarding win or loss is provided after each choice. After the learning criterion of eight consecutive cards chosen from the winning pack is met, the contingencies are switched. This constitutes the reversal phase of the task. If the criterion is again met, the contingencies are switched again for a total of 50 trials, allowing up to 50 reversals. Points are gained for each correct response and lost for each incorrect response. The ability to “unlearn” the association between a stimulus and reward and re-associate the stimulus with punishment is a distinct, frontally mediated, form of learning as shown in both animal (Ongur & Price, 2000) and imaging studies (O’Doherty et al., 2001; Rogers, Andrews, Grasby, Brooks, & Robbins, 2000). This task has been found to correlate with poor performance on the Iowa Gambling Task among adults suffering from orbitofrontal lesions (Fellows & Farah, 2005). The dependent measure on the Reversal Learning task was the subject’s final score (total points attained).

2) Balloon Analogue Risk Task (BART): The BART is a computerized task in which participants have chances to ‘earn money’ by pressing a button and inflating a simulated balloon. Each balloon has a random point of explosion that, if reached, causes a loss of money from a temporary bank. After each pump (key press) that does not cause explosion, participants may choose to transfer their money to a permanent bank. With each turn, participants must weigh the option of pumping the balloon and potentially gaining more money, against the potential risk of losing all money for each balloon if they cause it to explode (Lejuez, Aklin, Zvolensky et al., 2003). This decision making task that involves making multiple choices in a

context of increasing risk (Lejuez, Aklin, Jones et al., 2003) is variably used to assess impulsivity (Mitchell, Schoel, & Stevens, 2008) and reward processing skills. The task has been found to correlate with drug use in adolescents (Aklin, Lejuez, Zvolensky, Kahler, & Gwadz, 2005; Lejuez, Aklin, Zvolensky, & Pedulla, 2003; Lejuez et al., 2002) and adults (Lejuez, Aklin, Jones et al., 2003). For the BART the dependent variable used in analysis was the average number of pumps on unexploded balloons (adjusted average pumps).

Externalizing and Internalizing Problems

The Youth Self Report (YSR) of the Achenbach System of Empirically Based Assessment (Achenbach & Rescorla, 2001) (ASEBA) was completed by participants using a self administered version of the questionnaire and processed using the ASEBA's Assessment Data Manager (Achenbach, 2002). Externalizing tendencies were defined by reports of rule-breaking and aggressive behavior. Internalizing tendencies were defined by endorsements of problems related to anxiety/depression, withdrawal/depression, and somatic complaints. The YSR has been found to correlate with diagnoses made by trained interviewers using the Diagnostic Interview Schedule for Children (Morgan & Cauce, 1999) and with ratings made by parents (Achenbach, Dumenci, & Rescorla, 2003).

Analysis

Descriptive analyses were conducted using SPSS. Because we used multiple measures to assess ECFs and impulsivity, it was important to identify underlying factors for each set of indicators (Huizinga et al., 2006). Hence, we used structural equation modeling (SEM) to identify the factors and to test relations between them. In particular, we tested models in which measures of the three types of ECF and the two measures of impulsivity predicted risk taking as assessed by a variety of behaviors. We anticipated that risk behaviors would form a single factor but that impulsivity might form two factors, one for sensation seeking and another for poor behavior control (lack of planning or thinking and problems associated with those tendencies) assessed by the Eysenck scale. Assessment of externalizing behavior tends to reveal correlation between externalizing and internalizing problems (Krueger, Chentsova-Dutton, Markon, Goldberg, & Ormel, 2003; Youngstrom, Findling, & Calabrese, 2003). Hence, we expected to find the same pattern in our data.

We used the program EQS to test alternative measurement models and relations between factors (Bentler, 2004). The program allows for the simultaneous estimation of direct and mediating effects on latent variables. It also provides the ability to impute missing values, which in this dataset were primarily observed for a measure of working memory using the digit-span test. Due to an administration error, scores for this test were not available for approximately 16% of the sample. Additionally, EQS offers robust statistics, which adjust for the effects of departures from multivariate normality due to skewness and kurtosis. All coefficients shown in the results have probabilities evaluated with robust standard errors.

We assessed goodness of fit using three criteria. First, a Chi-square test (χ^2) was used to compare the predicted covariance matrix with the observed matrix. We used the Yuan-Bentler scaled χ^2 which is provided for models with robust standard errors (Yuan & Bentler, 1998). A non-significant value for this measure indicates that the predicted model accounts for the covariation between measures. Chi-square tests, however, are very sensitive to sample size, and significant values do not necessarily indicate a poor fit with large samples. For this reason, we augment this measure with additional indices that are not as sensitive to sample size and represent a graded index of fit (Hu & Bentler, 1995): the Comparative Fit Index (CFI) and Root Mean Square Error of Approximation (RMSEA).

CFI is a comparison of two fit functions: one from the covariance matrix estimated from the fitted model and one from a model that assumes no association between the observed variables. Higher values reflect the relative advantage of the proposed model over a model with no association. Values greater than .90 are considered acceptable (Hu & Bentler, 1995). The RMSEA measures the mean residuals between the observed and predicted covariance matrix. Departures from zero represent poorer fit. RMSEA values less than or equal to .05 are considered acceptable (Kaplan, 2000).

Results

Table 1 presents the intercorrelations between the various measures analyzed in this study as well as their relations with male gender and age. For each measure, means and standard deviations were listed in the last rows of the table. Male youth tended to exhibit better cognitive control on the Flanker task but not on the Stroop, to perform worse on one reward processing task (reversal learning), to engage in more risk behaviors, to have fewer internalizing behavior problems, and to have higher levels of sensation seeking. Older youth tended to perform better on working memory and Stroop tasks and to display lower levels of internalizing problems. However, they also were more impulsive and engaged in more risk behavior.

Working memory performance tended to intercorrelate across the four tasks and to be related to performance on the cognitive control Stroop task. Working memory was also related to less impulsivity and to better performance on the BART (reward processing). Cognitive control measures did not correlate with each other and displayed few patterns with other indicators apart from working memory. The two measures of reward processing were not highly related but were inversely related to externalizing and internalizing problems. Reversal learning (reward processing) was also related to less impulsivity.

The three indicators of impulsivity were all highly interrelated and correlated with both externalizing and internalizing problems and risk behaviors. Externalizing and internalizing problems were also highly correlated and related to risk behaviors. Finally, the four risk behaviors tended to co-occur as expected.

Preliminary Model Tests

We first fit a model to test our measurement assumptions that cognitive control, reward processing, and working memory would underlie our assessments of these functions and their relations with age and gender. These tests indicated that although the four measures of working memory loaded on a single factor as expected, neither of the two cognitive control nor two reward processing assessments did so. Hence, in subsequent model tests, we treated these assessments as separately observed variables. In regard to impulsivity, sensation seeking and the two impulsivity indices loaded on a single factor as did the four risk behaviors. Furthermore, externalizing behaviors were strongly related to internalizing problems. Thus, we treated these variables as measures of a single underlying factor. As seen in Table 2, the loadings for each variable were significantly different from zero. It is also noteworthy that although both internalizing and externalizing problems loaded on a single factor, the externalizing score had a stronger loading than the internalizing score.

Examination of residuals between predicted and observed correlations revealed that boys were more likely to exhibit fighting than girls, that girls were more likely to exhibit internalizing problems than boys, and that internalizing problems declined with age. Because these deviations from the measurement model were not relevant to our tests of relations between ECF and risk behaviors, we included them as additional correlates in the model. This resulting model provided a good fit to the data, $\chi^2(110) = 174.8, p < .001$; CFI = .93, RMSEA = .038 (90% CI = .026, .048).

Testing Relations between Factors

Having defined an appropriate measurement model, we proceeded to assess how well each of the ECFs predicted impulsivity, risk behavior, and externalizing problem behaviors. This analysis revealed that none of the ECFs directly predicted risk behavior or problems apart from their relations with impulsivity. Hence, we dropped those paths as well as insignificant correlations between exogenous predictors to produce the final model shown in Figure 1.

This model fit the data well, $\chi^2(130) = 191.6, p < .001$; CFI = .93, RMSEA = .034 (90% CI = .022, .044). Significant paths in the model indicated that age was positively related while working memory and reversal learning were negatively related to impulsivity. In addition, impulsivity was positively and strongly related to both risk and problem behaviors. However, problem behaviors were no longer related to risk behavior after controlling for impulsivity. That is, the path from problem to risk behavior was not significant, $p = .14$. Although Stroop performance (cognitive control) was highly related to working memory performance, none of the other ECF tasks was significantly related to impulsivity.

The model indicates that impulsivity mediates the effects of age and ECF on both risk and problem behavior. We further tested the possibility that impulsivity explains both risk taking and externalizing problems by restricting the path from problems to risk taking to zero. This produced only a slightly less adequate fit to the data, $\chi^2(1) = 1.11, p > .15$. Hence, there was support for only one path leading to risk taking in this sample of preadolescents. Furthermore, the model accounted for nearly 70% of the variation in the risk behavior factor and slightly over 50% of the variation in problem behaviors. This indicates that impulsivity can account for a large share of the variation in both of these outcomes. Nevertheless, the amount of variation explained by ECFs, age, and gender was quite small (about 8%). This indicates that impulsivity was largely influenced by factors outside the model.

We examined residual correlations between the predicted and observed correlation matrix to identify unexplained relations. Only one stood out: performance on the two-back task (working memory) was negatively related to fighting, $r = -.20, p < .01$. Apparently this relation was unique to this measure of working memory and to fighting as none of the other risk behaviors was correlated with any of the working memory scores apart from what was explained in the model.

An Alternative Model

Although we found strong support for the model in Figure 1, it is always possible that an alternative model might account for the data equally well. We tested one such model by reversing the roles of impulsivity and problem behaviors. That is, we placed externalizing problems as the more proximal correlate of ECFs and demographics with impulsivity acting as a potential mediator of the relation between problems and risk behavior. This model also fit the data: $\chi^2(130) = 197.3, p < .001$; CFI = .92, RMSEA = .035 (90% CI = .024, .045). However, although externalizing behavior was strongly related to impulsivity (.733, $p < .001$), it was not directly related to risk behavior (.223, $p = .16$). On the other hand, impulsivity was strongly related to risk behavior (.641, $p < .001$). Hence, this model produced essentially the same result as the favored model: impulsivity is strongly related to externalizing behavior as well as risk behavior but externalizing behavior is only weakly related to risk behavior apart from impulsivity.

Discussion

This study of a community sample of pre-adolescent youth identified early initiators of several risk behaviors described by a single factor, confirming the existence of a general risk-taking

tendency at this early age. We also found evidence for a general tendency toward impulsive behavior defined by both sensation seeking and lack of thinking and planning when acting. Furthermore, consistent with our expectations concerning the importance of impulsivity as a precursor to early risk behavior, impulsivity was strongly related to risk behavior initiation. In addition, differences in externalizing and correlated internalizing problem behaviors were highly related to impulsivity, but these behaviors were not strongly related to risk taking once impulsivity was controlled. This finding suggests that impulsivity plays a large role in the emergence of both externalizing and health-risk behaviors. Both working memory performance and reversal learning (reward processing) were inversely related to impulsivity. However, none of the ECFs was directly related to risk behavior apart from relations with impulsivity, and as reflected in the small amount of variation explained in impulsivity, their relations with impulsivity were not strong. Performance on the cognitive control Stroop task was highly related to working memory performance; however, it was not related to either impulsivity or risk behaviors apart from working memory. Hence, the findings only support an indirect role for ECF in the emergence of early risk taking.

The central role of impulsive tendencies in the emergence of early risk behaviors is consistent with findings observed by others (Block et al., 1988; Crawford et al., 2003; Wong et al., 2006). It is also consistent with the theorizing of Chambers et al. (2003) and Spear (2000), who suggest that adolescence is the period when the rise in activity of the dopamine system encourages experimentation with novel and exciting behaviors. Our finding that age was positively related to impulsivity and that impulsivity mediated the relation between age and risk behavior is also consistent with this explanation.

The finding that impulsivity was highly related to externalizing behaviors was expected since such problems are characterized by deficits in impulse control (Gottfredson & Hirschi, 1990; Waschbusch, 2002; Waschbusch et al., 2002). We were surprised however to find that externalizing behaviors did not correlate with risk behavior once impulsivity was controlled. Tarter's neurobehavioral disinhibition model explicitly predicts such an association (Tarter et al., 2004; Tarter et al., 2003). Furthermore, longitudinal studies find that early evidence of conduct disorder and other externalizing behaviors is related to later drug use and fighting (Zucker, 2006). However, impulsivity may be the central predisposing condition underlying both early manifestations of conduct disorder and later health-risk behavior. Studies that examine very early temperamental factors find that behaviors symptomatic of poor behavior control predict later externalizing problems (Caspi et al., 1995; White et al., 1994), suggesting that impulsivity is an important factor in the development of such outcomes. Our results support this conclusion, although a potential additional link between externalizing behavior and risk behavior cannot be ruled out given the presence of some, albeit statistically non-significant, relation that remains.

The finding that working memory capacity was indirectly related to risk behavior initiation by virtue of its relation with impulsivity has not to our knowledge been previously observed. This finding suggests that youth with greater ability to manipulate information in working memory have greater control over sensation seeking and other impulsive drives. The finding is also consistent with research linking working memory performance with proxies for risky decision making, such as the IGT (Bechara et al., 1998; Bechara et al., 2001; Fellows & Farah, 2003, 2005). It is also consistent with interventions that find that improved working memory in children leads to reduced symptoms of impulsive behavior (Klingberg et al., 2005). The importance of working memory to the overall ability of PFC to exert control over behavior has often been noted (Fuster, 1997; Miller & Cohen, 2001) and is consistent with theories of PFC function that place particular emphasis on this ability. It is quite likely that youth who have limited ability to consider multiple and potentially conflicting goals are less likely to think before acting and to temper their interest in novel and exciting experiences. This would lead

them to develop a relatively stable style of behavior that is observed in trait measures of impulsivity. Working memory capacity is also strongly related to general cognitive ability as assessed in intelligence tests (Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008; Shamosh et al., 2008). It is possible therefore that working memory capacity is responsible for the small but persistent correlation that has been observed between IQ and youth engagement in multiple risk behaviors (Henry & Moffitt, 1997; Lynam, Moffitt, & Stouthamer-Loeber, 1993).

The finding that reversal learning performance (reward processing) was inversely related to impulsivity has also to our knowledge not been observed. This finding suggests that youth with deficits in the ability to adjust to new reinforcement contingencies are more likely to exhibit impulsive tendencies. The finding is consistent with studies of adults who suffered lesions to orbitofrontal brain regions and who also exhibit impulsive decision making (Fellows & Farah, 2003; Rolls, Hornak, Wade, & McGrath, 1994). Youth with such deficits may well develop impulsive styles of behavior that fail to recognize changes in reward contingencies. Furthermore, youth who exhibit weak performance on both working memory and reversal tasks would be expected to develop even greater impulsive behavior styles. Indeed, working memory and reversal learning performance were largely unrelated, consistent with the different brain regions to which they have been associated (dorsolateral for working memory and orbitofrontal for reversal learning).

Despite the directionality in our SEM, the relations between impulsivity and either working memory or reversal learning performance are purely correlational and subsequent waves of our study may help to determine whether development of ECF in general and working memory or reversal learning in particular predict declines in impulsivity. It is possible for example that impulsivity interferes with working memory performance by challenging the system with task irrelevant response tendencies that are difficult to control. This may lead to poorer performance on working memory tasks. It is also possible that impulsivity reduces attention to changes in reward contingencies. If either of these were the case, then developmental changes in impulsivity would predict changes in working memory or reversal learning rather than the other way around.

Another possibility regarding the relation between ECF and impulsivity is that as adolescents mature, their ability to control impulsivity increases and is more readily observable across different facets of ECF. Research on the development of ECF suggests that cognitive control ability is not fully mature until age 15 and that working memory and reward processing continues to mature into young adulthood (Huizinga et al., 2006; Luciana, Conklin, Hooper, & Yarger, 2005). Perhaps these functions, especially cognitive control, are not sufficiently developed until mid-adolescence to slow down the increase in impulsivity that characterizes adolescence. Our results indicate that age was positively related to working memory and to Stroop performance. Although these functions were not strong enough to inhibit age related increases in impulsivity, they may gain in strength as the PFC matures. This may explain why the research program by Nigg and colleagues finds a relation between impulse control and drug use at ages 15 to 17 but not at ages 12 to 15 (Nigg et al., 2006).

The finding that measures of cognitive control (Stroop and flanker tasks) and reward processing (BART) were not related to impulsivity, risk behaviors, or externalizing symptoms was somewhat surprising given the central roles that they are assumed to play in these outcomes. It is important to keep in mind however that one measure of cognitive control (Stroop) was highly related to working memory and hence may not have contributed prediction beyond what it shared with that ability. Nevertheless, other research has also failed to find any relations between ECFs and early use of drugs (Nigg et al., 2004; Tarter et al., 2003), and research using proxies for risk taking such as the IGT also fail to find strong relations with ECFs in adolescents (Crone & van der Molen, 2004; Hooper et al., 2004). Results of the BART have to our

knowledge only been correlated with drug use in small and older adolescent samples (Aklin et al., 2005; Lejuez, Aklin, Zvolensky et al., 2003).

Discrepancies between Adult and Early Adolescent Relationships

Given the absence of relations between several ECFs with early risk behaviors and the weak relation of working memory and reversal learning in comparison with impulsivity, it is important to ask why these measures of ECF correlate with drug use more strongly in adults (Bechara & Martin, 2004) or youth with more serious substance use disorders (Tarter et al., 2003). One possibility is that as youth experience increased drug use, ECFs become compromised so that their performance deteriorates. There is evidence that heavy use of potentially addictive drugs alters brain function producing deficits in working memory and inhibitory control (Jentsch & Taylor, 1999). Over time, these effects could introduce correlations between ECFs and drug use. For example, the finding that ECF did not correlate with drug use at ages 12 to 15 (Nigg et al., 2004) but did at ages 15 to 17 (Nigg et al., 2006) is consistent with such an account.

Another possible explanation for the absence of direct relations between ECFs and drug use in adolescents is that youth with poor working memory are more susceptible to the interfering effects of drugs on their behavior (Finn, Justus, Mazas, & Steinmetz, 1999). As a result, they are more susceptible to developing dysfunctional trajectories of drug use. Thus, deficits in working memory and other ECFs might not correlate with drug use and SUD until later in life after the deleterious effects of working memory limitations have had their effect. This explanation is consistent with the findings of Tarter et al. (2003) that early ECF did not predict drug use at age 16 but did predict SUD at age 19.

Age Related Changes in Risk Behavior and ECF

One finding that stands out in the pattern of age related differences in risk behavior is that although our sample of preadolescents tends to exhibit increasing risk behavior with development, they also exhibit increasing development of working memory. This pattern suggests that engaging in risk behavior is related to cognitive maturation and that exploring these risks is part of the natural development of adolescents. The finding that better working memory and reversal learning are related to less impulsivity suggests that the continued development of these capabilities may eventually overcome the adverse influences of impulsive tendencies, perhaps leading to their decline.

Implications for Intervention

Depending on the ultimate relations we observe between impulsivity, ECF, and risk behavior, we will draw different conclusions about appropriate interventions to reduce the risk of excessive engagement in potentially addictive and harmful behaviors. If ECF eventually matures to the point where it begins to control heavy use of drugs, then efforts to improve ECF should be a focus. However, if impulsivity is the major contributor to excessive drug use, then other strategies may be needed. There is evidence that training of life skills can reduce drug use (Botvin & Schenke, 1997), but less is known about how well these skills can control drug use for those with high levels of impulsivity. Future research may need to focus on this question, especially if ECF proves not to be critical to drug use prevention.

If drug use during adolescence retards the development of ECF and this enhances the risk for emergence of SUD and other disorders, then efforts to prevent early drug use itself will be a major focus of attention. Indeed, national campaigns to prevent drug use emphasize this trajectory. This explanation is consistent with considerable research indicating that drug abusers exhibit deficits in reward processing (Bechara, 2004; Bechara & Martin, 2004; Goudriaan, Grekin, & Sher, 2007). It is also possible, however, that early impulsive and

disruptive behavior leads to the use of drugs that then interferes with the normal development of age appropriate ECF. From the perspective of this explanation, early intervention to treat impulsive and disruptive behavior should reduce the likelihood of progressing on the dysfunctional trajectory.

In addition to these two explanations, it is also possible that early manifestations of risk for SUD and conduct disorder are mere markers for a developmental path that unfolds whether preadolescents use drugs or not. For example, Prescott, Aggen, & Kendler (1999) find using twin data that early use of alcohol does not add increased risk of later alcohol dependence above the effects of genetic predispositions to alcohol abuse. Other genetically-informed research also suggests that early substance use is more environmentally driven while later emergence of dependence and problems with drugs is more under the influence of genes (McGue et al., 2006; Pagan et al., 2006). From this perspective, discouraging early use of drugs and other risky behavior may not be the best strategy; instead interventions that enhance the control of underlying impulsive tendencies may be more successful in reducing the development of risk-behavior trajectories.

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Figure 1. Standardized path coefficients for SEM predicting risk behavior. Indicators for each factor are in Table 2. Significant path coefficients ($p < .05$) are in bold. Unexplained variation in each factor ($1 - R^2$) is indicated by open circles and associated coefficients.

Table 1

Intercorrelations between gender, age, ECFs, impulsivity, problem and risk behaviors.

Characteristic	Male	Age	WM1	WM2	WM3	WM4	CC1	CC2	RP1	RP2	E1	E2	SS	PB1	PB2	RB1	RB2	RB3	RB4
Age	.080																		
WM1 Corsi	.086	.231																	
WM2 Two Back	-.002	.094	.156																
WM3 Digit Span	-.031	.169	.236	.243															
WM4 Spatial WM	-.047	.166	.365	.288	.332														
CC1 Flanker	.099	-.015	.028	.004	-.043	-.003													
CC2 Stroop	.119	.156	.277	.252	.146	.342	-.042												
RP1 Reversal	.084	.009	-.022	.064	.015	.099	-.028	.162											
RP2 BART	.028	.116	.085	.059	.127	-.032	-.082	.098											
E1 Eysenck1	.001	.114	.013	-.120	.116	.003	-.014	-.107	-.103	-.021									
E2 Eysenck2	.069	.082	-.060	-.116	.103	.074	.019	.054	-.101	-.020	.455								
SS	.134	.068	.054	.014	-.028	-.039	-.012	-.033	.008	.038	.356	.336							
PB1 Internal	.120	.113	-.054	.004	-.024	.047	-.080	.030	-.144	.154	.382	.280	.208						
PB2 External	.093	.053	-.058	-.013	-.063	.007	-.045	.008	-.105	-.009	.487	.400	.337	.606					
RB1 Alcohol	.071	.123	.049	.002	.003	-.057	-.029	-.101	.023	.045	.271	.209	.213	.186	.280				
RB2 Gambling	.146	.120	.079	.002	.015	-.072	.042	-.113	.016	.049	.303	.205	.251	.104	.237	.323			
RB3 Fighting	.243	.054	-.083	.189	-.063	.037	.053	.062	-.113	-.030	.257	.312	.166	.162	.378	.122	.312		
RB4 Smoking	-.012	.146	-.001	-.039	.066	-.016	-.109	-.015	-.030	.058	.204	.222	.096	.127	.318	.209	.133	.097	
Mean	0.49	11.4	5.2	110.7	16.0	30.7	40.4	0.28	1060	24.6	0.40	0.32	11.4	12.3	9.0	0.21	0.38	0.29	0.03
SD	0.50	0.9	3.0	13.8	3.1	19.3	31.3	0.23	357	11.3	0.32	0.30	3.1	8.2	7.0	0.50	0.69	0.45	0.17
Characteristic	Male	Age	WM1	WM2	WM3	WM4	CC1	CC2	RP1	RP2	E1	E2	SS	PB1	PB2	RB1	RB2	RB3	RB4

Note: Significant coefficients at $p < .05$ are in bold and at $p < .01$ are shaded.

WM is working memory; CC is cognitive control; RP is reward processing; E1 is Eysenck1, the absence of thinking when acting; E2 is Eysenck2, reports of problems associated with acting without thinking; SS is sensation seeking; PB is problem behavior measured in the YSR; RB is risk behavior.

Table 2

Standardized factor loadings and probabilities for measures of working memory, impulsivity, risk and problem behaviors.

Variable	Standardized Loading	Probability ^a
Working Memory		
Corsi Block Tapping Total Correct	.535	<.001
Letter Two Back Total Correct	.431	<.001
WISC Digit Span Total Raw	.446	
Spatial Working Memory Between Errors	-.673	<.001
Impulsivity		
Lack of Thought	.733	<.001
Problems	.626	
Sensation Seeking	.496	<.001
Risk Behavior		
Alcohol Frequency	.479	<.001
Gambling Frequency	.512	
Fighting Past Year	.456	<.001
Ever Smoked Cigarettes	.376	.030
Problem Behaviors		
Internalizing	.643	
Externalizing	.943	<.001

* Note: To identify the model, one variable on each factor was fixed to an unstandardized value of 1. These variables do not have significance tests.