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Executive Functions and Adolescent Risk Taking

- A dual system approach

Louise Falk and Anna Rickardsson

Handledare: Timo Mäntylä

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This study examined the relation between executive functioning (EF) and risk taking in adolescents using a dual system approach. According to the dual system perspective adolescents are prone to engage in risky behaviors as a result of an imbalance between the cognitive control system and the affective system (Casey, Getz & Galvan, 2008; Cohen, 2005; Steinberg, 2008; Van Leijenhorst et al., 2010). We investigated both the possible direct impact EF capacity has on risk taking as well as how the developmental trajectory of EF influences adolescent risk taking. 34 participants between 15-18 years of age from a non-clinical group carried out four computerized tasks. Two tasks measured risk taking, the Balloon Analogue Risk Task (BART) and the Columbia Card Task (CCT) and two tasks measured EF, N-back and the Matrix Monitoring Task. The participants had earlier carried out similar EF tasks in 2004 and 2008. The results showed that risk taking tendencies correlated negatively with performance in the EF tasks. No correlation was found between developmental trajectories of EF and risk taking. An alternative explanation for this result is presented. Our findings indicate support for the dual system perspective and we discuss some practical implications of the dual system way of looking at risk taking.

Keywords: executive functions; risk taking; adolescence; dual system

Studies show that risk taking increases during adolescence and that adolescents risk taking tendencies can be related to a wide variety of dangerous behaviors such as car accidents, drowning, STDs and smoking (Blum & Nelson Mmari, 2004) as well as a heightened risk for drug- and alcohol use (Silveri, Tzolos, Pimentel & Yugelun, 2004; Bates & Labouvie, 1997). Risk taking follows a ∩-shaped trajectory where it is relatively low during childhood, increases and peaks during adolescence and early adulthood and later decreases in adulthood (Figner, Mackinlay, Wilkening & Weber, 2009; Steinberg, 2010). While we know that adolescents are more vulnerable to risk taking compared to children and adults the mechanisms underlying this fact are not fully understood.

We will start our study by introducing the general concept of risk taking. Then a newer dual system perspective in adolescent risk taking research will be presented more elaborately. This perspective has gained a lot of support from several different theoretical frameworks that will be briefly presented in order to introduce the current research field.

Different perspectives on risk taking

Traditional cognitive development research has focused on the assumption that risk taking tendencies during adolescence are due to underdeveloped cognitive capacity among adolescents compared to adults. However, even though higher cognitive functions such as reasoning, metacognitive skills and executive functioning (EF) are not fully developed until late adolescence or early adulthood (Baird & Fugelsang, 2004) there are little evidence that adolescents are inferior to adults when it comes to evaluating risks, consequences, and relative costs and benefits from dangerous behaviors (Beyth-Marom, Austin, Fishoff, Palmgren & Jacobs-Quadrel, 1993; Steinberg, 2008). Since the fact remains that adolescents still take more risks many researchers believe that immature cognitive skills cannot be the only explanation for adolescents risk taking tendencies. Instead, it is reasonable to assume that accelerated risk taking in adolescence is mediated by an interaction of multiple factors, including emotional, social, cognitive and psychobiological development (Boyer, 2006).

The concept of risk taking behaviors has been conceptualized in many different ways and could be seen as a quite wide construct. It is often defined in terms of behaviors that are related to a certain likelihood of an unwanted outcome (Boyer, 2006). The concept of risk taking can be applied to a wider variety of behaviors and has been investigated from numerous theoretical frameworks. There exists no general consensus concerning the exact definition of risky behaviors yet gambling, drug-use and behaviors involving physical danger are often mentioned (Leigh, 1999). The research on risk taking often focus on undesirable risk taking behaviors, such as gambling, alcohol use or different types of criminal behaviors (Boyer, 2006). The most frequent method to study risk taking in psychological research has been to use different decision-making tasks in laboratory settings as well as asking individuals about their real life risk behaviors using questionnaires (Figner et al., 2009; Boyer 2006).

A large number of different perspectives have been used to examine risk taking in psychological research (Boyer, 2006). Cognitive developmental research, for example, has focused on decision-making skills and how risk is analyzed. Research in the field of emotional development have instead examined the function emotion plays in risk taking and has related it to emotional regulation. Social development research has focused on the context in which risk taking develops and often studied parent-child and peer relationships. Finally, psychobiological research has been concerned with neurological bases of risk taking behaviors.

The dual system perspective

As the research field has grown, many researchers have underlined the importance of integrating different perspectives when studying risk taking. One perspective that has emerged and acquired support during the past several years is the dual system model of risk taking. This perspective combines cognitive and socioemotional development and their underlying neural mechanisms and characterizes adolescent risk taking as a competition between two systems. Specifically, this dual system perspective focuses on the dynamic interplay between the "hot" affective system and the "cold" deliberative control system (Casey, Getz & Galvan, 2008; Cohen, 2005; Steinberg, 2008; Van Leijenhorst et al., 2010). According to this view, adolescents are prone to take more risks because these two systems develop at different speeds and they are more likely to engage in risky behaviors when the affective system is involved. The affective system is assumed to develop faster and is automatic and spontaneous (Galvan et al., 2006; Galvan et al., 2007; Steinberg, 2008). This socioemotional system is easily triggered in affective laden situations and increases reward-seeking tendencies. It is often activated during situations involving a high degree of emotional as well as social stimuli, such as among peers (Steinberg, 2007). Studies have also shown that areas triggered in such situations are closely related to areas involved in reward processing (Galvan et al., 2005; Nelson, Leibenluft, McClure, & Pine, 2005). The cognitive control system, on the other hand, develops slower and more gradually and is more deliberate and based on rules of logic. It also plays an important part in the ability to self-regulate by inhibiting impulses from the affective system. The cognitive control system has been associated with EF and prefrontal brain areas where EF is localized (e.g., Cohen, 2005; Steinberg, 2007). EF could be seen as an umbrella concept that has been applied to a variety of functions. The EFs that are recurrent in the literature are shifting of mental sets, inhibition of dominant responses and updating and monitoring of working memory (Miyake, Friedman, Emerson, Witziki, Howerter & Wager, 2000; Friedman, Miyake, Young, DeFries, Corley, & Hewitt, 2008) and these EFs are moderately correlated (see Miyake et al., 2000 for a more extensive overview of EF). Because this cognitive control system is not complete until early adulthood this increases vulnerability to risky behavior during adolescence since the affective system overrides the cognitive control system.

Support for the dual system perspective

Support for the dual-system perspective has been found within a wide array of theoretical frameworks such as neuroimaging, neuropharmacological as well as behavioral sciences. Firstly, evidence from functional magnetic resonance imaging (fMRI) has shown that two different developmental trajectories account for adolescent risk taking (Van Leijenhorst et al., 2010; Casey et al., 2008; Steinberg, 2008). The affective reward related regions follow a ∩-shaped pattern while regions in the brain related to cognitive control follow a linear development. Brain regions such as the nucleus accumbens (NAcc) and amygdala have been associated with reward processing and the affective socioemotional system (Bjork, Knutson, Fong, Caggiano, Bennett, & Hommer, 2004; Ernst et al., 2005; Galvan et al., 2006). Cognitive control functions have been shown to correlate with dorsal anterior cingulated cortex (ACC), and ventral lateral prefrontal cortex (VLPFC) as well as the orbital frontal cortex (OFC) (Galvan et al., 2006; Eshel et al., 2007). Van Leijenhorst et al. (2010) compared four different age groups on a gambling task and could demonstrate a ∩ -shaped curve of activation in NAcc with the peak in adolescence when making high-risk choices. Other support for the dual-system model comes from Galvan et al (2006). Using fMRI they could show that NAcc activity among adolescents were similar but exaggerated when exposed to rewards compared to adults. They also found that activity in OFC were more similar to the activation pattern in children suggesting that the development of the cognitive control system develops slower compared to the affective system (Galvan et al., 2006).

Neuroimagining studies have also been able to indicate that risk taking declines between adolescence and adulthood most likely as a result of improvement in self-regulation (Steinberg, 2008). Improved self-regulation is the result of a more mature cognitive control system, which implicates improved EF. This is probably an effect of both increased white matter and decreased grey matter in the control related brain regions. The increase of white matter makes information sharing more efficient both within the frontal cortex and between cognitive control related regions and affective related regions (Paus, 2005). This increase of white matter goes on until late adolescence (Leenrot, Gotagy, Greenstein, Wells, Wallace & Clasen, 2007), suggesting a later development of control related regions compared to affective related regions (Steinberg, 2008). The decrease of grey matter could be a result of synaptic pruning where unused neurons are being eliminated leading to more efficient processing (Paus, 2005). These findings suggest that the cognitive control system with age becomes more effective in self-regulation (Steinberg, 2008).

Secondly, neuropharmacological studies have found correlations between sensation seeking and dopamine levels (Zuckerman & Kuhlman, 2002). This indicates that adolescence is a time of heightened vulnerability to reward seeking and risk taking. Dopamine plays a central role in the reward circuitry and the dopaminergic system goes through remarkable changes at the time of puberty (Chambers, Taylor & Potenza, 2003; Spear 2002). This change consists of increased dopamine levels in the PFC relative to affective related brain regions which is the result of a reduced amount of dopamine receptors. This could account for changes in sensation seeking and helps explain why risk taking increases during adolescence.

Thirdly, findings from behavioral sciences have shown that there is no difference between adolescents and adults when it comes to risk taking behaviors and decision-making on tasks involving low emotional arousal (Millstein & Harpern-Felsher, 2002; Figner et al., 2009). In other words, when the affective system is not activated adolescents seem to be able to process risks as well as adults. Other support comes from behavioral studies on susceptibility to peer pressure. One study by Gardner and Steinberg (2005) indicated that under conditions of elevated emotional arousal adolescents takes significantly more risks than adults. They compared risk taking tendencies in adolescents, young adults and adults using a driving game. Adolescents took more risks in the game when surrounded by peers while adults risk taking tendencies were not affected in the different conditions. This can also be seen as support for the dual system notion that the affective system overrides the cognitive control system during adolescence.

EF in relation to risk taking

One implication of the dual system line of reasoning is that risk taking should reflect an imbalance between the “hot” and the “cold” systems. More specifically, developmental differences in executive control functions should predict risk taking behaviors in adolescents. Indirect support of this view comes from studies that have focused on impaired executive control functions and decision-making. EF has shown to be strongly related to decision-making (Eslinger & Damasio, 1985; Manes et al., 2002; Del Missier, Mäntylä & Bruine de Bruin, 2010) and these studies have shown that components of EF are selectively associated with decision-making competence. Furthermore, studies on Attention Deficit Hyperactivity Disorder (ADHD) have provided indirect support for this hypothesis in that children with ADHD are overrepresented in accident statistics (Discala, Lescohier, Barthel & Li, 1998; Jensen, Shervette, Xenakis & Bane, 1988). Following the assumption that ADHD is characterized by impaired EF (e.g., Barkley, 1997), these findings might be interpreted to suggest that the “cold” system of the dual-system framework is impaired in ADHD. More direct evidence for this hypothesis was recently provided by Mäntylä, Stills, Gullberg, and Del Missier (in press). They investigated risk taking in adults with ADHD compared with a non-clinical control group. The results showed that the ADHD group could be selectively distinguished from the control group concerning risk taking behavior. ADHD was related to higher levels of risk taking on a selection of decision tasks. Findings from their study supported the notion that ADHD is connected to impaired performance on decision-making tasks that demands a high level of cognitive control, i.e. the “cold” system.

Other support for the notion that EF predicts subsequent risk taking behaviors in adolescence was reported by Forman, Mäntylä, and Carelli (2010). In their follow-up to Mäntylä et al., (2006) study of the development of the working memory updating component of EF in relation to time monitoring strategies they found that adolescents (12-16 years of age) used riskier time monitoring strategies compared to children and adults. Time monitoring strategies concerns the coordination of the individuals experience of time. Forman et al. (2010) also found that a riskier monitoring strategy was related to relative changes in updating performance. Since they could not use the same EF tests during both studies, due to age-related improvements in EF capacity, they could only investigate the participants relative change in EF from study 1 (T1) to study 2 (T2). Participants could be divided into three groups depending on their relative change in updating performance. The groups were named Loss, Same and Gain. Participants who had improved their relative updating performance (Gain-group) used a less risky time monitoring strategy than the participants who had not developed as much in comparison to the first study. Forman et al. (2010) speculated that these results could be related to the dual system assumption since performance on EF tasks seemed to play a prominent part in explaining the riskier monitoring strategies. They also speculated that their findings could be explained by differences in self-image and metacognitive confidence, (i.e. confidence concerning thoughts of ones cognition), due to earlier EF capacity and related activities.

Based on the studies concerning risk taking and EF we aim to further examine this field. The aim of this study is to examine the relationship between EF and adolescent risk taking and investigate both the possible direct impact EF capacity has on risk taking as well as how the developmental trajectory of EF influences adolescent risk taking. In line with the dual-system theories of risk taking we hypothesize that less developed EF should correlate with a higher susceptibility to risk taking behavior in a nonclinical sample of adolescents. Based on the results of Forman et al. (2010) we also want to investigate whether the developmental trajectory of EF from childhood to adolescence can be related to adolescent's current risk taking. This study (T3) is a follow-up of Mäntylä et al. (2008) and Forman et al. (2010) studies. The same individuals that participated in the previous studies took part in this study and this makes it possible to get a profile of their relative EF development. Given that time monitoring strategies could be seen as a measure of risk taking and that these effects persist, we expect that the same pattern will appear using more explicit measures of risk taking such as the Columbia Card Task (CCT) and the Balloon Analogue Risk Task (BART). More specifically, we expect a positive correlation between the Loss-group and heightened risk taking behavior.

Method

Task Characteristics

Risk taking. Participants completed two computerized risk taking tasks, the BART and the CCT. Both tasks are frequently used laboratory simulations of everyday risk taking behavior, with reasonable measurement properties. The BART has shown to correlate with real-life risk taking (Lejuez, Aklin, Zvolensky & Pedulla, 2003). In the BART (Lejuez et al., 2002), the objective of the test is to inflate balloons with a balloon pump appearing on the computer screen. For every click at the pump the balloon expands and a certain amount of money is earned but the risk for bursting the balloon increases. If the balloon bursts the money earned on that very balloon is lost. The total amount of money earned is shown on the screen. The participant was always allowed to stop pumping and collect the money in the permanent bank.

The CCT assesses risk taking from a dual system perspective (Figner et al., 2009). It shares several features with established risky-decision tasks, such as the BART and the Iowa Gambling Task (IGT), in that risk increases within a trial over time. Tasks with these characteristics have shown to trigger affective processes (Aron, Shohamy, Clark, Myers, Gluck & Poldrack, 2004; Shohamy, Myers, Grossman, Sage, Gluck & Poldrack, 2004). In the CCT participants turned over cards on a computer screen. There were both gain and loss cards and a trial could continue as long as gain cards were turned over. It was possible to quit turning cards before a loss card was encountered. The more gain cards turned over before stopping the higher the score. More cards turned over represented a riskier strategy. The CCT differs from other risky decision tasks in that it includes two versions of the card task: one that provokes the affective system (the "hot" version) and one that avoids triggering the affective system (the “cold” version). In this study, the “hot” CCT version was used in which the participants got to take decisions stepwise and were also given instant feedback concerning whether the card they turned over was a gain or a loss card. Following every card turned over participants could decide whether to continue turning over cards or end the trial and collect the points they had earned.

Executive functioning. Following the study of Forman et al. (2010), participants completed two tasks of working memory, the N-back and the Matrix Monitoring task. The N-back task is commonly used to measure working memory updating (e.g., Owen, Mc Millian, Laird & Bullmore, 2005; Jaeggi, Buschkuehl, Perrig & Meier, 2010). In the 3-back version of the task, a noun appeared on the computer screen for 2 s every 4 s, and participants decided whether the noun currently presented on the screen matched the noun that appeared three items earlier by pressing a designated key on the computer keyboard. The task consists of 96 words, including 24 targets.

In the Matrix Monitoring task (Salthouse, Atkinson & Berish, 2003) a 4x4 matrix appears on the computer screen, with a dot placed in one of its cells. The screen goes black after 2.5 seconds and arrows appear on the screen to indicate the movement of the dot. The matrix then reappears on the screen and the participant’s task is to determine whether the new placement of the spot is correct by either pressing a “yes” or “no” key on the computer’s keyboard. The participants completed two blocks, including 16 trials with three arrows (Block 1) and 16 trials with four arrows (Block 2).

Participants

34 adolescents, 22 girls and 12 boys from 15 to 18 years of age (mean age 16, 8 years) participated in the study. All participants had previously taken part in Forman et al. (2010) and Mäntylä et al. (2008) studies concerning time monitoring strategies and executive functions. Eight of the adolescents from Forman et al. (2010) study had either declined to participate, changed their contact information or had moved to another part of the country. Written parental consent was obtained for those children who were under 16 years of age. All participants were instructed to show their parents a letter with information about the study before they accepted to participate. The participants were all paid 250 SEK for participating but they were also told that it was possible to get an extra amount depending on their performance in the computerized tasks. In fact all participants received an extra amount of 50 SEK so that no one would be penalized for their performance.

Procedure

Data collection took place in a laboratory at the Department of Psychology, Umeå University. Each participant was tested individually and the administrators of these tests did not have any knowledge of the participant’s earlier performances.

The test session consisted of four computerized tests (BART, CCT, N-back and Matrix Monitoring task). Participants were divided into two groups where the two groups did the tests in opposite test orders to control possible order effects. Each test session took on average an hour to complete. At the beginning of each session participants were informed about the general disposition of the test session and the fact that they would get a monetary bonus depending on how they performed on the tasks. The bonus was used to increase their involvement in the computerized tasks. Both the BART and the CCT had explicit instructions that real money was at stake.

Results

The descriptive data is presented in Table 1. Lower scores on the N-back and the Matrix Monitoring task indicates better EF performance since the scores on these tasks show errors made. Lower scores on the CCT and the BART indicates less risk taking on these tasks. As can be seen the performance in the Matrix Monitoring task was close to ceiling. As reported in Table 1. the mean and the SD is low which infers that participants did few errors on this task.

Table 1
Descriptive statistics for N-back, Matrix Monitoring Task, CCT and BART

Test	M	SD	Skew.	Kurt.	n
N-back, T2	6.5	3.5	1.9	4.6	34
N-back, T3	7.6	4.2	1.3	1.1	34
Matrix Monitoring, T2	3.7	2.6	1.6	3.9	34
Matrix Monitoring, T3	2.4	1.3	.67	-.38	34
CCT	202.2	57.3	-.18	-.21	34
BART	199.4	64.9	-.23	-.19	34

EF and risk taking

To examine the relation between risk taking and EF, we completed two sets of analysis. In the first analysis, we examined whether individual and developmental differences in EF, as measured by the two updating tasks, were systematically related to risk taking, as measured by the CCT and the BART. These correlations are summarized in Table 2. An overall pattern of these data suggest a positive association between these two sets of measures. Specifically, participants who made many errors in the N-back task also turned over more cards in the CCT, compared to participants with more efficient EF capacity. However, these effects were selective in that the N-back task did not correlate with the BART and that the Matrix Monitoring task showed significant correlations neither with the CCT nor the BART. A reasonable explanation of these latter effects is, as mentioned before, that performance in the Matrix Monitoring task was close to ceiling (i.e. the mean error rate was < 10%, varying between 0% to 15%). This observation was also consistent with its nonsignificant correlations with the CCT and the BART, respectively.

Table 2

Pearson Correlations for N-back, Matrix Monitoring Task, CCT and BART

	Nback	Matrix Monitoring	CCT	BART
Nback	1	.28	.39*	.17
Matrix Monitoring	.28	1	-.02	-.15
CCT	.39*	-.02	1	.03
BART	.17	-.15	.03	1

* $p < .05$.

The second analysis examined risk taking in relation to relative changes in working memory development. To this end, relative change was computed by transforming Matrix Monitoring and N-back scores to z-scores. Difference in z-scores between the first and the second study constituted the base for dividing the participants into three groups. Participants who changed their relative position with 1 standard deviation below the mean between the first and the second study constituted the "Loss" group (n=9). Participants who changed their relative position with 1 standard deviation above the mean constituted the "Gain" group (n=9). The remaining participants formed the "Same" group (n=16). Relative change in EF between T1 and T2 did not correlate with the BART (r_{33}=.14;*ns*) or the CCT (r_{33}=.01;*ns*).

Discussion

The findings support the hypothesis that adolescents with less developed EF are prone to take more risks in comparison to adolescents with more developed EF. Adolescents with less developed EF turned over significantly more cards in the CCT and there was a tendency that they also pumped more in the BART. Due to ceiling effects in the Matrix Monitoring task scores from this test were excluded from the overall estimate of EF. These results correspond to dual system theories of risk taking that proposes that increased risk taking tendencies among adolescents could be explained by deficient cognitive control functions in relation to the affective system.

The hypothesis that the developmental profile of EF affects later adolescent risk taking was not supported by the data. This does not correspond to the results of Forman et al. (2010) study suggesting that risk taking could be explained by developmental changes in EF. One explanation could be that change in EF and risk taking did correlate during T2 in Forman et al. (2010) study but that these effects later diminished. Risk taking may have declined as an effect of age. According to Steinberg (2010) the peak in reward seeking occurs during mid-adolescence (13-15 years of age). Participants in our study were older, more specifically 15-18 years of age. At this age EF may have developed in a way that makes the adolescents more able to control the affective system, thus leading to a decrease in their vulnerability to risk taking. Another reasonable explanation to our findings is that the time monitoring task used by Forman et al. (2010) does not reflect risk taking.

Forman et al. (2010) also considered metacognitive development and its consequences for risk taking. In hindsight this thought seems very interesting as it offers another dimension in how to understand our results. Forman et al. (2010) reported that the Gain group showed a faster EF development than the Loss group. They also made the implicit assumption that both groups were approximately equal at T1 and that the Gain group developed faster and was assumed to have better EF at T2 than the Loss group which they could use to reduce risk taking. This hypothetical pattern of EF development is illustrated in Figure 1a and could be called the control-deficit explanation. Here the Loss group could be seen to take greater risks than the Gain group due to differences in “cool” cognitive control functions. Our hypothesis was based on this assumption but an alternative view could be possible which is illustrated in Figure 1b.

This alternative explanation suggests that the two groups differed in EF capacity at T1 but not at T2. It was not possible for us to compare absolute EF scores since different EF tests were used in T1 and T2. According to this explanation, here referred to as the confidence explanation, the Loss group had better EF capacity than the Gain group when tested at T1 and the Gain group showed faster EF development in that they reached the level of the Loss group at T2. Looking at this alternative interpretation the two different groups were actually equal in terms of cognitive control functions at T2 and T3, which is assumed to mediate individual and developmental differences in risk taking. Since this implies that the two groups in fact had similar EF performance at T2 and T3 it underlines that adolescent risk taking can not solely be seen as a result of a competition between the cognitive control system and the affective system. Instead it highlights the importance of differences in self-image and metacognitive confidence. In Forman et al. (2010) study the Loss group showed a more adult-like monitoring strategy, but these individuals also overestimated their actual capacity of time keeping and thus produced very large timing errors compared to the Gain group. The Gain group instead used a less risky

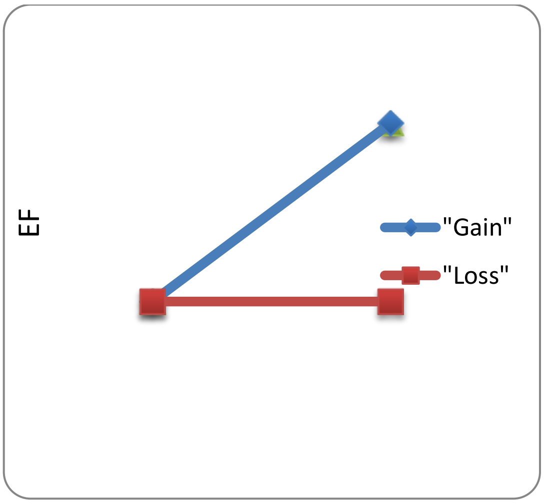

Figure 1a. Hypothetical graph of Loss and Gain groups EF development according to the control-deficit explanation.

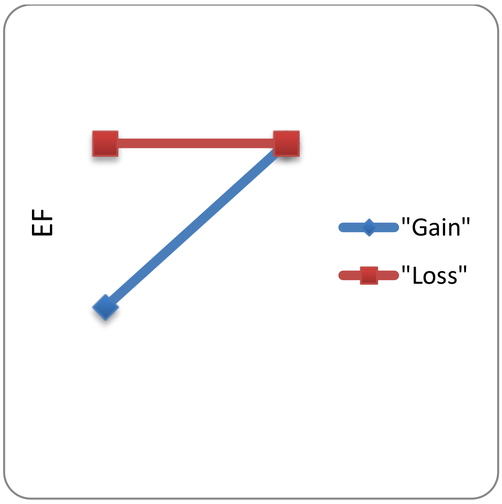

Figure 1b. Hypothetical graph of Loss and Gain groups EF development according to the confidence explanation.

monitoring strategy (i.e. checking the clock more often) and made fewer timing errors. The alternative explanation of this pattern could be that the Gain group might have been more under confident and risk-aversive due to their difficulties in executive functioning when they were younger. Since EF has shown to correlate with reading, arithmetic tasks and reasoning (Van der Sluis, de Jong & van der Leij, 2007) it is not farfetched to think that individuals who had deficient EFs when they were younger had a harder time on traditional school tasks which could have influenced their confidence and their self-image. In other words, this confidence explanation assumes that because the Gain group performed under average on EF tasks when they were around 10 years old they had a different self-image than the Loss group that performed above average. This self-image made them more realistic in their view of their abilities compared to the overconfident Loss group. Following this, it would be interesting to examine this metacognitive explanation in greater detail using for example measures of self-confidence and self-image and relate them to adolescent risk taking.

Another puzzling finding in our data was that the BART and the CCT did not correlate. This raises the question whether these tests measure the same aspect of risk taking? Because risk taking is a complex and multi-faceted concept we think it is important to question how risk taking is defined and if it can be seen as a single construct. There are for example researchers who claim that risk taking is domain specific and studies have shown that individuals are often not consistent in risk taking tendencies across different situations and domains (Blaise & Weber, 2006). This could be related to our alternative explanation since self-image and self-confidence might differ across different domains. With low self-confidence within a certain domain, perhaps due to earlier experiences, you may approach a task more carefully and thus be more risk aversive in that domain.

Overall, our results correspond with a growing body of research supporting the notion that adolescent's vulnerability to risk-taking is partially caused by an interaction of two separate systems that have different developmental trajectories. Our confidence explanation does not contradict the dual-system model of risk taking. Instead the confidence explanation adds an extra dimension to the dual system assumptions. Risk taking might be explained by both cognitive control functions in relation with the development of the socioemotional system as well as confidence regarding your abilities. This way of regarding the mechanisms underlying adolescent risk-taking influences the interventions used to treat and prevent these types of behaviors. According to the dual-system theory it is not adolescent's lack of cognitive capacity alone that puts them in danger of engaging in risky and possibly harmful behaviors such as smoking, unprotected sex and drug use. In other words, adolescents have the capacity to view and understand the pros and cons of risky situations in a similar way as adults. Instead it is their vulnerability for heightened emotional states that puts them at risk and it is the affective system that during this period is stronger and overrides the cognitive control system. In line with this view one could also regard adolescent risk taking as something inevitable and designing effective interventions could prove a challenge. Educational programs in schools aiming to raise awareness for the dangers of certain behaviors are limited in that they focus on increasing information. Those types of preventive efforts have also proven to have only a slight, if any, effect on individual's alcohol and drug habits (Thorsen & Andersson, 2000). Because it seems highly questionable that it is possible to speed up the development of cognitive control functions more efforts could be directed towards other types of interventions. One type of intervention that could be useful when working with adolescents could be an emotion-based intervention that focuses on increasing affect consciousness. Affect is a construct often used synonymously with emotions. It has been defined as a set of biological responses that triggers us to act (McCullough, Kuhn, Andrews, Kaplan, Wolf, & Hurley, 2003) and these types of interventions work towards increasing individual's knowledge and ability to identify and tolerate affects. If adolescents are more aware of their affects and are able to reflect on their emotions they could perhaps handle affective laden situations where risk taking often occurs more adequately.

Another solution would be to focus on more contextual factors since it is difficult to influence the developmental speed of the cognitive control system. Such a solution could be to invest in the everyday environments where adolescents spend their time and thus minimize the adolescent's possibilities to engage in risky activities. More specifically, to have adults present as well as providing adolescents with a wider variety of healthy activities to choose from.

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