Risk, Cognitive Control, and Adolescence: Challenging the Dual Systems Model

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Abstract

According to the dual systems model, adolescence is a period of imbalance between cognitive and motivational systems that results in increased tendency towards risk. In the study, we investigated the effects of rewards on risk-taking and cognitive control in 90 adolescents (13-16) and 96 adults (18-35). Our results challenge the assumptions of the model as we observed that rewards lead adolescents to more conservative decisions in one of the risk tasks used in the study. We also observed that in cognitive control tasks, rewards influenced reaction latencies, but not the efficiency of control processes.

Keywords: risk taking strategy, cognitive control, sensitivity to rewards, dual systems model

Introduction

As a developmental period, adolescence is commonly characterized by risk-taking, sensation seeking, impulsivity and the importance of peers. Such characteristics clearly serve an adaptive function during the transition to adulthood, fostering tendencies towards independence, novel experiences and social networks (Spear, 2000). At the same time, they expose adolescents to the negative consequences of their actions, with typical examples being reckless driving, experimenting with psychoactive substances or unprotected sex. In our study, we investigated adolescent sensitivity to rewards and its consequences for risk-taking and cognitive control.

The Dual Systems Model

The dual systems model by Steinberg (2008) is one of the most influential propositions attempting to explain adolescent behavior that is well established in cognitive and neurodevelopmental research (Defoe, Dubas, Figner, & van Aken, 2015; Geier, 2013). According to the model, adolescence can be characterized by a functional imbalance between the hyperactive motivational system, responsible for increased sensitivity to rewards, and the still maturing cognitive control system, responsible for reaction inhibition and effective management of information. In both human and animal adolescents, greater sensitivity towards pleasure, positive feedback and rewarding effects of social interactions are observed (Somerville & Casey, 2010; Spear, 2011). In humans, it has been established that early (11-13 years old) and middle adolescence (14-16 years old) are the periods of highest sensitivity to rewards. The presence of salient incentives coupled with the immaturity of control processes is believed to result in increased tendency towards risk.

Risk-taking, defined as a propensity towards actions "with the highest outcome variability" (Defoe et. al., 2015), is the most studied consequence of adolescent sensitivity to rewards. More precisely, risk-taking is a preference for actions leading to a big gain of low probability over actions leading to a small gain of high probability. According to the dual systems model, adolescents take more risks in the presence of salient incentives and when they are emotionally aroused. Studies focusing on age differences in risk-taking show that adolescents do manifest stronger tendency towards risk than adults, but only under specific task demands or in specific social contexts. A meta-analysis by Defoe et al. (2015) revealed that in studies using probabilistic gambling tasks (e.g. Iowa Gambling Task, Columbia Card Task, Balloon Analogue Risk Task), these specific task demands include primarily immediate outcome feedback, i.e. participants are informed of their gains and losses immediately after each decision. In studies using fast-paced driving tasks (e.g. Stoplight Task, driving simulators), it is usually the presence of a peer observer that encourages adolescents to take risks (e.g. Chein, Albert, O'Brien, Uckert, & Steinberg, 2011; Cascio et al., 2015). It seems unclear whether these two types of risk task measure one or more types of risky behavior. The use of probabilistic gambling tasks allow a better understanding of economic risk preference. In fast-paced driving tasks, the risk is more impulsive and more similar to everyday situations.

Beyond the risk context, the assumptions of the dual systems model are tested in a rewarded vs. neutral antisaccade paradigm. Interestingly, some results show that cognitive control is enhanced in adolescents, but not in adults, where it is financially rewarded (Geier, Terwilliger, Teslovich, Velanova, & Luna, 2010; Padmanabhan, Geier, Ordaz, Teslovich, & Luna, 2011). Such an effect does not correspond to the implication of the model that adolescent risk-taking stems from weaknesses of control processes. Rather, it indicates that adolescent sensitivity to rewards can in fact be adaptive and promote cognitive efficiency. Unfortunately, the effect seems to be difficult to replicate. Subsequent studies show individual differences such as increase, decrease or no change in cognitive control in adolescent response to rewards (Geier & Luna, 2012; Paulsen, Hallquist, Geier, & Luna, 2015). One study using the Continuous Performance Test showed a similar increase of performance in children, adolescent and adults in the rewarded condition (Strang & Pollack, 2014).

The Challenges for the Dual Systems Model

Despite the fact that the dual systems model does not specify whether tendency towards risk is adaptive or maladaptive (Strang, Chein, & Steinberg, 2013; Shulman et al., 2016), it is criticized mainly for its generality and the fact that it adopts a deficit perspective on adolescence (Pfeifer & Allen, 2012; Telzer, 2016). Actually, results from many studies contribute to the image of adolescence as the period of greatest lability, vulnerability to social evaluation, and decision making which may be suboptimal or even life-threatening. However, a high propensity towards risk may not be the domain of all but the most susceptible adolescents (Bjork & Pardini, 2015). An interesting new development for the model might be offered by research demonstrating that adolescent sensitivity to rewards can lead not only to risk-taking, but can also be channeled towards safe (Cascio et al, 2015; Telzer, Ichien, & Qu, 2015) or prosocial behavior (Telzer, Fuligni, Lieberman, & Galvan, 2013; 2014).

The conceptualization of adolescent risk-taking within the model and beyond it remains, however, the most intriguing issue. Are adolescents impulsive risk-takers, who, due to the immaturities of their control processes, cannot override risky tendencies in the presence of salient incentives (Willoughby, Good, Adachi, Hamza, & Tavernier, 2013)? Or is risk-taking rather a decision strategy adopted whenever it seems profitable? When we view risk-taking as a strategy, we can also see adolescents as having more control over their behavior than is assumed in the model. Decision strategies can vary depending on the task and the type of risky behavior (e.g. economic risk, driving risk). Adolescent sensitivity to rewards (e.g. financial rewards, immediate outcome feedback) can be similar or different in various risk tasks. Nevertheless, it seems to be associated with emotional arousal. Finally, an issue worth examining is whether cognitive control in adolescents is indeed weaker than in adults and more sensitive to rewards.

Hypotheses

To sum up, we expected that adolescents would be more sensitive to rewards than adults and that the difference in sensitivity would manifest in more efficient cognitive control and a higher tendency towards risk when performance is rewarded. Also, as the dual systems model does not provide a direct link between the presence of reward and its possible effect on risk-taking and cognitive control, we hypothesized that the effect may be mediated by the most obvious variable: emotional arousal.

Taking into consideration all of the above, we can formulate the following predictions.

Risk (1) When rewarded according to their performance, people will manifest more risk-taking compared to a no-reward condition.

Cognitive control (2) When rewarded, people will exhibit more efficient cognitive control.

Developmental changes (3) The simple effects expected in hypotheses (1) and (2) will be larger for adolescents than for adults.

Arousal (4) People will report higher arousal when rewarded according to their performance, compared to a no-reward condition. (5) The arousal level will be a substantial mediator between the type of condition, risk level and cognitive control efficiency.

Procedure

The one hundred and eighty six subjects (81 men) were recruited either via parent-teacher conferences in local schools (adolescents) or online advertisements (adults) from two groups: adolescents (N = 90, mean age = 13.82, SD = 0.89, range = [13, 16]), and adults (N = 96, mean age = 25.04, SD = 4.03, range = [18, 35]). Parental consent was obtained for all under age participants. The study was conducted in schools (adolescents) and the university psychological laboratory (adults). Participants were informed that the anonymized data would be used only for the scientific purposes of the study and that they could ask questions, withdraw their participation at any moment, and receive performance feedback after the study was completed.

The session lasted for about 90 minutes and consisted of two conditions, with a fifteen-minute break in between: (a) a set of tasks with rewards depending on the performance and (b) a set of tasks without any rewards. In each condition, participants performed four tasks, each preceded by a training session. Two tasks were cognitive control tasks (Stroop task, Antisaccade task), while the other two measured the tendency to take risks (Spaceride task and Stock Market task). The order of conditions and of the tasks within sets were randomized. In the middle of each condition (after performing two computer tasks), participants were asked to complete the SUPIN arousal scale. Therefore, each person performed four computer tasks and the SUPIN scale twice, once in a rewarded and once in an unrewarded condition.

Participants were paid for their attendance with vouchers (to a clothing store, a bookstore, or a movie theatre). The value of the vouchers depended on performance in each task in the rewarded condition and varied from \$5 to \$15 (mean \$10, equivalents in PLN).

The Tasks

The tasks were selected so as to measure different aspects of risk-taking and cognitive control. In contrast to the Stock

Market task, which investigates the tendency to make risky decisions based mostly on deliberative thinking, the Spaceride task was designed to detect the tendency to take risk in emotionally stimulating conditions. As two aspects of cognitive control, interference inhibition and response inhibition were measured separately by the Stroop task and the Antisaccade task. The SUPIN Scale was introduced to control the level of positive and negative affect during each research condition, as a possible moderator of task results.

Stock Market The task resembles a financial game in which participants use virtual currency to buy shares in two fictitious companies. In each turn of the game it was possible to buy a number of shares of one or two companies or no shares at all. The only restriction was the amount of money the participant had at a given moment, which was shown on the right side of the screen. The participant had 60 seconds to take a single decision, and 20 decisions to make during the game, which was also displayed on the screen. During the game the participant could see the history of changes of the prices of each companies' shares displayed on a chart. After each decision they also saw a table showing the current values of stocks and how much money they had earned or lost so far. The price changes were probabilistic (independent and normally distributed). The expected gain (mean price change) from investing in any of the companies was the same; however, the variance of the price changes was small for one company (safe) and large for the other (risky). The difference between the companies was revealed to participants at the beginning of the task.

Spaceride The task fulfilled a function similar to the "Stoplight" task (Chein et al., 2011), in which participants in a car-driving context had to quickly decide whether or not to take a risk to reach their destination as quickly as possible. The Spaceride task has the form of a game in which the participant controls a spaceship seen from above. The task was to fly as quickly as possible to the end of the cosmic route. There were a number of danger zones where there was a risk of collision with asteroid. Those zones were marked by a sound signal, a light on a radar, and the appearance of distant asteroids in the background. A cloud of fog also sometimes appeared and covered the spaceship and its surroundings, making it impossible to see asteroids approaching. In each danger zone, the participant had to decide whether to slow down and avoid a collision or speed ahead, risking a collision with an asteroid. A collision would immobilize the spaceship for longer than it would take to fly through a danger zone.

Stroop task The task (Stroop, 1935) was used to evaluate participants' ability to inhibit interference. In each trial of the task, one of four words ("red", "brown", "blue" or "green") appeared on the screen displayed in one of the four colors (also red, brown, blue, or green). In congruent trials (50% of trials), the color was the same as the meaning of the word (e.g. the word "brown" written in brown), while in incongruent trails the word was written in one of the other three colors (e.g. the word "red" written in blue, meaning interference was present). The participants had to press one of four keys corresponding to the displayed color of the word as quickly as possible and ignore the meaning of the word. To motivate the participants for a better response, a status bar visible on the top of the screen was additionally introduced. After every response the bar changed color to green when the response was correct, or to red when it was wrong. The faster the response, the shorter the bar, so the participant could see the accuracy and speed of every reaction during the game.

Antisaccade task The task (Unsworth, Schrock, & Engle, 2004) served as a measure of response inhibition. The participant had to inhibit the tendency to look at a sudden presentation of a peripheral lure stimulus and instead look at its mirror location in order to perceive the target stimulus (arrow) and correctly react to it (press one of three keys depending on the direction of the arrow). Feedback was additionally introduced in the present task to inform participants of their accuracy. The feedback took the form of a screen-wide rectangle displayed in green (in the case of a correct response) or red (when the reaction was wrong).

Modified SUPIN Scale The scale (Brzozowski, 2010) was derived from Watson & Clark's Positive and Negative Affect Schedule. Both positive and negative affect were measured, forming two subscales of the questionnaire. The scale consisted of 20 adjectives describing various emotions. Participants indicated on a five-point Likert scale (from 1 – "very slightly or not at all" to 5 – "extremely") how well each adjective described their current state. On the basis of the results of our preliminary study, we altered seven items of the scale to achieve better psychometric characteristics. The modified version of the scale was used in the present study.

Results

Statistics and data analysis One person did not finish the whole set of tasks, while 60 had their results removed for one task due to low accuracy (in the Antisaccade task) or outlying value; however, their remaining results were still used in the analysis.

A generalized linear mixed model using binomial distribution was fit to the Antisaccade task. The "Mediation" package in R was used for mediation analysis. Multi-factor analysis of variance with repeated measures was applied in all other analyses.

Condition (rewarded or not rewarded), group (adolescents or adults), and interaction between condition and age group were independent variables. The condition factor was applied within subjects while the age group was applied between subjects. We also controlled for position in series (first or second) and performance in analysis concerning risk tasks. Dependent variables (DV) were: number of correct responses in the Antisaccade task; Stroop effect in the Stroop task; proportion of high risk stocks in all stocks purchased (risk measure), and number of stocks purchased (alternative DV) in the Stock Market task; duration of pressing the break button (risk measure) and duration of pressing the break or accelerate button (alternative DV) in the Spaceride task. Alternative DV in the Spaceride task was logarithmized due to its skewness (γ_1 =2.17 before and 0.29 after transformation). The performance measure in the Stock Market task was the amount of “money” in the last trial, and in the Spaceride task it was the negative time of the journey. DV in the Antisaccade task was accuracy, and in the Stroop task it was Stroop effect. We also examined reaction latencies in Antisaccade and Stroop tasks.

Cognitive control There was neither an effect of condition nor an interaction between condition and age group in the Antisaccade task (β = 0.027, p = .47; and β = -0.03, p = .56 respectively, deviance = 1695.8) and the Stroop task (F[1,136] = 0.2, p = .66; and F[1,136] = 1.75, p = .19, respectively, η^2 = .037). However, there was a significant difference between adolescents and adults in reaction latencies in the Antisaccade task (734 ms for adolescents and 695 ms for adults, F[1,164] = 10,84, p = .001) and a nearly significant difference between conditions (707 ms for not rewarded and 719 ms for rewarded, F[1,152] = 3.58, p = .06, η^2 = .19). There also was a significant difference between the rewarded and unrewarded condition in reaction latencies in the Stroop task (936 ms for unrewarded and 906 ms for rewarded, F[1,136] = 101.97, p < .001, η^2 = .12).

Risk The performance in the Stock Market task did not depend on condition (F[1,180] = 0.1, p = .75), age group (F[1,182] = 0.59, p = .44), nor interaction between these two factors (F[1,180] = 1.65, p = .2, η^2 = .032). Neither did the performance in the Spaceride task depend on any of these predictors (F[1,182] = 0.13, p = .72; F[1,183] = 2.52, p = .11; F[1,182] = 1.24, p = .27, respectively, η^2 = .051).

There also was neither effect of condition (F[1,182] = 0.81, p = .37), age group (F[1,183] = 0.87, p = . 35), nor interaction between condition and age group on risk (F[1,182] = 0.008, p = .93, η^2 = .0078) in the Stock market task or (F[1,182] = 0.028, p = .88; F[1,183] = 1.57, p = .21; and F[1,182] = 0.26, p = .61, respectively, η^2 = .01) in the Spaceride task.

However, there was a significant effect of condition (242 for the unrewarded condition and 223 for the rewarded condition, F[1,181] = 8.96, p = .0031) and age group (200 for adolescents and 262 for adults, F[1,182] = 18.65, p < .001) and a nearly significant effect of interaction between condition and age group (F[1,181] = 3.43, p = .065, η^2 = .35) when alternative DV was used in the Stock Market task (see Figure 1), as well as an effect of interaction between condition and age group in the Spaceride task (F[1,182] = 4.75, p = .031). The effect of condition or age group in the latter task was not significant (F[1,182] = 1.08, p = .3; F[1,183] = 0.44, p = .14, respectively, η^2 = .019, see Figure 2).

Arousal The arousal differed significantly depending on condition (2.34 for not rewarded condition and 2.5 for rewarded condition, F[1, 180] = 43, p < .001, η^2 = .034), but it was not a mediator between condition and alternative DV in the Stock Market task (proportion mediated = -.06, 95% CI = [-.44, .25], p = .63).

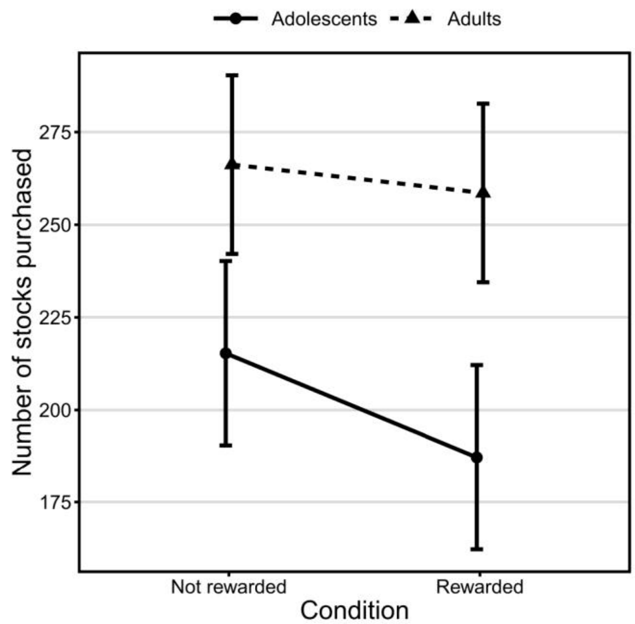

Figure 1: Quantity of stock purchased in the Stock Market task (alternative DV) in unrewarded and rewarded condition for adolescents and adults. Error bars indicate 95% confidence intervals.

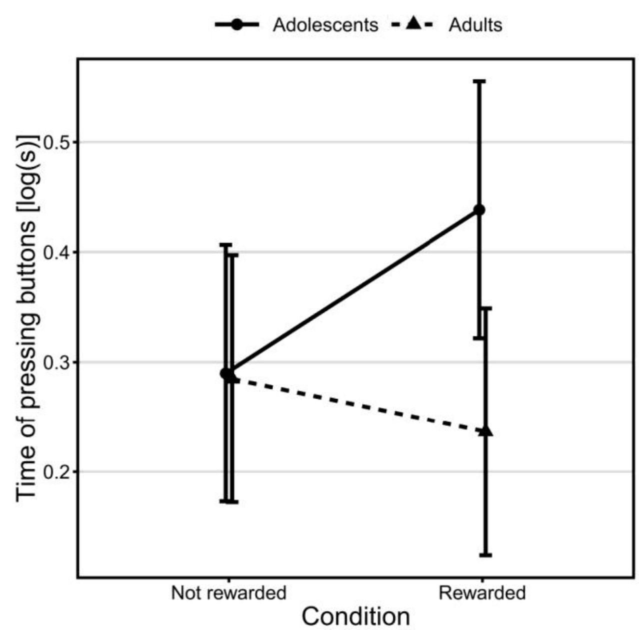

Figure 2: Logarithm of total time for which the accelerate or break buttons were pressed in the Spaceride task (alternative DV) in unrewarded and rewarded conditions for adolescents and adults. Error bars indicate 95% confidence intervals.

Discussion

The first important observation made in the present study is that participants were sensitive to rewards in risk tasks, but this sensitivity leads adolescents and young adults to different decision strategies, depending on the context of the task. Adolescent decisions, however, cannot be interpreted as an increase in tendency towards risk, which challenges the assumption of the dual systems model (Geier, 2013). In the Stock Market task we observed that adolescents generally purchased less stocks than adults and the number of purchased stocks decreased even more in the rewarded condition (Fig. 1). In the Spaceride task there were no differences between adolescents and adults in time taken to press the break or accelerate button in danger zones in the no-reward condition. However, in the rewarded condition adolescents pressed the brake and accelerator buttons more than adults, making the difference between the groups significant (Fig. 2). It is interesting why the presence of rewards led adolescents to purchase less stocks in the market and steer the spaceship more boldly through danger zones. Possibly, when they had the opportunity to earn real money, participants chose a strategy that leads, as they believe, to better performance in the task. If purchasing stocks in the market is generally perceived as leading to both big gains and big losses—the option with “the highest outcome variability” as Defoe et al. (2015) define risk—then purchasing less stocks when real money is earned can be interpreted as a strategy that protects participants from loss. Otherwise, flying more boldly through danger zones cannot be seen as a strategy preventing collisions. It should be noted that while in the Stoplight task (Chein et al., 2011) participants decide whether to stop at a yellow light or drive through the crossroads, in the Spaceride task it is possible to brake and accelerate through the entire length of danger zones. Flying more boldly (such as the “speed-brake-speed” strategy) in dangerous areas is related to maintaining high speed and attempting to slow down just before asteroids. Less bold flying is slower, but makes attempts to avoid collision more effective. Summing up these results, it appears that adolescents made more conservative decisions than adults in one of the tasks and more risky decisions in the other. The context of tasks is therefore a variable that determines whether adolescents manifest risk-taking or risk-aversion. We can speculate that more conservative decisions could be caused by a lack of familiarity with the contexts in which risk can occur (e.g. economic risk).

According to our hypothesis, participants reported higher emotional arousal in the rewarded condition. Such results suggest that the presence of a salient incentive leads to a greater motivational effort that manifests itself in higher reported arousal. We failed, however, to show that arousal mediates the relation between the presence of reward and risk-taking (or other decision strategy). As adolescents are viewed as impulsive risk-takers (Willoughby et al., 2013), the dual systems model predicts that high arousal in the rewarded condition enhances risk-taking because highly aroused adolescents cannot override risky tendencies. In our study, however, participants seemed to be able to make decisions irrespective of their arousal and did not allow it to negatively influence their performance. It might be the case that arousal leads to impulsive decision-making only in specific circumstances. For example, high arousal may trigger risk-taking only in individuals in a negative emotional state (such as anxiety) or under high cognitive load (see, e.g., Zangeneh, Blaszczynski & Turner, 2008). If the participants were in optimal emotional and cognitive state, reward-related arousal alone might not have been sufficient to cause a break-down in control processes and an increase in risk-taking. It is also possible that rewarding participants resulted in a higher but still optimal level of arousal, increasing not risk-taking, but effort. These explanations remain speculative and need further studies, but it seems that the dual systems model may oversimplify the proposed link between arousal and risk-taking.

Interesting results that challenge the dual systems model assumptions were also observed for the cognitive control measures. Firstly, adolescents were less accurate and slower in the Antisaccade task, while no differences between adolescents and adults were observed in the Stroop task. Thus, the antisaccade task seems to be more difficult for adolescents, a result which is consistent with previous studies (Geier & Luna, 2012; Paulsen et al., 2015) showing that performance in the Antisaccade task improves with age. Secondly, we found that reward had no effect on both the accuracy in the Antisaccade task and the Stroop effect. However, in the rewarded condition participants exhibited longer latencies in the Antisaccade task and shorter latencies in the Stroop task. These results are not surprising given the fact that participants were informed that they were being rewarded for accuracy in the first task and for response speed in the second. The intriguing issue here is why the presence of rewards influenced not the measures of cognitive control efficiency (reaction inhibition and interference control), but reaction latencies in the tasks. It is possible that rewards enhance not a measured skill (i.e. control processes) that might be difficult to improve, but the motivational effort to do well in the task. Such an interpretation seems to be consistent with the effects of reward observed in the risk tasks, where again not the performance (e.g. money earned in the Stock Market, driving time in the Spaceride), but the decision strategies (e.g. purchasing more or less stocks, driving more or less dynamically) were enhanced. Additionally, we failed to observe interaction between age, condition and cognitive control efficiency, which is contrary to the dual systems model and consistent with the behavioral results of Paulsen et al. (2015). The effects of reward on reaction latencies in both tasks were similar in adolescents and adults.

To conclude, the results obtained in the study challenge the assumptions of the dual systems model about the universality of adolescent risk-taking. Risk-taking as a consequence of the weakness of control processes and sensitivity to incentives possibly manifests itself in certain circumstances. In our study, adolescents made decisions which cannot be considered unequivocally risky or impulsive, despite the rewards. Further studies should help determine more precisely what set of circumstances triggers different behavioral responses in the presence of incentives and thus contribute to the development of the model.

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