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The contribution of "cool" and "hot" components of decision-making in adolescence: Implications for developmental psychopathology

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Abstract

Impairments in either "cool" or "hot" processes may represent two pathways to deficient decision-making. Whereas cool processes are associated with cognitive and rational decisions, hot processes are associated with emotional, affective, and visceral processes. In this study, 168 boys were administered a card-playing task at ages 13 and 14 years to assess response perseveration. This task was designed to initially reward playing and gradually associate playing with punishment. Measures of subjective ordering (cool processes) and neuroticism (hot processes) at age 13 years were used to examine how these individual characteristics relate to perseveration over time. A decrease in perseveration from age 13 to 14 was associated with cool processes whereas hot processes were associated with response perseveration only over time. A complementary but simultaneous assessment of cool and hot processes, such as neuropsychological and personality tests, could facilitate treatment planning of children with behavioral problems.

Keywords: Neuropsychology; Personality; Executive function; Decision making; Adolescence; Psychopathology; Card playing task

Whereas "cool" decision-making processes are associated with cognitive and rational decision-making, "hot" decision-making processes are associated with emotional, affective, and visceral responses. Both cool and hot decision-making can have clear adaptive or maladaptive value depending on the situation. On the one hand, effortful, reflective processing may be the most appropriate strategy to avoid repeating a mistake. On the other hand, a quick visceral response may be the most appropriate strategy in the face of oncoming danger.

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Impairments in either cool or hot processes may represent two pathways to deficient decision-making. The study of such processes has helped gain a better understanding of decision-making biases in the neurosciences (De Martino, Kumaran, Seymour, & Dolan, 2006) and in the science of neuroeconomics (Glimcher & Rustichini, 2004). In developmental psychopathology, however, more is known about the cognitive than the affective aspects of decision-making (Pennington & Ozonoff, 1996). Measures of decision-making are rarely analyzed simultaneously from cognitive and affective perspectives. Even though both cool and hot pathways may be involved, studies tend to emphasize the cool pathway at the expense of the hot pathway.

The contribution of affective processes to decision-making and performance has been studied with at least three different research paradigms. First, the contribution of affective processes to performance on cognitive tests has been studied by controlling for test motivation (Chan, Schmitt, DeShon, Clause, & Delbridge, 1997; Lynam, Moffitt, & Stouthamer-Loeber, 1993; Sanchez, Truxillo, & Bauer, 2000; Schmit & Ryan, 1992; Séguin, Nagin, Assaad, & Tremblay, 2004). Although this approach is useful for interpreting the contribution of affect to test performance, it does not enable a better understanding of the inherently affective aspects of specific tests. A second approach that emphasizes the contribution of affective processes to performance originates in research on social information-processing biases in aggression (Dodge et al., 2003; Lochman & Dodge, 1994). In this line of research, vignettes are used to assess decision-making biases; these vignettes typically present an ambiguous story that allows for an affectively charged interpretation. These vignettes are therefore designed to tap hot automatic as opposed to cool and more effortful processes. However, this research approach entails an implicit mixture of cool and hot processes that could be better separated, identified, and understood. In this paper, using a third paradigm, we will simultaneously examine cool and hot processes that bear on response perseveration as a measure of decision-making.

We will first very briefly review how both cool and hot processes emanate from a coordinated system. To do this, we will focus on working memory and neuroticism, two constructs that have been linked to dorsolateral prefrontal cortex and orbitofrontal cortex, respectively. Working memory abilities reflect an on-line capacity for manipulating information as opposed to maintaining that information (Crone, Wendelken, Donohue, van Leijenhorst, & Bunge, 2006). Working memory is therefore required for the complex organization of incoming information and responses. These abilities have their anatomical basis in the dorsolateral prefrontal cortex (Petrides, Alivisatos, Meyer, & Evans, 1993) and are highly reliant on effective dopaminergic transmission (Arnsten & Li, 2005; Sevy et al., 2006). This cool ability would decrease the likelihood of impulsive decision-making. Deficits in working memory are salient in physical aggression and hyperactivity (Séguin et al., 2004), and, more specifically, are related to violent behavior symptoms in conduct disorder (Barker et al., 2007).

In contrast, the concept of neuroticism captures a predisposition to mood swings, susceptibility to boredom, worry, anxiety, excessive interpersonal sensitivity, self-consciousness, and distractibility. Neuroticism appears to magnify sensitivities to punishment cues (Torrubia, Avila, Molto, & Caseras, 2001; Zuckerman, Joireman, Kraft, & Kuhlman, 1999) as well as to cues for rewards (Derryberry & Reed, 1994; Wallace & Newman, 1997). As such, one of the hallmarks of neuroticism is being “overly emotional, reacting too strongly to all sorts of stimuli, and find[ing] it difficult to get back on an even keel after each emotionally arousing experience” (Eysenck & Eysenck, 1975, p. 5). Neuroticism would be a characteristic of a more reactive sympathetic nervous system resulting in increased anxiety. It is positively associated with early waking cortisol (Portella, Harmer, Flint, Cowen, & Goodwin, 2005), but negatively correlated with anterior cortical thickness, particularly in the left orbitofrontal cortex, an effect that is possibly more pronounced in males (Wright et al., 2006). This latter finding is consistent with observations that the orbitofrontal cortex appears to play an important role in emotional appraisal (Rolls, 2004). Neuroticism would therefore be expected to impair decision-making when arousal is elicited in a non-specific fashion by cues for either punishment or reward. Such impairment in the ability to maintain flexible representations of motivational stimuli would constitute a deficit in hot processes (Zelazo & Müller, 2002). Accordingly, neuroticism is associated with inattention-disorganization characteristics of attention deficit hyperactivity disorder (Nigg et al., 2002), poor emotional regulation and affective instability (Miller & Pilkonis, 2006; Vaillant, DiRago, & Mukamal, 2006), as well as poor parenting (Ellenbogen & Hodgins, 2004).

The difference between cool and hot processes can be illustrated in the way in which they affect different phases of problem solving that are distinguished in the framework proposed by Zelazo, Carter, Reznick, and Frye (1997). The phases of problem-solving, from initially representing a problem, planning a strategy, executing the plan, to eventually evaluating the adequacy of an attempted solution, can all be seen as contributing to the function of goal-directed problem-solving. Working memory would be important for all phases. In contrast, Wallace and Newman (1997, 1998) proposed that neuroticism facilitates the automatic, involuntary deployment of attention at the cost of impairments in adaptive information processing and controlled self-regulatory processes. Although they did not articulate this effect in an executive function framework, they specifically proposed "this attentional process may adversely affect one's ability to engage in the controlled evaluation and correction of problematic cognitive and behavioral response tendencies" (Wallace & Newman, 1997, p. 135).

Following these principles, both cool and hot processes contribute to decision-making (Séguin & Zelazo, 2005; Zelazo, Müller, Frye, & Marcovitch, 2003). For this reason, it is probably impossible to design a task that is a pure measure of cool or hot decision-making. However, it is possible to design tasks that emphasize one or the other such as typical cognitive performance tasks and tasks designed to assess affective biases. Moreover, one could design a task that emphasizes the joint effects of cool and hot processes. One task that requires cool and hot processes is the card-playing task (CPT) (Siegel, 1978), also known as the door-opening task in studies of young children (Daugherty & Quay, 1991). The CPT uses one deck of cards with a predetermined sequence of "good" and "bad" cards. Good cards are rewarded and bad cards are punished. The player is asked to sample cards from this deck of 100 cards and is free to stop at any trial. The implicit underlying rule initially rewards playing but at a decreasing rate as trials accumulate (see Fig. 1). The rate of success decreases from 10/10 trials, to 0/10 trials across 10 blocks of trials. Thus, the corresponding earnings follow a quadratic function in relation to trials with maximum ambiguity in rewards and punishments lying between 40 and 60 cards, when the probability of winning is roughly equal to the probability of losing. At approximately 75 cards, the rate of punishment clearly exceeds the rate of rewards and we have previously defined this as the threshold for perseveration (Séguin, Arseneault, Boulerice, Harden, & Tremblay, 2002). Beyond this point, individuals make decisions to pursue playing despite their increasing loss. This task requires incidental learning and implicit reasoning because participants are not told that there might be an underlying rule. This essentially cool reasoning ability may offset a hot tendency to respond to rewards or punishment as experience with the task accumulates.

It has not been typical for studies of the CPT to examine whether both cognitive and affective components influence performance. In one study of the cognitive and motivational elements of impulse control, the CPT was considered a motivational instead of a cognitive task (Kindlon, Mezzacappa, & Earls, 1995). A varimax rotation artificially forced this task in an uncorrelated "motivational control" factor that included other tasks relying also heavily on inductive reasoning.

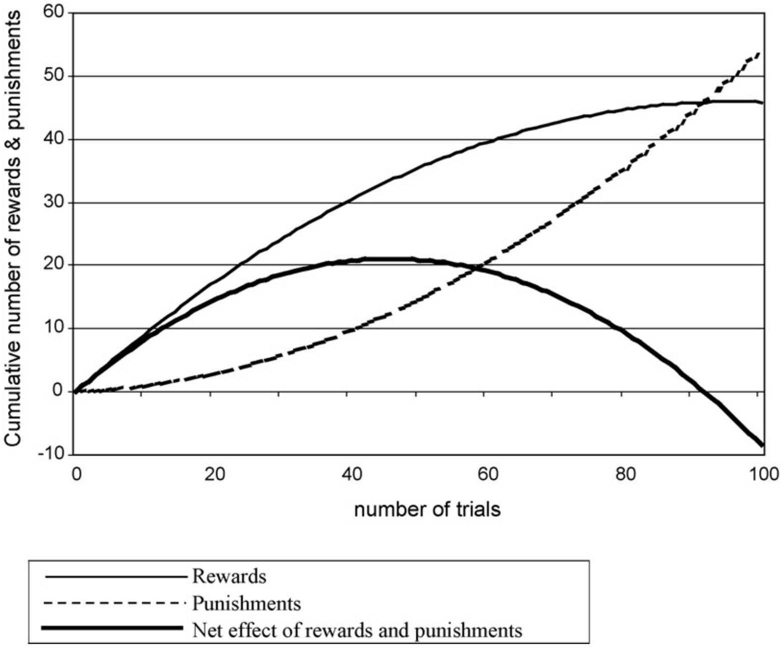


Fig. 1. Underlying pattern of the card-playing task.

Despite a relatively low loading on that factor (−0.44), the relation of the CPT to a "cognitive factor" could not be ascertained, although it was not correlated to an IQ measure. This stands in contrast to our earlier work in which we showed that working memory was associated with success on the CPT, and that neuroticism and working memory were statistically independent (Séguin et al., 2002). Furthermore, in contrast to Kindlon et al. (1995) who consider the CPT largely motivational in nature, we found that neuroticism was not correlated overall with number of cards played in two samples (Peterson et al., 2003). However, we note that the relation between neuroticism and performance on the CPT is rather complex. Specifically, we found that although boys with different histories of physical aggression perseverated equally on the CPT, neuroticism was predictably associated with perseveration in adolescent boys with an unstable history of physical aggression, but not in boys with a stable history of physical aggression or in non-aggressive boys (Séguin et al., 2002). Uncovering such differences in the correlates of response perseveration may be important for understanding developmental processes underlying psychopathology. Cool and hot processes have also been separated to distinguish primary and secondary psychopaths (Newman & Lorenz, 2002). Primary psychopaths are seen as those who are prototypically described as cold and unemotional, whereas secondary psychopaths may be best characterized as affectively unstable (Newman, MacCoon, Vaughn, & Sadeh, 2005).

Kindlon et al. (1995) also noted low temporal stability for CPT performance probably due to a significant drop of about 14 cards at time 2 from time 1 over a period of 2–5 months. This appears understandable a posteriori given the opportunity for learning to occur over repeated testing. Nonetheless, even despite repeated exposure to the CPT, some children, who were overheard saying, "I should stop now" (Kindlon et al., 1995, p. 658) perseverated even during the second administration of the CPT. But children could perseverate for different reasons. Although perseveration was not associated overall with neuroticism but was negatively associated with working memory when boys from our study first encountered the task, we wanted to know what kind of role these independent factors played over time. Theoretically, optimal function of cool and hot processes should help improve performance and facilitate learning over time, an effect that cannot be fully captured in a single administration of the CPT task. We thus administered the CPT twice with an interval of 1 year to describe perseveration across time in terms of cool and hot factors. We expected that optimal playing (i.e., not perseverating either year) and improvements over time (or learning) would be characterized by good performance on tests designed to assess cool and hot processes, and that perseverating as well as increases in perseveration across years would be characterized by poor cool and hot processes.

1. Method

1.1. Participants

To determine the contribution of cool and hot factors to decision-making we administered the CPT to 168 boys from an initial community sample of 1037 French Canadian boys who had been recruited in kindergarten from 53 schools in low socio-economic areas of Montréal (Tremblay et al., 1991; Tremblay, Pihl, Vitaro, & Dobkin, 1994). Boys from the sub-sample were invited to come to the laboratory for a day of assessment when they were 13 years and again when they were 14 years. Complete sampling details pertaining to age 13 and 14 years data collection have been documented elsewhere (Séguin et al., 2002; Séguin, Pihl, Harden, Tremblay, & Boulerice, 1995). Briefly, these boys are part of an ongoing longitudinal study that assesses, on a yearly basis, different aspects of development, using mother-, teacher-, and self-reports, as well as laboratory visits (Tremblay, Vitaro, Nagin, Pagani, & Séguin, 2003). The participants in this study were demographically similar to the remainder of the sample and showed similar rates of psychopathology as one would find in the general population for that age group. However, the rates of externalizing problems were in the higher end of the normal range in those who came to the laboratory (Séguin, Boulerice, Harden, Tremblay, & Pihl, 1999). Participants were treated according to APA ethical guidelines (American Psychological Association, 2002).

1.2. Procedure

1.2.1. Decision-making

The CPT was administered on a computer when the boys were 13 and 14 years of age. Face cards were rewarded by giving participants \$0.05 and number cards were punished by taking away the same amount. The participant kept the earnings at the end of the game. The participants were told that this was not a typical deck, so that counting cards would not be helpful. There were 10 blocks of 10 cards and the probability of face cards decreased gradually from 100% to 0% across those 10 blocks as shown in Fig. 1. The participants should perceive the implicit rule as they progress across blocks with maximum uncertainty in the middle blocks. The best strategy consists in stopping in those middle blocks where gains are maximal. However, due to the uncertainty involved, the optimal strategy would be to wait until this uncertainty is meaningfully reduced. We have demonstrated that boys who do best in this task tend to drop before 75 cards (Séguin et al., 2002). This single cut-off explained 65% of the variance of the continuous score when the boys were 13 years of age (Séguin et al., 2002) and therefore has been considered a more valid marker for perseveration than use of the continuous score (Fischer, Barkley, Smallish, & Fletcher, 2005).

1.2.2. Cool processes

At age 13 years, cool processes were assessed with a subjective ordering task designed to assess working memory (Petrides, Alivisatos, Meyer, et al., 1993; Wiegersma, van der Scheer, & Human, 1990). In this task, participants must randomly select numbers in a given range for which they are provided a starting number. At this age, ranges per difficulty level varied between 4, 6, 8, and 10 numbers with two trials per level. Participants were instructed not to use any pattern, to use all numbers in the range, and to avoid repeating a number. Thus participants must subjectively organize the problem in working memory without any external aid. Practice trials with 4-number problems were provided to the participants so they could learn to apply the rules. A good answer to a 10-number problem with 2 as a starting number could be 2, 3, 7, 9, 1, 8, 10, 4, 6, and 5. Trials were discontinued if the participants failed twice consecutively at the same level. Scores ranged from 0 to 8 with a mean of 3.36 (S.D. = 1.97), which represents success on 6–8 number trials (Séguin et al., 2002). Stability for this task over a 7-year period (ages 13–20 years, $n = 126$) was $r = 0.31$ ($p < .001$), and factor analysis showed that it loaded on an executive function factor (Séguin et al., 1995). This task is sensitive to dorsolateral cortex function (Petrides, Alivisatos, Meyer, et al., 1993; Wiegersma et al., 1990) and has been shown to be sensitive to physical aggression and hyperactivity (Séguin et al., 2004) as well as perseveration on the CPT (Séguin et al., 2002).

1.2.3. Hot processes

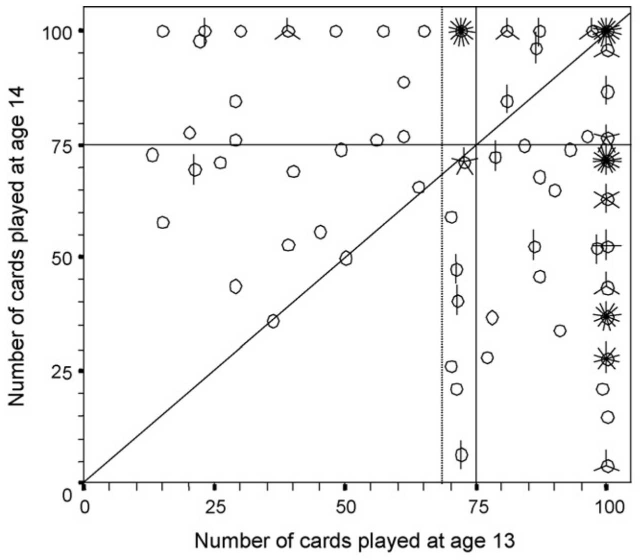
At age 13 years, a personality measure of neuroticism (Eysenck & Eysenck, 1975; Eysenck & Saklofske, 1983) was used to assess hot processes such as the sensitivity to rewards and punishment. Examples of the 20-item scale include: Are you moody? Do ideas run through your head so that you cannot sleep? Do you often feel life is very dull? Are you touchy about some things? Does your mind often wander off when you are doing some work? Do you sometimes feel especially cheerful and at other times sad without any good reason? Scores ranged from 0 to 19 ($M = 8.95$, S.D. = 4.79), and internal consistency was 0.84 in the current sample (Séguin et al., 2002). One and 6 months test–re-test were 0.74 and 0.72, respectively (Eysenck & Eysenck, 1975).

1.3. Data preparation

We used 75 cards as our cut-off for perseveration for both assessments. However, we cannot presume that all individuals who played below the cut-off were equally likely to not perseverate. Similarly, we could not presume that all individuals who played above the cut-off were equally likely to perseverate. In order to preserve the continuous nature of the underlying variable, we calculated probabilities of perseveration by rescaling the number of cards played between 0 and 75 to a range of 0.00–0.50, and the number of cards played between 75 and 100 to the range of 0.50–1.00. For each participant, the probabilities sum to 1. These values were then used to weigh analyses involving the categorical perseveration variables at ages 13 and 14 years and therefore increase their sensitivity. Subjective ordering and neuroticism scores were standardized for ease of interpretation.

2. Results

We first examined the distribution of perseveration across both assessments. In a second set of analyses, we examined patterns of perseveration across time in association with measures of cool and hot processes.



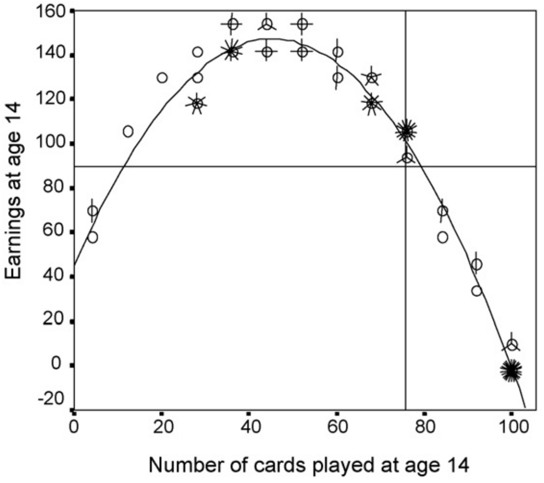
Note: Spikes represent frequencies of observations for a particular data point. Lines are drawn at 75 cards for both ages and at 67 cards for age 13.

Fig. 2. Sunflower plot of number of cards played at age 14 years as a function of number of cards played at age 13 years.

2.1. Response perseveration at 13 and 14 years

At 13 years, 65% of boys perseverated, whereas at age 14, only 36% of boys perseverated (weighted $\chi^2 = 12.59$, $\phi = -0.16$, $p < 0.0005$). This negative correlation reveals a learning effect over time. This effect of experience may be viewed by examining a sunflower plot of the number of cards played at age 14 years (*Y*-axis) as a function of the number of cards played at age 13 years (*X*-axis) in Fig. 2. Spikes represent frequencies of observations for a particular data point. The figure shows that all the boys who played fewer than 67 cards at age 13 played more cards at age 14 than at age 13 (all their values were above the diagonal). Although some boys who played 67 cards and more at age 13 played even more cards at age 14, the majority played fewer cards. However, the majority of those who dropped in the 67–75 cards range just before the a priori perseveration threshold at age 13 perseverated at age 14. The pattern is dichotomous within this narrow range; *all* of those who perseverated at age 14, i.e. who played >75 cards, played the full 100 cards. A similar, but reverse pattern is observed at age 14 years where one sees that a great number of boys who drop out just prior to the perseveration cut-off of 75 cards had played 100 cards at age 13 years. These boys are identified in Fig. 3 as well. Thus instead of an optimal point at which to withdraw, we speak of an optimal range.

We also examined whether boys who had perseverated at age 13 withdrew very early from the game at age 14 years or if they attempted to maximize gains. The plot in Fig. 2 shows the relation between earnings and number of cards played at age 14 for those who had perseverated at age 13. Besides several boys who played until the end of the task, the majority of cases were found in the mid range of number of cards played, which represents the range of highest gains possible. Therefore, it seems that not only did the boys learn not to perseverate, but they also learned to



Note: Spikes represent frequencies of observations for a particular data point. For some number of card playing values, values of earnings appear to be stacked due to graphics resolution. Horizontal line drawn at mean earnings. Vertical lines drawn at 75 cards.

Fig. 3. Earnings at age 14 years for those who perseverated at age 13 years.

optimize their gains. To test this, we performed a Mann–Whitney U-test on earnings as a function of perseveration a year earlier. We found that those who had perseverated at age 13 had higher ranking of gains at age 14 (93.16 vs. 75.1 – Mann–Whitney $U = 2661$, $p < 0.03$) than those who had not perseverated at age 13.

2.2. Response perseveration and hot and cold decision-making processes

We examined cognitive and affective processes as they relate to perseveration across time by crossing together perseveration at both ages in a 2 × 2 design. This yielded an age 13 by age 14 perseveration, 2 × 2 design with four groups: never perseverated, perseverated at age 13 only, perseverated at age 14 only, and perseverated at both ages. We used general linear model analysis of variance (GLM-MANOVA) from SAS (SAS Institute Inc., 2001) which is adapted for unbalanced designs. The multivariate models were all significant: for perseveration at age 13, Pillai's trace = 0.026, $F_{(2,163)} = 5.73$, $p < 0.005$; for perseveration at age 14, Pillai's trace = 0.048, $F_{(2,163)} = 10.70$, $p < 0.0001$; and for the interaction of perseveration at age 13 by perseveration at age 14, Pillai's trace = 0.032, $F_{(2,163)} = 7.06$, $p < 0.001$. The global effect for subjective ordering was significant ($F_{(3,164)} = 6.77$, $p < 0.01$, $R^2 = 0.046$). The specific effects for subjective ordering were as follows: for perseveration at age 13, $F_{(1,164)} = 10.09$, $p < 0.002$ (adjusted means for non-perseverative: $M = 0.19$, S.E. = 0.08; and perseverative: $M = -0.13$, S.E. = 0.06); for perseveration at age 14, $F_{(1,164)} = 11.61$, $p < 0.001$ (adjusted means for non-perseverative: $M = 0.20$, S.E. = 0.06; and perseverative: $M = -0.15$, S.E. = 0.08); for the interaction of perseveration at age 13 by perseveration at age 14, $F_{(1,164)} = 0.89$, $p < 0.35$. Similarly, the global effect for neuroticism was significant ($F_{(3,164)} = 7.91$, $p < 0.0001$, $R^2 = 0.05$). The specific effects for neuroticism were as follows: for perseveration at age 13, $F_{(1,164)} = 2.07$, $p = 0.15$; for perseveration at age 14,

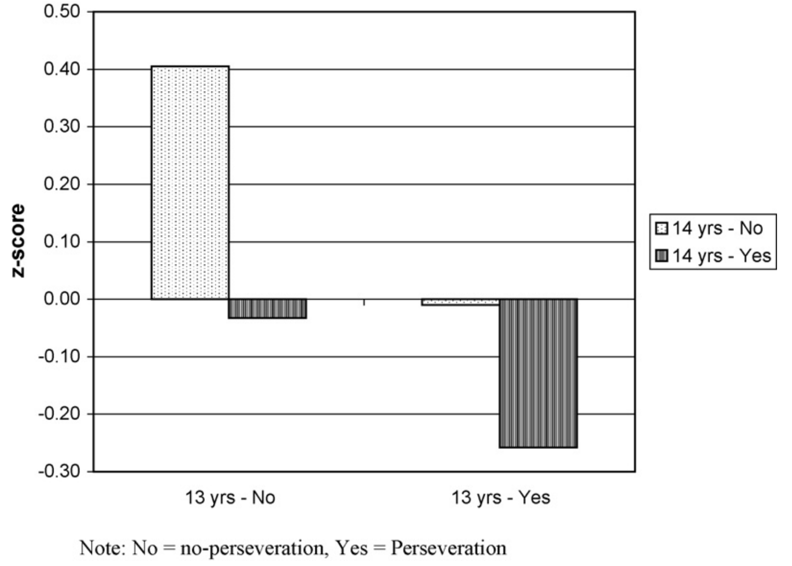


Fig. 4. Age 13 subjective ordering standardized score by perseveration at ages 13 and 14 years.

$F_{(1,164)} = 11.63$, $p < 0.001$; for the interaction of perseveration at age 13 by perseveration at age 14, $F_{(1,\ 164)} = 13.74$, $p < 0.0003$.

Weighted standardized means representing these effects are shown in Figs. 4 and 5. Fig. 4 shows that boys who never perseverated had the highest mean on the subjective ordering task and that the lowest scores were in the group that perseverated both times. Fig. 5 shows that boys who did not perseverate on the CPT at age 13 (13 No) but perseverated at age 14 (14 Yes) had the highest

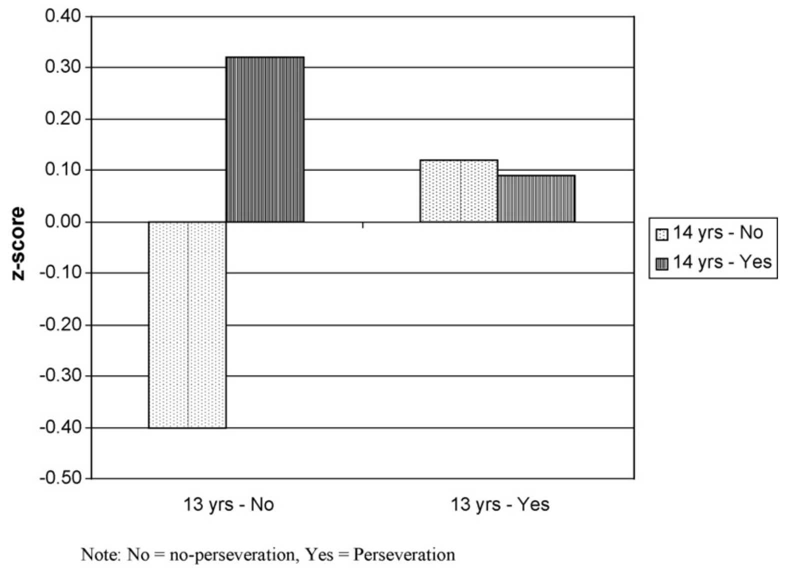


Fig. 5. Age 13 neuroticism standardized score by perseveration at ages 13 and 14 years.

neuroticism scores. By contrast, those who never perseverated had the lowest neuroticism score of the four groups. The two other groups had neuroticism scores slightly above the sample mean.

3. Discussion

This study of decision-making clearly indicates an overall learning effect over time. The proportion of boys who made poor decisions dropped by about 45% over the two assessments. More importantly, cognitive (cool) and affective (hot) processes influenced this learning effect. Learning was only associated with cool processes, as expected. In other words, cognitive processes were associated with best decision-making at either time, and could be enhancing learning over time in a clearly additive fashion. In contrast, no such learning effect over time was associated with hot processes. A statistical interaction indicated that hot processes were associated with suboptimal decision-making only over time and that highest amount of neuroticism was associated with poor decision-making only at age 14 years. Nonetheless, the learning effect may be optimal for those boys whose hot affective processes are better regulated. Still, cognitive and affective processes may both contribute to learning in that successful decision-making also requires the efficient regulation of hot affective processes. This idea is supported by the finding that the least amount of neuroticism was associated with best decision-making at both times.

The potential advantage afforded by cool processes to decision-making appear not only to enable an individual to better appraise a new situation, but also to learn from this experience when the situation is encountered later. This idea is the foundation of our educational system. Whereas individuals with the best cognitive abilities may do very well when encountering novel situations, others need to encounter stimuli more often in order to develop optimal responses. Cognitive abilities facilitate this learning over time.

In the present study, better decision-making was also characterized by low levels of neuroticism. Thus, individuals who can maintain affective stability and control their level of arousal when faced with motivationally significant stimuli performed better on the CPT. These individuals may be better at concentrating on key elements of a situation to derive the information relevant for better decision-making. This may be true regardless of cool abilities, because both domains were essentially uncorrelated. However, the most affectively unstable scores were found in the group who moved from a seemingly advantageous to a disadvantageous, if not self-defeating, decision-making. Their pattern of response appears to have been "nothing-or-all". This suggests that little learning of the underlying rule occurred at age 13 years and that optimal performance at that time may have been the result of initial avoidance or discomfort with novelty. It cannot really be due to a high sensitivity to punishment, because these individuals would have stopped much sooner when they encountered the task a second time. Instead, it is more likely that neuroticism disrupted attentional networks in a manner that is not specific to reward or punishment, as proposed by Wallace and Newman (1997). Finally, those who made poor decisions at age 13 years had a moderate amount of neuroticism, regardless of their performance at age 14 years. This suggests that other unaccounted attentional, cognitive, or affective processes would explain their decision.

3.1. Implications for developmental psychopathology

The CPT has been used extensively to study decision-making in childhood externalizing behaviors such as physical aggression (Séguin et al., 2002), hyperactivity (Fischer et al., 2005), oppositional disorders (Matthys, van Goozen, Snoek, & van Engeland, 2004; van Goozen et al., 2004), and other maladaptive behaviors (Goudriaan, Oosterlaan, de Beurs, & van den Brink, 2005; Peterson et al., 2003). Understanding the different ways in which hot and cool processes contribute to task performance could have important implications for understanding how children with maladaptive behavior solve problems in affectively significant contexts. Given what we report here, a complementary but simultaneous assessment of cool and hot processes, such as neuropsychological and personality test batteries, could facilitate treatment planning. We would therefore predict that an affectively dysregulated child with poor cool abilities will require learning strict stimulus–response associations in a more behavioral framework, whereas an affectively dysregulated child who shows good working memory can probably develop a broader perspective, provided a basic motivation to change behavior. Thus, an affective bias will be much more difficult to change in an individual who also has difficulty with flexible thinking on a cool task. On the other hand, a cognitively more sophisticated individual may benefit from cognitive restructuring of these biases through cognitive therapy, which is effective with some of the most severe forms of psychopathology (Beck & Rector, 2005) and is particularly useful to master affective disorders such as depression (Hollon et al., 2005) and anxiety (Paquette et al., 2003). Those therapies involve explicit identification of the underlying affective biases and corresponding beliefs. The therapist models problem-solving and coaches the individuals to use cool abilities by breaking down problems in specific steps, identifying and questioning assumptions, generating alternatives, reformulating goals, identifying roadblocks to behavior change (executing behaviors differently), and enabling careful monitoring of progress.

3.2. Implications for research, and limitations

Studies seeking to understand cognitive and affective processes underlying decision-making would benefit from examining such processes over repeated testing, with shorter delays between test administrations. With the CPT we would expect, for example, a further drop in perseveration and maximization of gains over additional exposures. However, the learning rates would likely differ as a function of cognitive and affective processes. Differences between learning rates could in turn be related to problem behaviors and help us understand how individuals affected by those problems make decisions over time.

Beyond these considerations, this study has limitations. We have discussed the concepts of cognitive and affective processes. However, we have only measured one aspect of each process, and the measures did not account fully for perseveration. Our cool task, for example, essentially involved deductive reasoning. A cool task emphasizing inductive reasoning, such as conditional association tasks (Petrides, 1985; Petrides, Alivisatos, Evans, & Meyer, 1993), may be a nice complement that could better match the actual inductive nature of the CPT. Conditional association tasks are affectively neutral and require deriving a stable set of underlying rules in an inductive manner with the use of feedback. Similarly, measures of attention could also provide insight into other cool processes (Newman, 1998). Further, other aspects of affective processes, such as anxiety regulation, could also be relevant to identify children who tend to be highly sensitive to punishment cues, and the personality concept of extraversion might prove useful in detecting sensitivity to rewards. We also cannot attribute the change from ages 13 to 14 years entirely to 'learning'. Unmeasured developmental processes and brain maturation in early adolescence could also partly explain the improvement in decision-making over time (Paus, 2005; Paus et al., 1999). Thus this task could be administered across key developmental landmarks, such as those prior to and following the onset of puberty with parallel assessments of key cool and hot processes. A matched control group exposed to the task only at age 14 years would also help untangle learning from maturational effects.

3.3. Concluding comments

In conclusion, the present study shows that both cool and hot processes are associated with decision-making when motivationally significant cues are salient. Future research should broaden the study of the cognitive and affective components that bear on performance on such tasks with a more comprehensive test battery in a developmental perspective with assessments at different stages of development. This research could be conducted on different types of psychopathologies. Finally, a complementary set of assessments of cognitive and affective processes could help select the most appropriate treatment for children with problem behaviors.

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