Attentional control in preschool predicts cognitive control at age 18

Inge-Marie Eigsti[1]

Vivian Zayas[2]

Walter Mischel[3]

Yuichi Shoda[2]

Ozlem Ayduk[4]

Mamta B. Dadlani[5]

Matthew C. Davidson[6]

J. Lawrence Aber[7]

B.J. Casey[6]

[1]Corresponding author. Department of Psychology, University of Connecticut

406 Babbidge Road, Unit 1020

Storrs, CT 06269

(860) 486-6021, inge-marie.eigsti@uconn.edu

[2]Department of Psychology, University of Washington

[3]Department of Psychology, Columbia University

[4]Department of Psychology, University of California – Berkeley

[5]Sackler-Lefcourt Center for Child Development

[6]Sackler Institute for Developmental Psychobiology, Weill Medical College of Cornell University

[7]Steinhardt School of Education, New York University

Word count: 3647

Abstract

In this longitudinal study, preschoolers who directed their attention toward reward aspects (high temptation focus) in a delay-of-gratification task were less efficient (slower) at detecting targets in a go/nogo task over ten years later. These results could not be explained by differences in error rates. The overall findings suggest that preschoolers' ability to effectively direct their attention away from tempting aspects of the rewards in a delay-of-gratification task may serve as a developmental precursor for the ability to perform inhibitory tasks such as the go/nogo task years later. Because performance on the go/nogo task has previously been characterized as involving activation of fronto-striatal regions, the present findings also suggest that the delay-of-gratification task may serve as an early marker of individual differences in the functional integrity of this circuitry. (129 words)

Attentional control in preschool predicts cognitive control at age 18

Cognitive control is the foundation of the ability to guide and control behavior and optimize outcomes (Braver & Cohen, 2001; Miller & Cohen, 2001). While performing tasks in the service of a desired goal, cognitive control enables individuals to suppress attention and responses to irrelevant information, even when that information is highly salient (Allport, 1987; Cohen & Servan-Schreiber, 1992). Although individual differences in cognitive control seem to be evident as early as 18 months of age (Posner & Rothbart, 2000), the degree to which these differences in early life predict cognitive control later in life has not been assessed. The present longitudinal investigation examined this ability with the delay of gratification task in preschoolers and the go/nogo paradigm when they became adolescents and young adults. Both tasks require the individual to effectively control attentional and behavioral responses to salient information, a hallmark of cognitive control and cognitive development (Casey et al., 2001).

Many developmental studies have shown that cognitive control becomes more efficient with development (Case, 1972; Flavell, Feach, & Chinsky, 1966; Keating & Bobbitt, 1978), not reaching full maturity until after age twelve (Passler, Isaac, & Hynd, 1985). This increase in efficiency is marked by a decrease in an individual's susceptibility to interference from competing information (e.g., Casey, Tottenham, & Fossella, 2002; Munakata, 2001). A range of tasks has been used to study cognitive control in children and adolescents, including Strooplike tasks (Tipper, Bourque, Anderson, & Brehaut, 1989), directed forgetting (Harnishfeger & Bjorkland, 1993), and go/nogo tasks (Luria, 1961). In one well-studied measure of cognitive control, the go/nogo task, participants are instructed to respond to target stimuli, but to refrain from responding to other nontarget stimuli. Children age seven to twelve show greater difficulty than adults in this task (twice as many errors overall and slower reaction time; Durston, Thomas, Yang et al., 2002). Moreover, parametrically increasing the number of go stimuli preceding a nogo stimulus has been shown to increase the task difficulty as indexed by greater proportion of false alarms, especially for children (Durston, Thomas, Worden, Yang, & Casey, 2002). That is, as the number of preceding go stimuli increases, there is a concomitant increase in the response salience of the go response, and subjects typically become more prone to errors in the nogo trials. This manipulation has been shown to provide a particularly sensitive probe of developmental changes in attentional control (Durston, Thomas, Yang et al., 2002).

In the preschool years, performance in the classic delay-of-gratification task has been shown to reflect children's ability to control their attention in the face of temptation (Mischel, 1974). In this paradigm, preschoolers try to postpone immediate gratification in order to attain a more valued outcome later (e.g., two cookies instead of just one). Research using this paradigm has provided compelling evidence for meaningful *individual differences* in attentional control (Rodriguez, Mischel, & Shoda, 1989). While some children are able to wait the entire fifteen-minute period in order to obtain the more valued reward, other children are not. Extensive research has shown that a key ingredient of success in the delay of gratification situation is the ability to allocate attention strategically during the waiting period (Mischel, Shoda, & Rodriguez, 1989).

Specifically, those children who are able to direct their attention *away* from the rewards and temptations in the situation (low temptation focus) are able to wait longer than those children who direct their attention *toward* them (high temptation focus).

The delay of gratification task has been widely studied, in part, because four-year-olds' performance in this task is diagnostic of consequential long-term outcomes, including adaptive social, cognitive and emotional functioning in adulthood. For example, four-year-old children who are more successful at waiting in the delay of gratification situation have been found as adolescents to be significantly more attentive, able to concentrate, and to exhibit greater self-control and frustration tolerance (Shoda, Mischel, & Peake, 1990). They also score higher on the Scholastic Aptitude Test (SAT) and are perceived as more interpersonally competent by parents and peers (Mischel et al., 1989). As adults, they are less likely to use drugs (Ayduk et al., 2000).

It is noteworthy that there are significant procedural differences in the delay of gratification task and the go/nogo task. Nevertheless, the two paradigms share a fundamental feature: In both tasks, performance requires controlling a prepotent response, whether it is producing a behavioral response in the go/nogo task, or attending to the temptations in the delay task. In addition, performance on the two tasks may rely, in part, on similar neural circuitry. Performance of the go/nogo paradigm has been linked to the development of fronto-striatal related circuitry (Booth et al., 2003; Durston, Thomas, Yang, et al., 2002; Vaidya et al., 1998). Activation of both the orbitofrontal region and anterior cingulate cortices relate to behavioral performance on the go/nogo task, differentiating children ages 7 to 11 years from young adults (Casey, Trainor, Orendi et al., 1997). Although no empirical study has directly examined the neural and biological basis underlying performance in the delay of gratification paradigm, existing research (e.g., Rothbart, Derryberry, & Posner, 1994) suggests that the anterior cingulate and limbic system may account for individual differences in the ability to effectively and flexibly deploy attention during the delay of gratification task (Mischel & Ayduk, 2004). Thus, circumstantial evidence suggests that performance in both the delay and the go/nogo tasks reflects similar biological and neural systems.

In the present study we examined whether attention control assessed in the delay of gratification task when subjects were four years old would be predictive of their performance on a go/nogo task as adolescents and young adults. We hypothesized that preschoolers who were able to focus their attention away from salient and tempting features of the delay situation (low temptation focus) would be more efficient in performing the go/nogo task, as indexed by faster reaction times to go trials. In contrast, we predicted that individuals who focused on the tempting aspects of the delay situation as preschoolers (high temptation focus) would have greater difficulty performing the go/nogo task. Moreover, a parametric manipulation of the number of preceding go trials was expected to increase the difficulty of the task, particularly for individuals who were predisposed to attending to the tempting features of the delay task.

Method

Subjects

Fifteen females and 19 males participated in a delay-of-gratification assessment when they were approximately 4 years of age (*mean age* = 4 years, 10 months, *SD* = 3 months; *range* = 4.33 – 5.25 years). At follow-up, they were approximately 14 years older (*mean age* = 18 years, 2 months, *SD* = 3 years, 3 months; *range* = 11.36 – 22.82

years old). The mean estimated IQ was 119 (*SD* = 10, *range* = 105 – 138) based on completion of subtests of the Wechsler Abbreviated Scale of Intelligence (WASI, Wechsler, 1999). Written consent (and assent when applicable) was obtained prior to testing, and procedures followed all applicable human research subjects guidelines.

Procedure

Delay-of-Gratification Situation. At age four, each participant was asked by a female experimenter to indicate a preference for either a smaller reward (e.g., one cookie) or larger reward (e.g., two cookies). All children in the present study selected the larger reward. The experimenter then explained to the child the rules of the game. The child was told that the experimenter would have to leave the room for a while to prepare for the next activity. If the child waited for the experimenter to return, without eating the reward or getting up from the seat, the child would receive the larger reward. If instead the child did not want to wait, he or she could ring a desk bell to summon the experimenter and receive the smaller reward. After confirming the child's understanding of the game, the child was seated at a table with the two rewards and a desk bell. The experimenter then left the room and did not return until 15 minutes had passed or the child had rung the bell, eaten the rewards, stood up, or shown any signs of distress.

The child's behavior during the waiting period was videotaped and subsequently coded second-by-second to obtain a fine-grained measure of attentional control. Temptation focus was the proportion of time that the child spent attending to consummatory aspects of the task, specifically, looking at or touching the bell or rewards. Delay time, or the number of seconds that a child was able to wait before ringing the bell, eating the rewards, or leaving his or her seat, was also recorded, but was not significantly related to performance on the go/nogo task. This is not surprising because delay time depends not only on effective attentional control, but also on a number of other factors, such as motivation to attain the delayed rewards. Temptation focus, in contrast, is a more direct measure of attentional control which appears to be particularly heuristic for predicting self-regulatory competence (e.g., Derryberry & Rothbart, 1988; Sethi, et al., 2000). Thus, the results reported here focus specifically on the measure of attentional control, temptation focus.

The go/nogo paradigm. The computer-administered go/nogo task required the subject to press a response button whenever a target "go" stimulus was present (75% of trials), but not to respond to the infrequently (25%) presented nontarget "nogo" stimulus. An illustration and detailed description of the go/nogo task is provided in Figure 1. The task included a manipulation of *context* (i.e., the number of go trials that preceded a nogo trial). Nogo trials were pseudo-randomly presented following a series of 0 to 6 go trials. This manipulation also provided go trials that were pseudo-randomly presented following 0 to 5 go trials. There were 16 trials per condition with the exception of Go-6 (Go trials following 5 Go's) and Nogo-6 (Nogo trials following 6 Go's), which consisted of 8 trials each in order to keep the design balanced.[1]

INSERT FIGURE 1

Results

Participants in the Delay-of-Gratification task waited an average of 530 seconds (8.8 minutes), with a range of 12 to 900 seconds and *SD* of 365 seconds. A total of 13

[1] There were also 8 Nogo-0 (Nogo trials following another Nogo trial) to avoid strategic responding; these Nogo-0 trials were not analyzed.

children waited for the entire 900 second period and 21 did not. Consistent with previous work (Peake, Hebl, & Mischel, 2002), children who waited the full 900 seconds spent proportionally less time, 7% (SD = .05) vs. 13% (SD = .11), engaging in temptation focus (i.e., attending to the bell and rewards), t(adjusted for unequal variances) (df = 31.06) = 2.04, $p < .05$.

Association between Age and Go/Nogo task performance

Age at follow-up was negatively correlated with overall false alarm rates in nogo trials, r =-.64, $p < .0001$.[2] Correlations between age and false alarms on nogo trials as a function of the number of preceding go trials were as follows: Nogo-1, r = -.57, $p < .001$; Nogo-2, r = -.41, $p < .02$; Nogo-3, r = -.64, p = .0001; Nogo-4, r = -.47, $p < .01$; Nogo-5, r = -.55, $p < .001$; Nogo-6, r = -.49, $p < .003$.[3]

Association between Individual Differences in Temptation Focus and Go/Nogo task performance

Temptation focus (i.e., attention to reward and bell) assessed in the delay-of-gratification task in preschool was not correlated with FAs and misses, although the correlations (r = .15, *n.s.* and r = .10, *n.s.*, respectively) were in the expected direction. ANOVA also showed no significant main effect of temptation focus, $F(1, 32) = .18$, *n.s.*, and no significant temptation focus × context interaction, $F(5, 160) =.70$, *n.s.*, on false alarms. Thus, temptation focus was not related to FA. The false alarm rates, however, were very low, especially among older participants consistent with previous work

---

[2] The proportion of misses (i.e., incorrectly failing to respond to go trials) was low (M = .02, SD = .04) and was negatively correlated with age (r = -.50, p = .002), suggesting that older participants made fewer misses.

[3] Because reaction times to Go-6 and false alarms to Nogo-6 are based on half as many trials as in the other conditions, correlations involving these variables are less reliable and thus likely to be an underestimate.

(Durston, Thomas, Yang et al., 2002), and the resultant "floor effect" may have masked differences between high vs. low temptation focus individuals.

Temptation focus assessed during preschool years was positively correlated with overall reaction time on go trials, $r = .38$, $p < .03$. Because reaction times were not significantly correlated (*r*s ranged from -.20 to .02, all *p*s > .26) with overall accuracy, faster reaction times on go trials were not at the expense of greater error (i.e., not due to speed-accuracy trade-off). These results indicate that individuals who focused their attention on tempting aspects of the delay situation were, on average, less efficient (slower) in performing the go-nogo task.

Further, correlations between temptation focus and reaction times on go trials appeared to strengthen in magnitude as the number of preceding go trials generally increased (Go-1, $r = .27$, *n.s.*; Go-2, $r = .37$, $p = .03$; Go-3, $r = .34$, $p = .05$; Go-4, $r = .39$, $p < .02$; Go-5, $r = .41$, $p < .02$; Go-6, $r = .31$, $p < .08$). (Note the correlation involving Go-6 was likely an underestimation due to having half as many trials in that condition compared to the other conditions.)

Context effect

We tested for the effect of context and its interaction with age using Hierarchical linear models (HLM) (HLMwin v 5.04; Bryk, Raudenbush, & Congdon, 2001). In the present study, the HLM consisted of a level-1 and level-2 model. The level-1 model estimated, for each participant j (j = 1-34), a regression line that predicted each participant's false alarm rate from the six levels of context i (i = 1-6) (i.e., number of preceding go trials) and residual error term, r_{ij}. The level-1 model was represented as follows:

$$(1.0) \quad [False\ Alarm_i]_j = b_{0j} + b_{1j}[Context_i] + r_{ij}$$

Because the level-1 predictor (i.e., context) was group-mean centered, the intercept, b_{0j}, is interpreted as participant j's mean false alarm rate (i.e., collapsing across levels of context). The slope, b_{1j}, is interpreted as the effect of the context manipulation, for each participant j, on false alarm rates.

The level-2 model predicted the level-1 coefficients (b_{0j} and b_{1j}) from the between-subjects factor (e.g., age and temptation focus). Specifically, as shown in equation 1.1, each participant j's mean false alarm rate, b_{0j}, was predicted from her age and temptation focus and a residual term, μ_{0j}.

$$(1.1) \qquad b_{0j} = \gamma_{00} + \gamma_{01}\,[Age_j] + \gamma_{02}\,[Temp.\ Focus_j] + \mu_{0j}$$

where the intercept, γ_{00}, is interpreted as the average false alarm rate for the entire sample; γ_{01} is the coefficient in the linear regression predicting each participant j's b_{0j} from participant j's age; and γ_{02} is the coefficient in the linear regression predicting each participant j's b_{0j} from participant j's temptation focus.

The level-2 analyses also predicted each participant j's context effect, b_{1j}, from participant's age and temptation focus and a residual term, μ_{1j}, as shown in equation 1.2:

$$(1.2) \qquad b_{1j} = \gamma_{10} + \gamma_{11}\,[Age_j] + \gamma_{12}\,[Temp.\ Focus_j] + \mu_{1j}$$

where the intercept, γ_{10}, is interpreted as the average context effect for the entire sample; γ_{01} and γ_{02} are the coefficients in the linear regression predicting each participant j's b_{1j} from participant j's age and temptation focus, respectively.

In all HLM analyses, level-2 predictor variables were grand-mean centered.

False Alarms on Nogo Trials. As shown in Table 1, γ_{00}, which represents the mean false alarm rate for the sample, was 15% (*SD* = 14%). Moreover, the linear effect of context was statistically significant (γ_{01} = .026, $t(31) = 3.506$, $p = .002$), such that false alarm rates increased, on average, 3% with each increase in number of preceding go trials.[4]

INSERT TABLE 1

Participants' age at the time of the follow-up had a significant effect on false alarm rates. Specifically, younger individuals made significantly more false alarms on nogo trials (γ_{01} = -.002, $t = 4.041$, $p < .0001$). For every 1 year increase in age, false alarms decreased by 2.4 %. Moreover, there was a significant age × context interaction (γ_{11} = -.0004, $t = 2.43$, $p = .021$), indicating that differences in false alarm rates between older and younger subjects increased as the number of preceding go trials increased.

To illustrate the data, we performed a median split on the independent variable of age (Table 2) and examined its relationship with false alarms to nogo trials. As shown in the left panel of Figure 2, adolescents (18 years old and younger) made more false alarms than adults. For both adolescents and adults, the number of false alarms increased as the number of preceding go trials increased (see right-hand panel of Figure 2). Moreover, the context effect had a more negative effect on false alarm rates for younger individuals.

[4] The percentage of misses (i.e., incorrectly failing to respond to go trials) was low (*M* = 2%, *SD* = 4%) and was negatively correlated with age ($r = -.50$, $p = .002$), suggesting that older participants made fewer misses.

INSERT TABLE 2

INSERT FIGURE 2

Temptation focus assessed during the delay-of-gratification task did not predict differences in false alarm rates on nogo trials.[5] The temptation focus × context interaction was not statistically significant.

Reaction Times on Go trials

Reaction times on go trials were analyzed using the HLM analyses described above, differing only in the outcome variable. Results of the HLM analyses are reported in Table 3.

INSERT Table 3

The mean reaction time on go trials for the entire sample was 318.49 ms (*SD* = 36.63 ms). The linear effect of context on reaction times was not statistically significant.

Age was not significantly associated with participant's average reaction time on go trials nor did it interact with context.

Temptation focus (i.e., attention to reward and bell) assessed in the delay-of-gratification task in preschool was positively associated with participants' mean reaction time on go trials assessed in the go/nogo task over 10 years later ($\gamma_{02} = 73.48$, $t = 2.55$, $p < .016$). These results indicate that with every 1 unit increase on temptation focus, there

[5] Correlational analyses showed that misses were also not correlated with temptation focus, although the correlation ($r = .10$, *n.s.*, respectively) was in the expected direction.

was a corresponding 74 ms second increase (slowing) in reaction times on go trials. The temptation × context interaction was not statistically significant.

Because reaction times were not significantly correlated (*r*s ranged from -.20 to .02, all *p*s > .26) with overall accuracy, faster reaction times on go trials were not at the expense of greater error, and thus not due to speed-accuracy trade-off. Moreover, when IQ was simultaneously entered as a level-2 predictor (along with temptation focus and age) in equation 1.2, IQ significantly predicted reaction time on go trials ($\gamma_{03} = -1.07$, $t(30) = 2.10$, $p < .044$). Nonetheless, even when the effect of IQ was statistically controlled, temptation focus remained a significant predictor of reaction time on go trials ($\gamma_{02} = 73.21$, $t = 2.74$, $p < .01$).

To illustrate these results, we performed a median split on the independent variable of temptation focus (Table 4) and examined its relationship with reaction times to go trials. As shown in the left panel of Figure 3, individuals high in temptation focus were, on average, slower at correctly detecting go trials compared to individuals low in temptation focus. Differences between high and low temptation focus individuals were largest in context with the greatest number of preceding go trials.

INSERT Table 4

INSERT FIGURE 3

Discussion

In a longitudinal investigation, we found, as expected, that preschoolers who directed their attention toward reward aspects (high temptation focus) in a delay of gratification task were more able as adolescents and young adults to efficiently perform the go/nogo task, as reflected by faster reaction times to go trials without a corresponding decrease in accuracy. Moreover, there was suggestive evidence that the association between temptation focus and reaction time to go trials was stronger in conditions in which the prepotency of making a go response and the need for greater inhibition was greatest.

False alarms to nogo trials significantly decreased with age. These developmental findings are consistent with previous reports (e.g., Durston, Thomas, Worden et al., 2002; Durston et al., 2003) documenting the greater accuracy, reflected in lower false alarm rates, of young adults, as compared to children, on this task. Moreover, also consistent with previous studies (Durston, Thomas, Worden et al., 2002; Durston, Thomas, Yang et al., 2002), the proportion of false alarms on nogo trials increased as the number of preceding go responses increased.

Previous studies have documented striking individual differences in the efficiency of cognitive control (Fan, McCandliss, Sommer, Raz, & Posner, 2002), and further found promising links to genetic variability (Fan, Fossella, Sommer, Wu, & Posner, 2003). Extending this work, the present findings suggest that the effectiveness of the attention control system, as reflected in preschoolers' ability to direct attention away from tempting aspects of the rewards in a delay-of-gratification task, may share a common mechanism with, or serve as a precursor for, their long-term ability to inhibit attentional and behavioral responses, as reflected years later in performance on the go/nogo task. Moreover, because slower reaction times in the go/nogo task have been well documented as being associated with immature development of fronto-striatal and related circuitry (Booth et al., 2003; Casey, Trainor et al., 1997; Davidson et al., 2004; Durston, Thomas, Worden et al., 2002; Durston, Thomas, Yang et al., 2002; Durston et al., 2003; Konishi et al., 1999; Vaidya et al., 1998), the findings suggest that high temptation focus in the delay of gratification task at age 4 to 5 years may already be a marker of the subsequent development of individual differences in this system in adolescence and adulthood.

References

Allport, A. (1987). Selection for action: some behavioral and neurophysiological considerations of attention and action. In H. H. A. F. Sanders (Ed.), *Perspectives on Perception and Action* (pp. 395-419). Hillsdale, NJ: Laurence Erlbaum Associates.

Ayduk, O., Mendoza-Denton, R., Mischel, W., Downey, G., Peake, P. K., & Rodriguez, M. (2000). Regulating the interpersonal self: strategic self-regulation for coping with rejection sensitivity. *Journal of Personality and Social Psychology, 79*(5), 776-792.

Booth, J. R., Burman, D. D., Meyer, J. R., Lei, Z., Trommer, B. L., Davenport, N. D., et al. (2003). Neural development of selective attention and response inhibition. *Neuroimage, 20*(2), 737-751.

Braver, T.S. & Cohen, J.D. (2001). Working memory, cognitive control, and prefrontal cortex: Computational and empirical studies. *Cognitive Processing*, 2, 25-55.

Case, R. (1972). Validation of a neo-Piagetian capacity construct. *Journal of Experimental Child Psychology, 14*, 287-302.

Casey, B. J., Castellanos, F. X., Giedd, J. N., Marsh, W. L., Hamburger, S. D., Schubert, A. B., et al. (1997). Implication of right frontostriatal circuitry in response inhibition and attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child and Adolescent Psychiatry, 36*, 374-383.

Casey, B. J., Durston, S., & Fossella, J. A. (2001). Evidence for a mechanistic model of cognitive control. *Clinical Neuroscience Research, 1*, 267-282.

Casey, B. J., Tottenham, N., & Fossella, J. (2002). Clinical, imaging, lesion, and genetic approaches toward a model of cognitive control. *Developmental Psychobiology, 40*(3), 237-254.

Casey, B. J., Trainor, R., Giedd, J., Vauss, Y., Vaituzis, C. K., Hamburger, S., et al. (1997). The role of the anterior cingulate in automatic and controlled processes: A developmental neuroanatomical study. *Developmental Psychobiology, 30*, 61-69.

Casey, B. J., Trainor, R. J., Orendi, J. L., Schubert, A. B., Nystrom, L. E., Giedd, J. N., et al. (1997). A developmental functional MRI study of prefrontal activation during performance of a go- nogo task. *Journal of Cognitive Neuroscience, 9*(6), 835-847.

Cohen, J. D., & Servan-Schreiber, D. (1992). Context, cortex, and dopamine: A connectionist approach to behavior and biology in schizophrenia. *Psychological Review, 99*(1), 45-77.

Davidson, M. C., Horvitz, J. C., Tottenham, N., Fossella, J. A., Watts, R., Ulug, A. M., et al. (2004). Differential cingulate and caudate activation following unexpected nonrewarding stimuli. *Neuroimage, 23*(3), 1039-1045.

Derryberry, D. & Rothbart, M.K. (1988). Affected, arousal, and attention as components of temperament. *Journal of Personality and Social Psychology, 55,* 958-966.

Durston, S., Thomas, K. M., Worden, M. S., Yang, Y., & Casey, B. J. (2002). The effect of preceding context on inhibition: an event-related fMRI study. *Neuroimage, 16*(2), 449-453.

Durston, S., Thomas, K. M., Yang, Y., Ulug, A. M., Zimmerman, R. D., & Casey, B. J. (2002). A neural basis for the development of inhibitory control. *Developmental Science, 5*(4), F9-F16.

Durston, S., Tottenham, N. T., Thomas, K. M., Davidson, M. C., Eigsti, I. M., Yang, Y., et al. (2003). Differential patterns of striatal activation in young children with or without ADHD. *Biological Psychiatry, 53*, 871-878.

Egner, T., & Hirsch, J. (2005). The neural correlates and functional integration of cognitive control in a Stroop task. *NeuroImage, 24*(2), 539-547.

Fan, J., Fossella, J. A., Sommer, T., Wu, Y., & Posner, M. I. (2003). Mapping the genetic variation of executive attention onto brain activity. *Proceedings of the National Academy of Sciences, 100*(12), 7406-7411.

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14*, 340-347.

Flavell, J. H., Feach, D. R., & Chinsky, J. M. (1966). Spontaneous verbal rehearsal in a memory task as a function of age. *Child Development, 37*, 283-299.

Harnishfeger, K. K., & Bjorkland, F. (1993). The ontogeny of inhibition mechanisms: A renewed approach to cognitive development. In R. Pasnek (Ed.), *Emerging themes in cognitive development.* (Vol. 1, pp. 28-49). New York: Springer-Verlag.

Hollingshead, A. B. (1975). *Four factor index of social status*. New Haven, CT: Yale University Department of Sociology.

Keating, D. P., & Bobbitt, B. L. (1978). Individual and developmental differences in cognitive processing components of mental ability. *Child Development, 49*, 155-167.

Konishi, S., Nakajima, K., Uchida, I., Kikyo, H., Kameyama, M., & Miyashita, Y. (1999). Common inhibitory mechanism in human inferior prefrontal cortex revealed by event-related functional MRI. *Brain, 122*(5), 981-991.

Luria, D. M. (1961). *The Role of Speech in the Regulation of Normal and Abnormal Behavior.* New York: Liveright.

Metcalfe, J., & Mischel, W. (1999). A hot/cool-system analysis of delay of gratification: dynamics of willpower. *Psychological Review, 106*(1), 3-19.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*, 167-202.

Mischel, W. (1974). Processes in delay of gratification. In L. Berkowitz (Ed.), *Advances in experimental social psychology* (Vol. 7). San Diego: Academic Press.

Mischel, W., & Ayduk, O. (2004). Willpower in a cognitive-affective processing system: The dynamics of delay of gratification. In K. D. Vohs & R. F. Baumeister (Eds.), *Handbook of self-regulation: Research, theory, and applications* (pp. 99-129). New York, NY: Guilford Press.

Mischel, W., Shoda, Y., & Rodriguez, M. L. (1989). Delay of gratification in children. *Science, 244*(4907), 933-938.

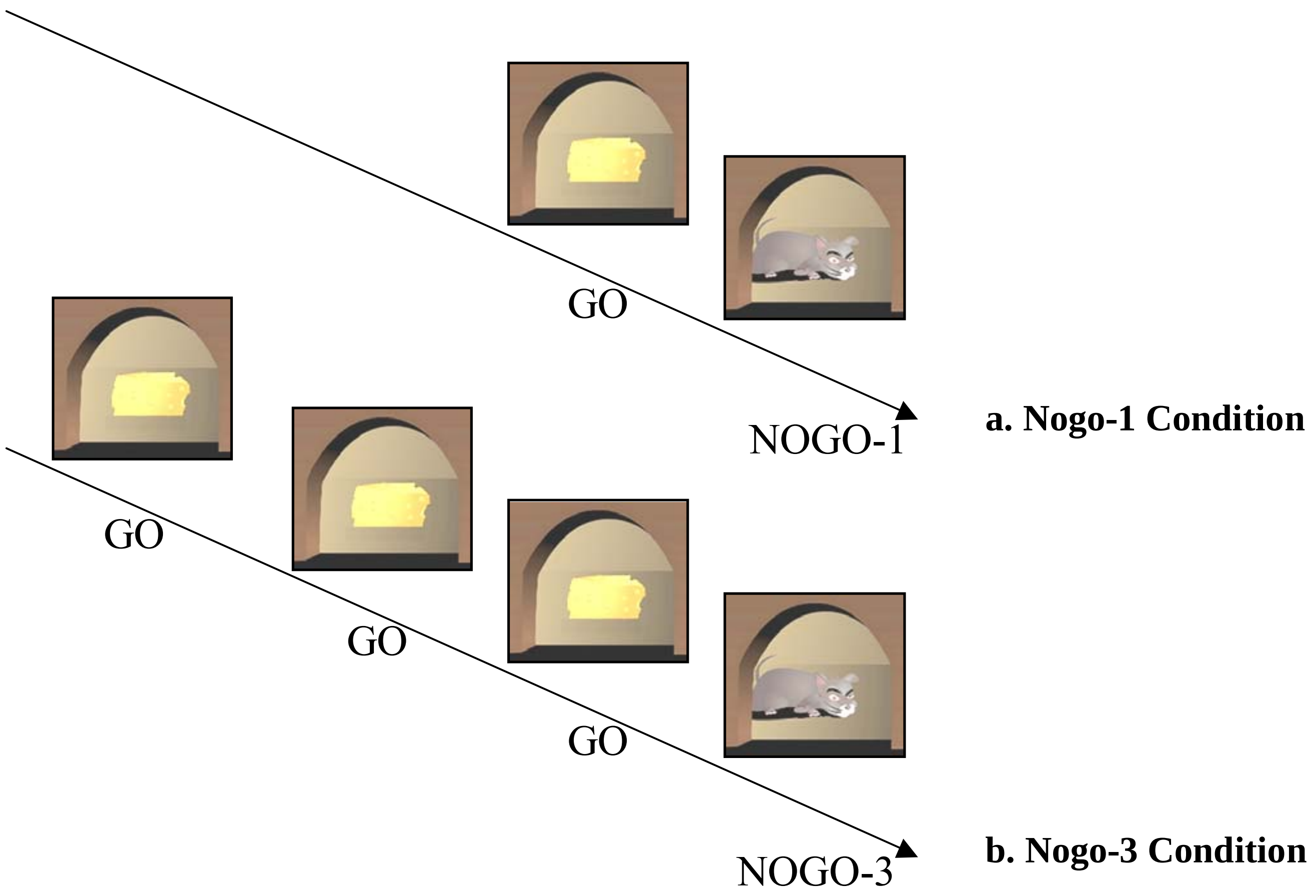
Munakata, Y. (2001). Graded representations in behavioral dissociations. *Trends in Cognitive Sciences, 5*(7), 309-315.

Noble, K. G., Norman, M. F., & Farah, M. J. (2005). Neurocognitive correlates of socioeconomic status in kindergarten children. *Developmental Science, 8*(1).

Passler, M. A., Isaac, W., & Hynd, G. W. (1985). Impulsivity: A multidimensional concept with developmental aspects. *Journal of Abnormal Child Psychology, 8*, 269-277.
Peake, P. K., Hebl, M., & Mischel, W. (2002). Strategic attention deployment for delay of gratification in working and waiting situations. *Developmental Psychology, 38*(2), 313-326.
Posner, M., & Rothbart, M. K. (2000). Developing mechanisms of self-regulation. *Development and psychopathology, 12*(3), 427-441.
Rodriguez, M. L., Mischel, W., & Shoda, Y. (1989). Cognitive person variables in the delay of gratification of older children at risk. *Journal of Personality and Social Psychology, 57*(2), 358-367.
Rothbart, M. K., Derryberry, D., & Posner, M. I. (1994). A psychobiological approach to the development of temperament. In J. E. Bates & T. D. Wachs (Eds.), *Temperament: Individual differences at the interface of biology and behavior*. Washington, DC: American Psychological Association.
Sethi, A., Mischel, W., Aber, J. L., Shoda, Y., & Rodriguez, M. L. (2000). The role of strategic attention deployment in development of self-regulation: predicting preschoolers' delay of gratification from mother-toddler interactions. *Developmental Psychobiology, 36*(6), 767-777.
Shoda, Y., Mischel, W., & Peake, P. K. (1990). Predicting adolescent cognitive and social competence from preschool delay of gratification: Identifying diagnostic conditions. *Developmental Psychology, 26*, 978-986.
Tipper, S. P., Bourque, T. A., Anderson, S. H., & Brehaut, J. C. (1989). Mechanisms of attention: a developmental study. *Journal of Experimental Child Psychology, 48*(3), 353-378.
Vaidya, C. J., Austin, G., Kirkorian, G., Ridlehuber, H. W. Q., Desmond, J. E., Glover, G. H., et al. (1998). Selective effects of methylphenidate in attention deficit hyperactivity disorder: a functional magnetic resonance study. *Proceedings of the National Academy of Sciences, USA, 95*, 14494-14455.
Volkow, N. D., Fowler, J. S., Wang, G. J., & Goldstein, R. Z. (2002). Role of dopamine, the frontal cortex and memory circuits in drug addiction: Insight from imaging studies. *Neurobiology of Learning and Memory, 78*(3), 610-624.
Wechsler, D. (1999). *Wechsler Abbreviated Scale of Intelligence*: The Psychological Corporation (Harcourt).

Figure 1

Schematic representation of go/nogo task.



Note. Stimuli were presented for 500 ms with a 1000 ms interstimulus interval (trial length = 1500 ms). Subjects were instructed "to feed a mouse by pressing to get the cheese, but not to press otherwise." The target (go) stimulus was a cartoon picture of cheese and the nontarget (nogo) stimulus was a cartoon picture of a cat. The above diagram shows the trial sequence for (a) nogo-1 (i.e., a nogo trial preceded by 1 go trial) and (b) nogo-3 (i.e., a nogo trial preceded by a 3 go trials). The task consisted of 384 trials divided into two 192-trial runs, and lasted 576 seconds total. Cartoons were chosen as stimuli for the task, because they were assumed to be appropriate and motivating for both children and young adults (Davidson et al., 2004).

Table 1

HLM coefficients estimating the effect of context, age, and temptation focus on false alarm rates

	coeff.	*s.e.*	*df*	*t*	*p*
Predictor					
Intercept, γ_{00}	.149	.019	31	7.81	.000
Context, γ_{10}	.026	.007	31	3.51	.002
Age, γ_{01}	-.002	.001	31	4.04	.000
Temp. Focus, γ_{02}	-.005	.097	31	-.05	.957
Context $\times$ *Age,* γ_{11}	-.0004	.00016	31	2.43	.021
Context $\times$ *Temp. Focus,* γ_{12}	-.083	.051	31	1.63	.114

Table 2

Demographics by age group

	Adolescents (*n* = 18)	Young adults (*n* = 16)
Age at follow-up in years*** (*SD*); *range*	15.6 (2.5); 11-18	20.5 (1.0); 19-22
Gender	10 M: 8 F	9 M: 7 F
Estimated IQ (WASI) [a] (*SD*); *range*	119 (9); 105-138	120 (10); 105-136
Socioeconomic status (SES) [b] (*SD*); *range*	64 (4); 53-66	63 (5); 50-66

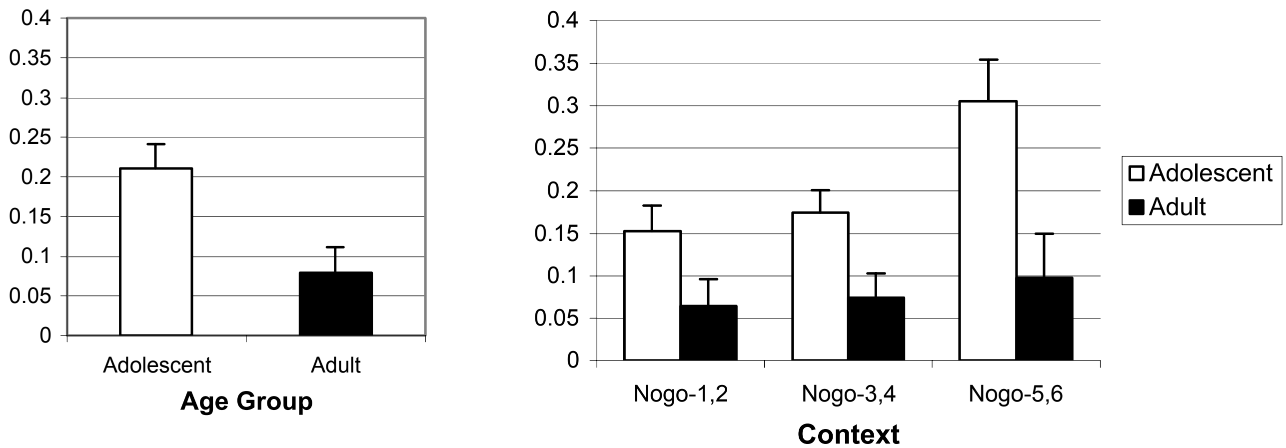
*** $p < .001$

[a] IQ scores were estimated from two subtests of the Wechsler Abbreviated Scale of Intelligence (WASI, Wechsler, 1999).

[b] SES = Hollingshead Four-Factor Index of Social Status (Hollingshead, 1975). While SES is a strong predictor of many measures of achievement (e.g., language function, literacy, and academic test scores), it has not been shown to account for individual variance in a delay-of-gratification task (Noble, Norman, & Farah, 2005). Thus, while participants are drawn from a small range of SES, results are likely applicable beyond this range.

Figure 2

False alarm (FA) rates on nogo trials as a function of age (adult vs. adolescent) and context (number of preceding go trials).



Note. Adolescent = 11 - 18 years; Adult = > 19 years. Bars represent standard error of the mean. For illustrative purposes, the data were combined as follows: nogo-1,2 was the mean of nogo-1 and nogo-2; nogo-3,4 was the mean of nogo-3 and nogo-4; and nogo-5,6 was the mean of nogo-5 and nogo-6.

Table 3

HLM coefficients estimating the effect of context, age, and temptation focus on reaction times

	coeff.	*s.e.*	*df*	*t*	*p*
Predictor					
Intercept, γ_{00}	318.49	5.66	31	56.29	.000
Context, γ_{10}	.38	1.15	31	.33	.746
Age, γ_{01}	-.14	.13	31	1.05	.305
Temp. Focus, γ_{02}	73.48	28.81	31	2.55	.016
Context $\times$ *Age,* γ_{11}	-.03	.03	31	.98	.337
Context $\times$ *Temp. Focus,* γ_{12}	4.36	4.47	31	.98	.337

Table 4

Demographics by temptation focus

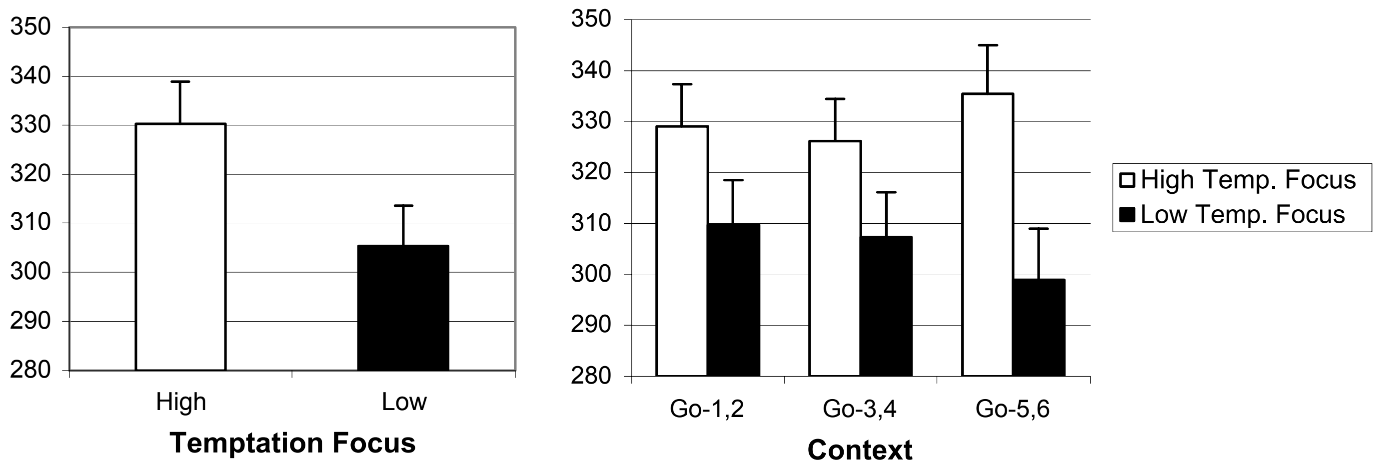
	High temptation focus [a] (*n* = 18)	Low temptation focus [a] (*n* = 16)
Mean age in years (*SD*); *range*	17.3 (3.4); 11-22	18.3 (3.1); 11-22
Delay time in seconds (*SD*); *range*	514 (388); 12-900	549 (349); 13-900
Waited 900 seconds in delay task (vs. those who did not wait) [b]	11 waited: 7 did not	10 waited: 6 did not
Gender	10 M: 8 F	9 M: 7 F
Estimated IQ (WASI) (*SD*)	120 (10); 105-138	119 (10); 105-135

[a] *High temptation focus* refers to subjects who, during the delay-of-gratification task, spent a greater proportion of time focusing their attention toward tempting features (the rewards or bell). The *low temptation focus* group spent a lesser proportion of time directing their attention away from tempting features.

[b] Analyses using the continuous (i.e., nondichotomized) measure of temptation focus showed that children who waited the full 900 seconds spent proportionally less time, 7% ($SD = .05$) vs. 13% ($SD = .11$) engaging in temptation focus (i.e., attending to the bell and rewards), t (adjusted for unequal variances) ($df = 31.06$) = 2.04, $p < .05$.

Figure 3

Mean reaction time (RT) on go trials as a function of temptation focus (high vs. low) and context (number of preceding go trials).



Note. Bars represent standard error of the mean. For illustrative purposes, the data were combined such that go-1,2 was the mean of go-1 and go-2, go-3,4 was the mean of go-3 and go-4, and go-5,6 was the mean of go-5 and go-6.