Now it's your turn!: Eye blink rate in a Jenga task modulated by interaction of task wait times,
effortful control, and internalizing behaviors

Kelley E. Gunther¹, Xiaoxue Fu², Leigha A. MacNeill³, Morgan Jones¹, Briana Ermanni⁴, &
Koraly Pérez-Edgar¹

¹The Pennsylvania State University, Department of Psychology, State College, PA, USA

²The University of South Carolina, Department of Psychology, Columbia, SC, USA

³Northwestern University Feinberg School of Medicine, Chicago, IL, USA

⁴Virginia Tech, Department of Psychology, Blacksburg, VA, USA

ORCID (where available)

Kelley E. Gunther: <https://orcid.org/0000-0002-9964-7896>

Xiaoxue Fu: <https://orcid.org/0000-0002-6124-731X>

Leigha A. MacNeill: <https://orcid.org/0000-0001-8218-3653>

Koraly Pérez-Edgar: <https://orcid.org/0000-0003-4051-9563>

Abstract

Dopamine is a versatile neurotransmitter implicated in many domains, including anxiety and effortful control. Where high levels of effortful control are often regarded as adaptive, other work suggests that high levels of effortful control may be a risk factor for anxiety. Dopamine signaling may be key in understanding these non-linear relations. Eye blink rate is a non-invasive proxy metric of midbrain dopamine activity. However, much of the work with eye blink rate has been constrained to screen-based tasks which lack in ecological validity. We tested whether changes in eye blink rate during a naturalistic effortful control task differ as a function of parent-reported effortful control and internalizing behaviors. Children played a Jenga-like game with an experimenter, as the experimenter took an increasingly long time to take their turn across trials. Blinks-per-second were computed during each wait period. Multilevel modeling examined the relation between duration of wait period, effortful control, and internalizing behaviors on eye blink rate, noting a significant 3-way interaction. Probing this interaction revealed that for children with low reported internalizing behaviors (-1 SD) and high reported effortful control (+1 SD), eye blink rate significantly decreased as they waited longer to take their turn. These findings index task-related changes in midbrain dopamine activity in relation to naturalistic task demands, and that these changes may vary as a function of individual differences in effortful control and internalizing behaviors. We discuss possible top-down mechanisms that may underlie these differences.

Key words: Dopamine, eye blink rate, internalizing behaviors, effortful control, ecological validity

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Introduction

Proficient effortful control is typically linked with positive developmental outcomes. Effortful control includes abilities such as suppressing a dominant response in favor of a subdominant behavior and planning one's behaviors, contributing to broader self-regulation (Rothbart & Rueda, 2005). High levels of effortful control are frequently associated with behaviors tied to adaptive socioemotional development, including better emotion regulation (Kochanska et al., 2000), greater prosociality (Pereira et al., 2021) and reduced risk of externalizing problems (Eisenberg et al., 2009; Kim-Spoon et al., 2019; Pereira et al., 2021; Valiente et al., 2003). Effortful control is also frequently regarded as a protective mechanism against internalizing problems (Eisenberg et al., 2009; Kim-Spoon et al., 2019).

However, in considering adaptive levels of effortful control it may be possible to have “too much of a good thing.” Specifically, high levels of effortful control may be a risk factor maladaptation in development. Murray and Kochanska (2002) found in a longitudinal sample of children from toddlerhood to the preschool years that there was an inverted “U” relation between level of effortful control and problem behaviors. Moderate levels of effortful control predicted fewer problem behaviors, while higher incidence of problem behaviors were predicted by levels of effortful control at the extremes. Additionally, the authors found that children with higher levels of effortful control had more parent-reported internalizing behaviors.

These perhaps counterintuitive relations between effortful control and adaptive development are also mirrored in the inhibitory control literature, a component part of the

multifaceted construct of effortful control. Some work has found an inverse relation between inhibitory control and internalizing symptomatology (Ansari & Derakshan et al., 2011; Basten et al., 2011; Kooijmans et al., 2000; Lengua, 2003; Wolfe & Bell, 2014). However, other research has found that increased inhibitory control may actually serve as a risk factor for higher levels of internalizing behaviors (Carlson & Wang, 2007; Eggum-Wilkens et al., 2016). Theoretical work suggests that overcontrolled behavior may potentiate attentional responses to environmental stimuli, particularly negatively valenced cues, thus prolonging periods of negative affect which may pave the way for internalizing symptoms in development (Henderson et al., 2015; Henderson & Wilson, 2017).

Dopamine signaling as a correlate of adaptive socioemotional behaviors and effortful control

There is limited research examining potential mechanisms underlying the idiosyncratic relations between levels of effortful control and anxiety risk. Prior work, including from our own lab (**BLINDED**), suggests that dopaminergic activity may relate to individual differences in internalizing risk as well as proficiency in behaviors encompassed by the effortful control umbrella. Dopamine is a versatile neurotransmitter associated with a wide spectrum of social and nonsocial behaviors. However, dopaminergic activity is difficult to measure directly and non-invasively in human models because most current common neuroimaging techniques do not reliably index neurochemical changes (Badgaiyan, 2014). Techniques such as positron emission tomography (PET) that can track dopamine binding are invasive, generally unforgiving to motion from the participant, and not often friendly for work in children (Badgaiyan, 2014; Cervenka et al., 2012).

In humans, eye blink rate is regarded as a peripheral index of striatal dopamine activity (Eckstein et al., 2017; Jonkees & Colzato, 2016; Karson, 1983; Van Slooten et al., 2019), specifically linked to striatal D1 and D2 receptors (Jonkees & Colzato, 2016), which are in turn broadly related to both cognitive and emotional control (Ayano, 2016). Eye blink rate and dopamine activity are positively related, where increases in eye blink rate are associated with increases in dopamine binding (Jonkees & Colzato, 2016; Karson, 1983; Van Slooten et al., 2019), although the exact mechanism underlying this association remains unclear (Bacher & Smotherman, 2003). This association has been validated through pharmacological studies in both animal (Groman et al., 2014; Karson, 1983; Kleven & Koek, 1996) and human (Cavanaugh et al., 2005; Jongkees & Colzato, 2016; Semlitsch et al., 1993) models, using dopamine agonists and antagonists, as well as in special populations with disorders characterized by low and high levels of dopamine, such as Parkinson's (Fitzpatrick et al., 2011; Hall, 1945; Karson et al., 1982) and Schizophrenia patients (Chan et al., 2010; Jongkees & Colzato, 2016), respectively. As such, eye blink rate has been used to index dopaminergic activity as young as infancy (Tummeltshammer et al., 2019; Werchan et al., 2016) and through adulthood (Barkley-Levinson & Galvan, 2017; Slagter et al., 2015).

Prior work has found interrelations between dopaminergic activity and effortful control. Zhang and colleagues (2015) found in a sample of healthy 18- to 25-year-olds that increased eye blink rate was associated with increased accuracy as well as efficiency on a go/no-go task. However, directionality is not entirely consistent across this line of work. For example, Colzato and colleagues (2009) found in a sample of healthy adult participants that increased eye blink rate was associated with *decreased* efficiency on a stop signal task.

Furthermore, patterns of dopamine receptor binding generally show an inverse relation with anxiety symptomatology (Moraga-Amaro et al., 2014; Cervenka et al., 2012). In cross-species work, dopamine depletion is linked to anxiety-like behaviors (Zerrindast & Khakpai, 2015). For example, low counts of systemic dopamine D3 receptors were associated with increased anxiety-like behaviors in a mouse model (Moraga-Amaro et al., 2014). Also, in humans, increased binding potential to D2 receptors in the medial prefrontal cortex (mPFC) and hippocampus was associated with decreases in reported social anxiety symptoms after treatment with cognitive behavioral therapy (Cervenka et al., 2012).

While seemingly no work has investigated interrelations between anxiety symptoms and eye blink rate, studies have investigated associations between dopaminergic activity and behaviors that in part describe the anxious phenotype, as well as between eye blink rate and anxious behaviors. These behaviors include variation in emotion regulation, reward processing, reinforcement learning, and patterns of exploration versus exploitation (Amstadter, 2008; Ayano, 2016; Caouette & Guyer, 2014; Pérez-Edgar, 2018; Silk et al., 2012).

For example, in a sample of adolescents, Barkley-Levinson and Galván (2017) found that eye blink rate was positively associated with the tendency to maximize reward within a task, suggesting that, specifically for adolescents, dopamine binding may be positively related to reward sensitivity. Additionally, Van Slooten and colleagues (2019) found that lower eye blink rate was related to individuals exploiting familiar, higher-valued options in a task, while higher eye blink rate was associated with the propensity to explore unfamiliar, lower-valued options. This work maps onto prior findings, where exploitive tendencies are associated with anxiety and

both anxiety and exploitive strategies are linked with lower dopamine binding (Cervenka et al., 2012; Moraga-Amaro et al., 2014; Van Slooten et al., 2019).

In sum, prior work shows associations between multi-modal measurements of dopaminergic activity and effortful control, as well as with anxiety-related behaviors. However, only limited research utilizes eye blink rate, and to date we are unaware of work that examines eye blink rate, anxiety, and effortful control within the same model to see how these constructs may interact.

Naturalistic assessments of cognitive processes

Much of the reviewed work has relied on computer-based tasks, which allow for greater control and repetition. However, this control often comes at the cost of external validity. In addition, traditional tasks are often not developmentally sensitive, leading to the use of alternate tasks. For example, many assessments of effortful control take the form of “games” that a child plays with the experimenter. In one such game, a snack delay task, a child must wait to retrieve a candy from a clear plastic cup. Alternately, children are asked to walk on a taped line as slowly as possible (Kochanska et al., 2000). These kinds of paradigms offer ecological validity by more closely resembling encounters a child may have in real life versus a computer task (Chaytor et al., 2006; Ladouce et al., 2017).

The Tower of Patience task has also been widely used to assess effortful control in children. The child and a familiar experimenter take turns either building a tower with blocks (Buss et al., 2014; Dyson et al., 2012; Kochanska et al., 1996; Murray & Kochanska, 2002; Pereira et al., 2021; Smith et al., 2013; von Suchodoletz et al., 2009) or withdrawing blocks from a Jenga-style tower (Durbin et al., 2007; Ruf et al., 2008). With each turn, the experimenter follows a schedule of increasingly lengthened delays to take their turn, making the child wait

longer to continue game play. Behavioral measures focus on different violations of the turn-taking rule, such as the child skipping the experimenter's turn and continuing to choose their own block, with the operationalization that less adherence to the turn-taking rule is associated with lower effortful control (Buss et al., 2014; Kochanska et al., 1996; Murray & Kochanska, 2002; Smith et al., 2013).

While many tasks assessing facets of effortful control move beyond the computer screen, dopaminergic activity has traditionally been measured in more constrained settings. PET can be used to measure dopamine binding in specific brain areas, but involves minimal motion on the part of the participant and severely limits tasks, as well as its use with children (Cervenka et al., 2012; Jonkees & Colzato, 2016). Other work (CITE) frequently uses electromyography or stationary eye tracking to quantify eye blink rates, but the associated tasks are also required to involve very little movement on the part of the participant and often are also presented on a computer screen. Therefore, little is known regarding the relation between eye blink rate and behavior in more naturalistic paradigms, particularly when embedded in a social context.

Mobile eye tracking can capture an individual's ocular activity while ambulatory, via convenient setups worn by the participant (Pérez-Edgar et al., 2020). An emerging literature has used mobile eye tracking to quantitatively measure visual attention patterns in naturalistic scenes in populations ranging from infancy to adulthood (Foulsham & Kingstone, 2017; Franchak et al., 2017; Fu et al., 2019). The same technology can be used to measure eye blinks while the participant is not constrained to a computer screen (Gunther & Pérez-Edgar, 2021). Leveraging this technology, we can then capture eye-blinks in the moment as children engage in a task eliciting effortful control.

In approaching this task, we also considered naturalistic time scales for analysis. Rather than averaging eye blink rate across the entire task, we parsed the blink data so we could compute blinks per second, and per wait period. This allowed us to assess how eye blink rate changed in part as a function of the task demands. Taking microlongitudinal approaches to data analysis and examining fluctuations over time may reveal patterns missed by taking averages across an entire task (Gunther et al., revise and resubmit).

Current Study

In this study, we collected eye blink rate during the Tower of Patience game, during which children were asked to wait increasingly long periods of time to take their turn. This task was designed to assess effortful control in a more true-to-life setting. We tested whether the duration that children were asked to wait for each trial, their parent-reported effortful control, their parent-reported internalizing symptoms, and/or the interaction of these variables significantly related to eye blink rate, a peripheral measure of dopamine activity. Where we expected significant interaction between time, parent-reported effortful control, and parent-reported internalizing symptoms, due to a paucity of prior research in this domain we did not have specific hypotheses pertaining to directionality of these associations.

Method

Participants

Participants in the current analyses were 55 children ranging from 5- to 7- years of age ($M = 6.15$ years, $SD = 0.60$, 49.1% female) identifying as White (87.3%), Asian (5.4%), African American (3.6%), Latino (1.8%), and other (1.8%), reflecting the demographics of the surrounding semi-rural community. Families were recruited using a University database of families expressing interest in participating in research studies, as well as community outreach

and word-of-mouth. We oversampled for high levels of Behavioral Inhibition (BI), a risk factor for social anxiety disorder in childhood and adolescence (Chronis-Tuscano et al., 2009), as part of the original study aims examining naturalistic visual attention in the context of risk for anxiety. Seventeen children (30.91%) in the final sample were classified as BI. Exclusion criteria for enrollment in the study included non-English speakers, gross developmental delays, or report of severe neurological or medical illnesses. All study procedures were approved by the Institutional Review Board at the Pennsylvania State University. All parents and children completed written consent/assent and were compensated for their time.

As part of recruitment, 163 children were screened for BI via parent report with the Behavioral Inhibition Questionnaire (BIQ; Bishop et al., 2003). Consistent with the previous literature (Broeren & Muris, 2009; Fu et al., 2017; Poole et al., 2020), children were recruited as a BI participant if their total BIQ score was greater than or equal to 119 or if their social novelty subscale score was greater than or equal to 60. Of the full screening sample, 39 children (23.9%) met the BI criteria.

After screening, 70 children (20 BI) were brought to the lab to complete a battery of episodes assessing temperamental reactivity, including the “Tower of Patience” episode included in these analyses (described further below). The mean age of the sample was 6.11 years ($SD = 0.60$) with 34 females (48.8%). The sample predominantly identified as White ($n = 61$, 87.1%). Participants were excluded due to: technical problems ($n=9$), requesting removal of the eye tracker ($n=1$), non-completion of the game ($n=4$), and being the twin of another participant ($n=1$). Figure 1 depicts a visualization of participant recruitment.

Procedure

Parents completed a series of online questionnaires about themselves and their children

prior to the laboratory visit.

Behavioral Inhibition. The BIQ (Bishop et al., 2003) includes 30 questions that assess a child's response to novelty, using a likert scale ranging from 1 ("Hardly Ever") to 7 ("Almost Always"). While the BIQ was used to recruit participants and enrich the sample categorically, BI was assessed as a continuous variable in the analyses, such that higher scores reflected higher levels of BI ($M = 92.82$, $SD = 27.48$). The BIQ had excellent internal consistency in this study (Chronbach's $\alpha = 0.95$).

Effortful Control. Effortful control was measured via parental report with the very short form of the Children's Behavior Questionnaire (CBQ-VSF; Rothbart et al., 2003). The CBQ-VSF includes 36 questions that assess aspects of a child's temperament including surgency, negative affect, and effortful control. A 7-point likert scale is used representing responses ranging from "extremely untrue of your child" to "extremely true of your child." We used the effortful control subscore as a continuous variable in our analysis, which is related to inhibitory control, attentional control, low intensity pleasure, and perceptual sensitivity (Putnam & Rothbart, 2006). Higher scores on this subscale reflect higher levels of effortful control ($M = 5.10$, $SD = 0.67$). The CBQ-VSF had good internal consistency in this study (Chronbach's $\alpha = 0.69$).

Internalizing behaviors. Internalizing behaviors were measured via the internalizing subscale of the Child Behavior Checklist (CBCL; Achenback & Edelbrock, 1983) and assessed as a continuous variable, such that higher values reflected a higher count of reported internalizing behaviors. We chose to use count of internalizing behaviors in these analyses rather than count of anxiety symptoms. While anxiety disorders are seen in children as young as preschool-age (Franz et al., 2013), it is more common for onset to be as late as adolescence or

adulthood (Beesdo et al., 2009). Since the sample for the current study is both young and healthy, there is relatively low likelihood that many children in this sample will display symptoms at or near a clinical threshold. Measuring internalizing behaviors is a broader classification that includes symptoms of anxiety, thus offering greater analytic variability and a better developmental match within the sample.

The mean count of internalizing behaviors in this sample was 6.09 ($SD = 5.10$, $range = 0 - 25$). The internalizing subscale of the CBCL also had good internal consistency in this study (Chronbach's $\alpha = 0.84$).

Tower of Patience task. The Tower of Patience task was used to elicit effortful control. In this episode, the child was seated at a table and introduced to a Jenga-like game, where they took turns playing with a familiar experimenter. They were told that they would alternate withdrawing wooden blocks from a vertically stacked tower and needed to avoid the tower's collapse. Each selected block was placed in an adjacent box after every turn. The blocks were three different colors, with each vertical third of the tower colored either blue, yellow, or red. Based on these colors the child was also introduced to a scoring scheme, where the lower third of blocks in the tower were worth three points if selected, the middle third were worth two points, and the final top third were each worth one point. The children were told that the player with the most points at the end of the game won. With each subsequent turn, the experimenters increasingly delayed in choosing a block to remove from the tower. The increasing delays were presumed to be increasingly frustrating for the child, and thus required greater effortful control to adhere to the turn-taking rules.

While a "naturalistic" task, the task was constrained in that the experimenter was provided time intervals to adhere to as closely as possible during the game. There were 7 trials

with time intervals as follows: trial 1 = no wait period, trial 2 = 10 second wait period, trial 3 = 20 second wait period, trial 4 = 30 second wait period, trial 5 = no wait period, trial 6 = 40 second wait period, trial 7 = 60 second wait period. After the final 60-second wait period, the experimenter would “accidentally” knock down the tower to end game play.

If the tower accidentally fell over during the progression of trials, the experimenter would re-build the tower, take a turn with no wait period, and then continue with the next specified trial. During each wait period, the experimenter was instructed to keep gaze and behavior ambiguous, so it was not clear to the child what was causing the delay. If the child spoke to the experimenter during the wait period, the experimenter either disregarded the child or provided a brief non-committal answer. If the child violated the turn-taking rule, the experimenter would wait until the trial was over to remind the child, “Remember how to play this game. First, I take a block, and then you take a block, then I take one, then you take one. That’s how we play this game.” Any subsequent violations of turn-taking were left unacknowledged. Four research assistants acted as the primary experimenter in the current sample (all female).

Ambulatory eye tracker. Participants wore a Pupil binocular ambulatory eye tracker (Pupil Labs; Kassner et al., 2014) to record their eye blinks throughout the Tower of Patience task. The headset consists of two separate cameras, each pointing at an eye, as well as a camera centered on the space immediately in front of the child, capturing their world view. Data were recorded either with Pupil Capture v.0.9.6 (Pupil Labs) installed on a Microsoft Surface Pro 3 tablet with Windows 10 used in an earlier phase of the larger study ($n = 12$ in final sample) or with Pupil Capture v.0.9.12 (Pupil Labs) installed on a MSI VR One Backpack PC also running Windows 10 ($n = 43$ in final sample). A monitor located in a separate room was remotely connected to the PC enclosed within the backpack for real-time monitoring of data quality during

the experiment. The headset plus the backpack were light enough so as not to hinder naturalistic movement during the session.

Data processing

Eye blink rate. Eye blinks were event coded during each wait period of the Tower of Patience task using Datavyu (Datavyu Team, 2014). Two independent coders completed behavioral coding for the sample, overlapping on 33% of videos to ensure reliability. Reliability between coders was calculated using a paired sample *t*-test, showing statistically comparable codes ($t = 0.89, p = 0.38$). Descriptive statistics for eye blink rate per trial can be seen in Table 1.

Behavioral coding. A coding scheme was developed to mark the onset and offset of each wait period, as well as the child's violations of the turn taking rule and their verbal and physical prompts to the experimenter to take their turn. Behavior was coded using Datavyu (Datavyu Team, 2014). A combination of the child's mobile eye tracking footage, a video captured of the scene using a video camera set up behind a two-way mirror, and audio recorded in the room was used to provide the most comprehensive coverage of behavior during the episode.

Trial onset was defined by when the child's selected block hit the bottom of their box used to store the drawn blocks. The trial offset was marked when the experimenter's selected block hit the bottom of their box, and/or the experimenter verbally told the child, "Now it's your turn!" If trials were out of order due to experimenter error or due to the tower falling before the game was completed, the coders adjusted the label of the trial such that it most closely matched the amount of time that the child had to wait, rather than the temporal order of trials originally established in the protocol.

A violation of turn taking was defined as the child removing blocks from the tower before the experimenter had chosen their block. The onset of the violation of turn taking was

defined as the child touching the block in the tower. A verbal prompt was defined as the child encouraging the experimenter to take their turn or commenting on how long they had been waiting. Examples include, “It’s your turn” or “Why do you take so long?” Chatter related to the game but not pertaining to the wait time or the experimenter’s pending turn (e.g., “I used to play this game at home.”) was not coded as a verbal prompt. A physical prompt was defined as physically directing the experimenter’s attention to the tower, which included pushing a block toward the experimenter, pointing at the tower, or attempting to select but not actually withdrawing a block. Gestures accompanied by vocalizations pertaining to the child’s own self planning (e.g., “What if I pick this one?”) were not coded as a physical prompt.

Summary variables computed included the total number of verbal prompts, physical prompts, and turn skips across all wait periods, as well as the latency to the child’s first verbal prompt. In coding the latency, a wait period was scored as the full time as per the protocol if the child makes no verbal prompts. If they did make a prompt, the onset of that wait period during which the prompt occurred was subtracted from the onset of the verbal prompt, and rounded to the nearest second. This value and the duration of all previous wait periods were summed. For this computation, any wait period durations that exceeded the prescribed wait time were truncated to the maximum wait time for that trial. If the child made no verbal prompts through the episode, they were then assigned the total value of all wait periods in the protocol, 160 seconds.

Three independent coders completed behavioral coding for the sample, overlapping on 24% of videos to ensure reliability. Frame-by-frame reliability for trial onsets/offsets as well as coded behaviors was computed across coders. Coders agreed on 94% of frames denoting the onset and offset of each trial, 98.3% of frames in which there was a verbal prompt, 99.3% of

frames in which there was a physical prompt, and 99.5% of frames in which there was a turn skip.

Data cleaning. Eye blink rate for each wait period was computed by dividing the number of coded blinks within each wait period by the coded duration of the wait period in seconds, yielding a unit of blinks per second.

In order to minimize noise in our naturalistic paradigm, we cleaned data on a trial-by-trial basis to retain trials that adhered as closely as possible to the protocol. We removed trials in which the trial duration was more than 2 standard deviations above or below the mean trial duration. This resulted in the removal of 17 trials in total (out of 269). Additionally, trials that were skipped by the experimenter in error (N=1) were treated as missing data. Means and standard deviations of the cleaned trial durations can be seen in Table 2.

Results

Descriptive statistics. With the relative novelty of this experimental design, we first sought to describe these behavioral and physiological measures within our sample and how they may correlate (Table 3, Table 4)

Multilevel model. We used multilevel modeling to examine the interaction between level of effortful control, level of internalizing symptoms, and the length of trial in seconds on repeated measures of eyeblink rate. We controlled for level of BI in this model to account for our sampling scheme. The model was based on 252 repeated measures of eye blinks per second, nested within 55 persons. Length of trial was also entered as a random effect. All variables in the model were continuous. The results from the multilevel model can be seen in Table 5.

Of note, there was a significant three-way interaction between internalizing symptoms, effortful control, and trial wait time on eye blink rate, $b < 0.001$, $p = .04$. There was also a trend-level main effect of trial wait time on eye blink rate, $b = 0.01$, $p = .06$.

To further understand the nature of this three-way interaction, we probed the interaction with simple slopes testing. Both internalizing behaviors and levels of effortful control were split into low, medium, and high levels by grouping at -1 SD, mean, and +1 SD, respectively. Here we found that for children with low (-1 SD) internalizing and high (+1 SD) effortful control, blinks per second significantly decreased as trial wait time increased, $b < -0.001$, $p = .02$ (Figure 2).

We noted from descriptive statistics that child sex was significantly related to reported effortful control and that child age was related to number of verbal prompts at trend level. We tested another model entering these variables as additional covariates and all effects reported above were the same in significance and directionality.

Discussion

Prior work suggests that dopamine has far-reaching correlates in many domains of development, including cognitive and socioemotional realms. Further understanding dopamine neurotransmission as it pertains to childhood behavior may help to elucidate the mechanisms that link executive functioning and risk for social maladaptation, like anxiety disorders. However, measuring dopaminergic activity is logistically difficult and paradigms are largely limited to PET scans or pharmaceutical manipulations. These constraints have historically limited both investigations in populations of healthy children as well as the type of paradigms that can be used while dopaminergic activity is concurrently measured.

Eye blink rate provides a peripheral measure of midbrain dopaminergic activity, and advances in ambulatory data collection have made it feasible to measure eye blink rate during a

naturalistic task in real time (Gunther & Pérez-Edgar, 2021). Here, we recorded eye blinks while children participated in the “Tower of Patience” episode, a task designed to elicit and assess effortful control. Notably, participants provided a relatively low level of analytic variability in their behavior. Indeed, only 3 children outright skipped the experimenter’s turn when the task requested that they wait until the experimenter chose a block. Additionally, 31% of the sample ($N = 17$) did not make any verbal prompts during these wait periods. Additionally, these overt behaviors measured were not significantly correlated to effortful control or internalizing behaviors as assessed by parent report (Table 4).

This relative homogeneity in overt behavior coupled with variation in attentional and neural processes is not uncommon in developmental work. In an overlapping sample, we found few behavioral differences as children interacted with a stranger wearing a scary gorilla mask, but did find that level of BI predicted proportion of gaze allocated to the stranger’s head/mask over time (**BLINDED**). Similarly, Wolfe and Bell (2014) found no behavioral differences in executive functioning ability as a function of shyness in a sample of preschoolers, but found that medial frontal EEG power differentiated between these groups.

This relative homogeneity in behavior provided a unique opportunity to investigate how changes in dopaminergic activity over the course of task demands may relate to or characterize individuals within the sample, above and beyond overt behaviors. While children across the sample had similar net behaviors, different neural mechanisms may have supported this response for different children. In this analysis we found a significant three-way interaction between reported effortful control, reported internalizing symptoms, and wait duration on eye blink rate. Probing the interaction revealed that for children with low reported internalizing symptoms and high reported effortful control, their eye blink rate significantly decreased as wait times during

the game increased. Therefore, for children with an effortful control and internalizing profile that may be considered adaptive, midbrain dopamine binding decreased as the task became more taxing for the child.

We did not have specific hypotheses pertaining to directionality of these associations. Generally, decreased dopamine levels are associated with greater anxiety, and associations between dopamine and components of effortful control remain mixed. Where some work has found an inverse relation between eye blink rate and efficiency on tasks requiring inhibition of a behavior (Colzato et al., 2009), these changes in eye blink rate over time may reflect these children with relatively high effortful control and relatively low internalizing symptoms becoming more efficient in inhibiting a prepotent response to skip the experimenter's turn as the task progresses. Alternately, where eye blink rate is positively associated with reward value and sensitivity (Barkley-Levinson & Galván, 2017; Tummeltshammer et al., 2019), decreases in eye blink rate may also reflect either conscious or subconscious changes in reward valuation for these children as the task becomes increasingly taxing.

This study is not without its limitations. We acknowledge a modest sample size in our analyses, although utilizing repeated measures of eye blink rate provided the necessary power to conduct these analyses. Additionally, while our task had increased ecological validity compared to the majority of prior work examining dopamine neurotransmission, our sample lacked generalizability due to sociodemographic homogeneity. Additionally, while we saw these data as an opportunity to investigate dopaminergic activity as a way to describe children with otherwise relatively invariant behaviors in response to the task demands, future research would benefit from analyses assessing interrelations between eye blink and overt behavior on similar tasks, and how eye blink rate may relate to rule violations during an effortful control task.

Taken together, these findings provide methodological proof of concept, as well as suggestions for best practices, in using eye blink rate as a peripheral measure of midbrain dopaminergic activity during a naturalistic task, and indexing changes in dopaminergic activity in response to task demands. We also find that changes in eye blink, measuring fluctuations in dopaminergic activity during changes in task demands, may vary as a function of effortful control and internalizing symptoms. These findings present dopamine binding as another important factor to consider in better understanding individual differences in both cognitive and socioemotional development.

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Figure 1. Visualization of participant recruitment

Figure 2. Graph probing three-way interaction between trial wait time, effortful control, and internalizing symptoms on blink rate. BI is included as a covariate in this analysis.

Table 1. Descriptive statistics for eye blink rate for each task trial

Trial Number	Mean EBR	Standard Deviation	Range	Skew	Kurtosis
Trial 2	0.11	0.1	0 – 0.41	0.69	-0.16
Trial 3	0.12	0.12	0 – 0.50	1.45	1.32
Trial 4	0.12	0.11	0 – 0.49	1.24	1.15
Trial 6	0.10	0.08	0 – 0.35	1.28	1.32
Trial 7	0.11	0.10	0 – 0.35	1.19	0.23

Note: Trials 1 and 5 did not require the participant to wait to take their turn

Table 2. Mean, standard deviation, and range of the duration of each task trial in seconds

Trial Number	Mean duration (seconds)	Standard Deviation (seconds)	Range (seconds)
Trial 2	15.95	3.74	7.32 – 25.15
Trial 3	26.48	4.02	17.36 – 36.04
Trial 4	37.69	4.04	30.06 – 46.79
Trial 6	49.43	5.95	36.36 – 63.70
Trial 7	64.00	7.50	45.45 – 83.64

Note: Trials 1 and 5 did not require the participant to wait to take their turn

Table 3. Descriptive statistics for behavioral and questionnaire-based variables

Measure	<i>M</i>	<i>SD</i>	Range	Skew	Kurtosis
Latency to first turn skip (seconds)	104.3	74.10	0.00-160.00	-0.61	-1.59
Latency to first verbal prompt (seconds)	35.24	49.21	0.00-160.00	1.28	0.19
Number of verbal prompts	2.76	3.46	0-14	1.53	1.66
Number of physical prompts	0.82	1.43	0-6	1.85	2.79
Number of turn skips	0.33	1.23	0-6	3.74	12.65
Internalizing symptoms (CBCL)	6.09	5.10	0-25	1.55	1.55
Effortful control (CBQ)	5.10	0.67	3.00-6.33	-0.56	-0.56
BIQ	92.82	27.48	43-149	-0.05	-0.05

Table 4. Spearman's correlation table showing interrelations between demographic variables and coded behavioral variables. Age and sex were included in correlations to test for any significant differences and inform subsequent modeling.

	1	2	3	4	5	6	7	8	9
1. Latency to first turn skip (seconds)	-								
2. Latency to first verbal prompt (seconds)	0.74***	-							
3. Number of verbal prompts	0.73***	0.36**	-						
4. Number of physical prompts	0.44***	0.15	0.66***	-					
5. Number of turn skips	-0.21	0.13	0.10	0.02	-				
6. Internalizing symptoms (CBCL)	-0.01	0.06	-0.05	-0.16	0.04	-			
7. Effortful control (CBQ)	-0.03	0.07	-0.05	0.02	0.15	-0.04	-		
8. Sex (0 = male, 1 = female)	-0.15	-0.19	-0.06	-0.08	-0.06	-0.09	0.32*	-	
9. Age (years)	-0.16	-0.09	-0.26+	-0.07	-0.04	-0.19	-0.16	-0.15	-
10. BIQ	-0.12	-0.08	-0.21	-0.15	-0.16	0.56***	0.01	0.00	0.05

+ $p < .1$, * $p < .05$, ** $p < .01$, *** $p < .001$.

Table 5. Results from multilevel model showing experimental variables moderating within-person differences in eye blink rate per trial of task.

	Est.	SE	<i>t</i>
Fixed effects			
Intercept	-0.08	0.20	-0.39
BI	< -0.001	< 0.001	-0.58
Internalizing symptoms	0.03	0.02	1.34
Effortful control	0.04	0.04	1.11
Trial wait time	0.01+	< 0.01	1.87
Internalizing * Eff. control	-0.01	< 0.01	-1.24
Internalizing * Trial wait time	< -0.001*	< 0.001	-2.11
Eff. control * Trial wait time	< -0.01*	< 0.001	-2.01
Internalizing * Eff. control * Trial wait time	< 0.001*	< 0.001	2.11
Random effects			
Trial wait time	< 0.001		
Residual	0.05		

Note: Model based on 252 repeated measures of eye blinks per second, nested within 55 persons.

+ $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$