Response time adjustment in the Stop Signal Task: Development in children and adolescents

Annie Dupuis[1,2], Maheshan Indralingam[2], Andre Chevrier, Jennifer Crosbie[3], Paul Arnold[4], Christie L. Burton[3], Russell Schachar[3]

[1] Biostatistics: Design and Analysis Unit, Research Institute, The Hospital for Sick Children

[2] Biostatistics, Dalla Lana School of Public Health, University of Toronto

[3] Department of Psychiatry, Neurosciences and Mental Health, Research Institute, The Hospital for Sick Children, University of Toronto

[4] Alberta Innovates Health Solutions (AIHS) Translational Research Chair in Child and Youth Mental Health, Departments of Psychiatry & Medical Genetics, Cummings School of Medicine, University of Calgary

CITATION

Dupuis, A., Indralingam, M., Chevrier, A., Crosbie, J., Arnold, P., Burton, C. L., & Schachar, R. (2019). Response Time Adjustment in the Stop Signal Task: Development in Children and Adolescents. Child Development, 90(2), e263–e272. https://doi.org/10.1111/cdev.13062.

Abstract

Adjusting speed to maintain fast and accurate performance is critical to goal-directed behavior. We examined development of response time adjustments in the stop signal task (SST) in 13,709 individuals aged 6-17 years (49.0% Caucasian) across four trial types: correct and incorrect go, successful (stop-inhibit), and failed (stop-respond) trials. People sped more after correct than after incorrect go responses and slowed more after failed stop trials than after successful trials. Greater slowing after stop-respond trials was associated with better response inhibition; greater slowing after stop-inhibit trials was associated with poorer response inhibition. Response time adjustments were evident in children as young as age 6, developed throughout childhood, and plateaued by age 10. Results were consistent with the predictions of the error detection and shifting goal priority hypotheses for adjustments.

Keywords: stop signal task; performance monitoring; error detection.

Abbreviations: ITSSRT – integrated stop signal reaction time; CGRTSD – correct go response time standard deviation

3 Development of response time adjustment in the SST.

People often confront situations that demand quick and accurate responses in ever-changing and ambiguous environments (Rabbitt, 1969). The high frequency and cost of errors have led to the evolution of a performance monitoring (also called “error detection”) system which scrutinizes our actions to detect errors and derives appropriate cognitive, affective, and autonomic adaptations essential to optimize future performance (Gehring et al., 1993; Holroyd and Coles, 2002). The ability to make response time adjustments reflects cognitive control and is critical to goal-directed behavior (Gehring et al., 1993; Holroyd and Coles, 2002).

Although the capacity to detect errors is present from an early age (Hanley et al., 2016), relatively little is known about how this ability develops. What is known is based largely on changes in electrophysiological indices of error detection (error-related negativity, ERN) rather than on direct measurement of adjustment. Previous behavioral studies show inconsistent age effects (Gupta et al., 2009; Schachar et al., 2004; Wiersema et al., 2007) but have included too few participants and covered too limited an age range to model developmental trajectories. No study has examined the development of response time adjustment in behavioral tasks from early childhood to late adolescence, a time of rapid neural, social and psychological changes (Shaw et al., 2011). The development of performance monitoring has also not been compared with that of other processes involving executive control such as response inhibition or motor execution.

The stop signal task (SST), primarily used to estimate the latency of the stopping process (stop signal reaction time, SSRT), can be used to study response time adjustments to performance errors. The SST involves a choice response time task (go task) and an inhibition task in which, on a random subset of trials, a signal is presented that instructs the participant to withhold their response (stop trials) on that particular trial. The delay between presentation of the go (X or O) and the stop signal (usually a tone) is dynamically adjusted so that, on average, participants are able to stop 50% of their responses when the stop signal is presented. Consequently, the SST affords an opportunity to compare how people of different ages adjust their response time after failed inhibition (stop-respond trials), after successful inhibition (stop-inhibit) and after correct and incorrect go responses.

Several hypotheses exist for response time adjustments in the SST in adults (Bissett and Logan, 2011). The error detection hypothesis (Laming, 1968; Rabbitt, 1966a, 1966b) holds that subjects slow their response time after errors in order to reduce the probability of future errors. This hypothesis predicts slowing after failed inhibition (stop-respond trials), but not after successful inhibition (stop-inhibit). The goal priority hypothesis (Leotti and Wager, 2010; Liddle et al., 2009) proposes that subjects shift their priority to the stop aspect of the task after stop signals because stopping requires caution relative to performance on the go task which requires speed. The goal priority hypothesis predicts slowing after all stop-signal trials. The response conflict monitoring hypothesis (Botvinick et al., 2001) maintains that the recruitment of control processes occurs as a result of conflict, or co-activation of competing responses (Ito et al., 2003; Stuphorn et al., 2000; Stuphorn and Schall, 2006). Accordingly, there should be greater slowing after stop-inhibit trials than after stop-respond trials because of greater conflict among competing responses on stop-inhibit trials. These hypotheses have not been tested in children or youth.

In this study, we examined the development of response time adjustments in the SST in 13,709 children and adolescents (aged 6-17) from the general community, compared development in response time adjustments with development in latency of response inhibition (SSRT) and response execution (correct go response time) and evaluated the predictions made by several competing models of performance following errors (Bissett and Logan, 2011).

Methods

Participants

Participants were 13,709 individuals aged 6-17 years (mean age = 11.0 years) who visited a local Science Centre (see Crosbie et al., 2013). The ethnic makeup of the sample reflected that surrounding diverse urban centre, with only 49.0% classified as Caucasian and a full 32.2% of the sample being of mixed heritage (four grandparents not all of the same ethnicity). Ethnicity was not associated with stop task variables (Crosbie et al., 2013). The study was approved by the Sick Kids institutional research ethics board. Participants received a small prize for their participation.

Participants were equally distributed between males and females (6798 females, 49.6%). Postal codes were referenced against 2006 Canadian national census data to obtain size-adjusted household income (Wilkins, 2009). Although there was a bias toward higher family income in the study sample compared to the surrounding community, family income had no significant effect on any of the stop task variables.

Stop Signal task

The SST involves two sub-tasks (the go task and the stop task). The go task involves discrimination of an X and an O presented one at a time for 1000 ms in the center of a computer screen following a 500 ms fixation point. Participants are instructed to respond as quickly as they can without making mistakes. On a random subset (25%) of trials, a stop signal (a tone presented through headphones) follows the onset of the go task. Upon hearing the stop signal, participants are instructed to withhold their response to the X or O on that particular trial. Stop signal delay, initially set at 250 ms, is dynamically adjusted depending on whether or not the participant successfully stops or fails to stop on a particular trial. If they stop, the delay is increased by 50 ms on the next stop trial. If they fail to stop, delay is decreased by 50 ms. Using this tracking algorithm, the stop signal delay converges on the delay at which individuals are able to stop 50% of the time.

Instructions were standardized and presented to participants via head phones and participants responded using a handheld controller. Participants were supervised throughout testing to ensure that they understood and complied with instructions. Following a practice block of 24 trials, four experimental blocks of 24 trials each (18 go and 6 stop-signal trials) were presented for a total of 96 trials (72 go trials and 24 stop-signal trials). Most participants completed all 4 blocks of the task with fewer than 1% completing only 1 (n=31), 2 (n=70), or 3 (n=102) blocks. Participants who only completed one block were excluded from analysis because there were too few trials for parameter estimation.

Estimates of adjustments in response time were obtained across four adjustment trial types: correct and incorrect go, stop-inhibit, and stop-respond trials.

Analyses

Typically, response time adjustment estimates are obtained after excluding incorrect go (e.g., responding X for an O), pre-push (responding prior to presentation of go signal), and no-response trials (failing to respond within the 3000 ms allowed) (e.g., Schachar et al., 2004). However, incorrect go and pre-push trials could reflect excessively fast responses and no-response trials could represent excessively slow responses (>3000 ms). If the distributions of go trial types preceding vs following each adjustment trial differ, the systematic exclusion of the most extreme responses would bias estimates of response time adjustments. We examined these assumptions by modeling the percentage of go trial event type (pre-push, no-response, incorrect go, correct go) directly preceding and following each adjustment trial type (correct go, stop-inhibit, stop-respond) using logistic regression (PROC GENMOD "SAS 9.4," 2012), controlling for time (pre- and post- adjustment trial), adjustment trial type, and their interaction.

Because response time is not recorded on no-response and pre-push trials, a novel approach was developed to incorporate information from these trials in our estimates of response time difference scores (see Supplemental Materials). For comparison, we also calculated adjustment after excluding pre-push and no response trials. In order to assess the impact of overall speed on the magnitude of response time change, we also calculated the response time adjustment as a % of mean response time.

Median response times pre- and post-trial for each adjustment type (correct go, stop-inhibit and stop-respond trials) were modelled using a high performance mixed model procedure (PROC HPMIXED "SAS 9.4," 2012) allowing heterogeneous variance and covariance for each combination of response time adjustment trial type and time (pre- and post- trial). Each participant contributed up to six median response time values to the analysis, one pre- and one post-median response time value for each adjustment trial type. Initially, the integer value of participant age was treated as a categorical variable and local regression smoothing of the predicted values was used to visually assess the shape of the developmental trajectory of the outcomes without imposing any distributional assumptions across age. Given the nonlinear shape of response time difference scores across integer age categories, piecewise regression models (PROC NLIN "SAS 9.4," 2012) were tested with a continuous age effect to determine if the developmental trajectory reached a plateau (a constant value with a slope of zero) within the observed age range. Piecewise regression is used to estimate the breakpoint (age at which the slope changes) and slopes in models where the rate of change is significantly different prior to and following a breakpoint. Gender was included in the final piecewise regression models to test for gender effects on the difference scores and their slope across age. Participants committed too few go errors to allow for no response and prepush adjusted estimates of pre and post response times around incorrect go trials. We present estimates of incorrect go response time adjustments across integer year of age in the supplemental materials (**Table S2**).

The association between response time difference scores and each of the following traditional SST outcomes: integrated stop signal reaction time (ITSSRT, Logan and Cowan, 1984), mean correct go response time, and the standard deviation of the correct go response time values (CGRTSD), was assessed by adding each SST variable separately to the three response time difference piecewise linear regression models, controlling for age. We used integrated SSRT (ITSSRT) in order to estimate SSRT when the probability of inhibition departed from 50%. ITSSRT was obtained using the formula ITSSRT = Response $\text{Time}_{1\text{-PSI}}$ – Mean Delay, where PSI is the probability of a successful stop inhibit, and Response $\text{Time}_{1\text{-PSI}}$ is the response time value at the(1-PSI)×100 percentile. The developmental trajectory of ITSSRT was examined using non-parametric smoothing of integer age estimates and piecewise linear regression was used to determine if the trajectory reached a plateau within the observed age range.

We ran multivariable linear regression models of CGRTSD controlling for participant age, post correct go, stop inhibit, and stop respond response time adjustments simultaneously. We then compared the go trial variability predicted by the model at age 10, with response time adjustments fixed to their average value for that age, to the predicted value with response time adjustments fixed to zero to evaluate the extent to which the systematic component of response time adjustments contributes to response time variability.

We compared the current method for estimating post error slowing based on matched pre and post go trials using the full go response time distribution to the standard method ($PES_{traditional}$): mean correct go response time (post stop-respond) – mean correct go response time and estimated the correlation and mean difference between the two methods.

Results

Post and pre trial events: Distribution of events on go trials preceding (pre) and following (post) each adjustment trial type were consistent with faster responses following than preceding correct go trials and slower ones following than preceding stop-respond trials (**Table 1**). Also consistent with speeding, incorrect go responses were more frequent following correct go trials than preceding correct go trials (Percentage of incorrect go responses: pre: 4.9%, post: 5.3%, $p < .0001$). Response times on incorrect go trials (mean: 564 ms, 95%CI 561; 566 ms) were significantly faster than response times on correct go trials (mean: 596 ms, 95%CI 594; 598 ms, paired t-test $p < .0001$). As expected in the presence of slowing, there were fewer incorrect go responses following than preceding stop-respond trials (pre: 7.6%, post: 5.7%, $p<.0001$). Similarly, more frequent no-response trials, suggesting extreme slowing, followed stop-respond and stop-inhibit trials. The rate of pre-push trials was significantly greater prior to and following stop-respond trials than trials preceding and following both correct go and stop-inhibit trials.

Post and pre response times: Response times preceding correct go trials were marginally faster than response times preceding stop-inhibit trials ($pre_{Correct\ Go} – pre_{Stop\ Inhibit}$: -7.0 ms, 95%CI -10.5;-3.5 ms, $p < 0.0001$). Responses following correct go trials were faster whereas responses following stop-inhibit trials were slower resulting in a post response time difference between the two adjustment trial types ($post_{Correct\ Go} – post_{Stop\ Inhibit}$: -43.4 ms, 95% CI -46.9;-39.9 ms, p <

0.0001). Trials preceding stop-respond trials were significantly faster than trials preceding correct go trials ($pre_{Correct\ Go} - pre_{Stop\ Respond}$: 16.5 ms, 95% CI 12.9; 20.1 ms, $p < .0001$) and stop-inhibit trials ($pre_{Stop\ Inhibit} - pre_{Stop\ Respond}$: 23.5 ms, 95% CI 19.5; 27.4 ms, $p < .0001$) consistent with the race model which posits that fast responses are more difficult to stop. Response times following stop-respond trials were significantly longer than all other response time estimates ($p < .0001$ for all comparisons).

Post-pre response time changes: In piecewise regressions of response time adjustments across age, there were no significant differences in breakpoint age across the three adjustment trial types and none of the slopes following the breakpoints were significantly different from 0. A repeated measures piecewise regression was used to estimate a common breakpoint across all three adjustment trial types resulting in a breakpoint at age 10.0 (95% CI 9.4; 10.6 years) at three significantly different plateaus ($p< .0001$ for all pairwise comparisons, **Table S3**): a post-pre correct go speeding of 16.3 ms (95% CI: 14.2; 18.4ms), post-pre stop-inhibit slowing of 13.0 ms (95% CI: 10.9; 15.1 ms), and a post-pre stop-respond slowing of 56.3 ms (95% CI: 54.2; 58.4ms). The resulting models have been superimposed over the nonparametric curves (**Figure 1**). With the exception of stop-inhibit prior to age 10, the piecewise regression estimates across continuous age values are very nearly identical to the locally weighted smoothing estimates of integer age mean values. The difference between the nonparametric curve and the initial piecewise regression line for stop-inhibit appears to be driven by the unusually low mean response time adjustment observed at age 6. There was no significant response time adjustment across incorrect go trials within each integer year of age (**Table S2**), however when the non significant effect of age was removed from the model, the overall response time adjustment showed a significant but minimal trend towards speeding (-3.6ms, 95%CL -6.9;-0.2, p=0.04). When expressed as a % change from median go RT, differences between the three trial types remain but the developmental trajectory flattens across all ages (correct go RT) or across younger ages with increases in adolescence (stop respond).

There were no significant gender by age interactions, such that the rate of change from age 6 to the plateau at age 10 did not vary by gender. Girls speeded more following a correct go (-2.1 ms, 95%CL: -3.7;-0.5, p=0.01) and slowed more after a stop inhibit (4.1 ms 95%CL: 0.1;8.1, p=0.05) and a stop respond (6.0 ms, 95%CL: 1.7;10.4, p=0.006). Although significant, these differences were trivial.

Association with other SST parameters: ITSSRT declined smoothly across the entire age range and piecewise regression did not show any evidence of a plateau. Beta coefficients (**Table 3**) were estimated for the three SST variables (ITSSRT, mean correct go response time, and correct go response time variability) used to predicted response time adjustments in models controlling for age. A positive beta coefficient corresponds to greater slowing/reduced speeding with greater values of the SST variable, with the opposite direction for negative coefficients. Longer (poorer) ITSSRT was associated with greater slowing (**Table 3**) following a stop-inhibit trial but less slowing following a stop-respond trial. Slower mean correct go response times were associated with greater post stop-respond slowing, but not with response time adjustments following a correct go or a stop inhibit. CGRTSD was significantly associated with response time adjustments across all three adjustment indices (p<.0001 for all models), with greater speeding following a correct go and slowing following a stop trial associated with greater response time variability. When the model was reversed to treat CGRTSD as the outcome, all three measures of response time adjustment were simultaneously significant in the model ($p < .0001$) but accounted for only a small proportion of the expected correct go response time variability. For example, a 10-year old participant with average response time adjustments has a predicted CGRTSD of 145 ms. Under the hypothetical scenario of no systematic response time adjustments, the predicted CGRTSD falls to 139 ms which is a negligible difference.

Stop-respond response time adjustment estimates calculated using the current approach were moderately correlated with values estimated using the traditional approach ($PES_{traditional}$) that does not control for local response time ($r = 0.53$, $p < .0001$). Current estimates showed significantly greater mean slowing than $PES_{traditional}$ (18.7 ms slower, 95% CI: 16.9; 20.6ms). Developmental trajectories were similar when response time adjustments were estimated after excluding no response and prepush trials (**Table S2**), with greater differences in estimates observed at younger ages when these types of trials are more prevalent. The greater frequency of no response trials in younger children is consistent with their longer response times, with 7.5% of 6 year-old children having at least one response time >2500ms.

Discussion

We studied response time adjustments in the SST, a task which demands balancing of speed and accuracy in a go task with the demand for stopping of responses on a random subset of trials. This is the first, large-scale study of the development of performance monitoring / response time adjustments. We compared the development of the ability to stop a speeded motor response (response inhibition), latency of go responses, and response time adjustments around four event types (correct and incorrect go, stop-inhibit, and stop-respond trials). We tested predictions of three competing hypotheses about the size and direction of these adjustments.

Results showed that response times were adjusted on a trial by trial basis depending on the nature of the preceding response supporting the view that subjects dynamically adjust their response times to balance speed and accuracy with the requirement to stop if needed. We also found significant slowing (and a greater proportion of no-response trials) after both stop-inhibit and stop-respond trials compared to go trials. Consistent with errors signaling more need for increased control, slowing after stop-respond trials (failed stopping) was significantly greater than after stop-inhibit trials (successful stopping). By contrast with slowing after stop trials, we found that response latencies were shorter (ie: there was speeding) after correct go responses. Speeding was noted after go errors, but given the low frequency of go task errors especially among older individuals, estimates of post go error adjustments were likely inexact.

Cross sectional trajectory analysis showed that early childhood is a period of rapid development of cognitive control based on the absolute amount of adjustment. Children as young as age 6 made strategic adjustments to their responses in the SST. The absolute amount of slowing after stop-inhibit and after stop-respond trials diminished over development with stable levels of adjustment occurring about age 10 years. This pattern is consistent with the use by younger individuals of a more reactive and less precise control approach compared with older individuals' use of a more proactive and precise control approach to adjustments. Further, the current results suggest that response time adjustment tendencies, which may reflect reinforcement learning mechanisms, seem to be fully developed at an early age. Alterations in these tendencies could strongly affect subsequent learning and development of other forms of executive function that rely on and interact with basic reinforcement learning mechanisms.

We also examined control adjustments as a function of a participant's overall speed based on the hypothesis that adjustments might be best understood relative to a person's base level of speed (Ratcliff and Smith, 2004). When looked at from this perspective it appears as if adjustments are stable up to age 10 with increasing control adjustments throughout adolescence. However, this pattern derives from the fact that response latencies decrease even though the absolute amount of adjustment does not. When the numerator and denominator change at different rates in a ratio score, results can be difficult to interpret.

Previous studies in children and adolescents have focused exclusively on adjustments following signal-respond trials (Schachar et al., 2004). Current results indicate that adjustments after stop-inhibit and stop-respond trials follow similar trajectories, although slowing after stop-respond trials is greater in magnitude.

Response time adjustments plateaued at an earlier age than response inhibition (SSRT) and go response time, both of which showed steady development until age 18. Earlier development of performance monitoring suggests that it might be a pivotal cognitive control process with a special and distinct place in the hierarchy of executive control. Greater magnitude of adjustment following stop-respond trials in contrast to reduced magnitude of adjustment following stop-inhibit trials predicted shorter ITSSRT (better response inhibition) indicating that those individuals who slow after stop errors are better at stopping. This relationship underscores the importance of performance monitoring for top-down control of task-specific processes such as response inhibition (Bhaijiwala et al., 2014; Chevrier et al., 2017)). Top-down control involves distributed brain networks that represent task set (Sakai, 2008). In the SST, top-down control involves fronto-parietal networks that restrain responses in case they need to be cancelled (Chevrier et al., 2015; Chikazoe et al., 2009). Bhaijiwala et al. (2014) found that preparatory activity is opposite in attention-deficit hyperactivity disorder (ADHD)—a condition characterized by deficient cognitive control and response inhibition— suggesting that in some conditions errors might generate atypical reinforcement signals and adjustment-related learning. These studies also show that post-error slowing in the SST involves activities in dopamine pathways that carry out reinforcement learning consistent with impaired dopamine function in ADHD (Volkow et al., 2011). Using the SST to measure response time adjustments could prove useful in behavioral studies of reinforcement learning.

The current findings are relevant to the evaluation of the predictions made by competing hypotheses for slowing in the context of the SST (Bissett and Logan, 2011). Slowing after both stop-respond and stop-inhibit trials is consistent with the goal priority hypothesis which posits that one shifts priority from going to stopping after presentation of a stop signal. But slowing after signal-inhibit and after signal-respond trials is not consistent with the conflict-monitoring hypothesis which posits slowing after signal-respond trials only. Slowing after stop-respond (errors) was significantly greater than after stop-inhibit trials in accord with the error detection hypothesis. Error detection theories attribute adjustments to local events occurring on preceding trials, whereas goal priority processes might be influenced by factors that extend beyond the immediately preceding trial, such as the subject's perception of the percentage of stop signals (Logan, 1981), explicit cues that indicate the importance of the stop signal (Verbruggen and Logan, 2009), and the magnitude of reward given for stopping and going (Liddle et al., 2009).

The observation of greater slowing after stop-respond than after stop-inhibit trials in the SST accords with the results of Schachar et al. (2004) and Verbruggen et al. (2008), but not with those of Bissett & Logan (2011). Bissett & Logan (2011) found equal slowing after stop-respond and stop-inhibit trials consistent with the goal priority hypothesis (Leotti and Wager, 2010;

Liddle et al., 2009), but inconsistent with error detection (Laming, 1968; Rabbitt, 1966a) and conflict monitoring hypotheses (Ito et al., 2003; Stuphorn et al., 2000; Stuphorn and Schall, 2006). The current result seems to contradict Bissett & Logan's (2011) speculation that participants might be less concerned with correcting errors in circumstances such as the SST where errors are frequent and involve speed than in typical choice response time tasks (Gehring et al., 1993). One possibility for the discrepancy between the current results and those of Bissett & Logan (2011) is the difference in average age (Bissett and Logan studied young adults). Another explanation might lie in their use of a longer task which could diminish the salience of inhibition errors. We speculate that cognitive control might be a function of error detection (greater slowing after stop-respond than after stop-inhibit) to a greater extent in early development with greater emphasis on goal priority shifts later in development.

Previous research into response time adjustments focused on comparing averages of response times on go trials with post stop-respond trials. That approach fails to take into account local changes in response time and excludes trials where no response time is available resulting in a truncated go response time distribution. Across development, response times on trials preceding stop-respond trials were faster and more likely to be pre-pushes than those preceding stop-inhibit trials. Both findings are consistent with evidence that faster responses are more difficult to stop than slower ones as predicted by the race model of response inhibition (Logan and Cowan, 1984). The current results address these two issues in the calculation of response time adjustment. First, the current approach controls for local adjustments in response times by restricting the analysis to matched pre- and post- index trial observations, unlike the traditional approach that compares post error response times to the average correct go response times. Using the current approach, stop-respond adjustments were moderately correlated with values estimated using the traditional approach; however, the traditional approach underestimated the magnitude of adjustments. Second, the current approach incorporates pre-push and no response trials into the response time distribution when estimating median pre- and post- response times. Although developmental trajectories using this method were similar to those estimated when no response and prepush trials were excluded, the impact of excluding trials was most evident at younger ages and at an individual level in participants with higher numbers of prepush and/or no response trials.

Greater go response time variability was related to adjustment (greater speeding after correct go responses and slowing after both stop-inhibit and stop-respond trials). Given the relationship of stop-inhibit and stop-respond adjustments to response inhibition, greater variability might reflect efforts at cognitive control rather than less control as is usually assumed. Suffice it to say, response time adjustments accounted for a small part of go latency variability. Future research will be needed to elucidate the range of control processes involved in response latencies. It would be useful to study the relationship of these variables in populations characterized by deficient cognitive control. The relationship between variability and go/stop speed could offer behavioral measures of these covert reinforcement influences which could be sensitive to alterations arising from psychopathological or genetic variation. The availability of a behavioral index of these processes could prove useful in assessment, monitoring and studies of mechanism such as genetic studies in which functional imaging at large scale is impractical.

Longitudinal study of response time adjustments is necessary to supplement the current cross-sectional data. Study of individuals younger than 6 years of age and older than 18 would further the understanding of development. Too few trials were run to model the effect of reaction time on n-2 and n+2 trials. Comparisons of adjustments across different task circumstances are warranted.

The current results show that even very young children adjust trial by trial performance in the context of a situation that demands balancing speed and accuracy on one hand with the occasional need to stop responses when required. These control processes are evident in speeding after correct responses and slowing after stopping. Magnitude of adjustments appeared to develop and plateau at age 10 years. By comparison, latency of response execution and of the stopping process continued to develop through adolescence. The current results demonstrate the importance of assessing response time adjustments on a trial by trial basis and of taking pre-pushes and no-responses into account. These results have implications for the study of normal and pathological development and the effects of drugs that alter performance monitoring. Early childhood is a period of rapid development in performance monitoring, a finding that might have implications for educational theory and practice.

Acknowledgements

This work was supported by the Canadian Institutes of Health Research (R.J.S., MOP-93696 and P.D.A., MOP-106573), the Toronto Dominion Bank Financial Group Chair in Child and Adolescent Psychiatry (R.J.S.), and the Alberta Innovates Translational Health Chair in Child and Youth Mental Health (P.D.A.). Conflicts of interest: Annie Dupuis, Maheshan Indralingam, Andre Chevrier, Jennifer Crosbie, Christie Burton, and Paul Arnold report no conflicts of interest. Russell Schachar consults for Highland Therapeutics Purdue Pharma and ehave.

Correspondence concerning this article should be addressed to Russell Schachar, Psychiatry, Neuroscience, and Mental Health, The Hospital for Sick Children, 555 University Avenue, Toronto, Ontario, Canada M5G 1X8. Electronic mail may be sent to

Russell.Schachar@sickkids.ca.

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Table 1: Event type (percent; 95% CI) on go trials preceding and following each trial type.

Event type	All go trials	Correct Go			Stop-inhibit			Stop-respond		
		Pre	*Post*	*p*[3]	*Pre*	*Post*	*p*	*Pre*	*Post*	*p*
Pre-push	0.85 (0.84;0.87)	0.58[1] (0.56;0.61)	0.59 (0.56;0.61)	0.8	0.52 (0.48;0.57)	0.50 (0.46;0.54)	0.4	1.33 (1.25;1.40)	1.40 (1.32;1.48)	0.1
No-response	2.0 (2.0;2.0)	1.7 (1.6;1.7)	1.1 (1.1;1.1)	<.0001↓	1.7 (1.6;1.8)	2.4 (2.3;2.5)	<.0001↑	2.4 (2.3;2.5)	3.3 (3.2;3.4)	<.0001↑
Incorrect go	5.5[2] (5.5;5.6)	4.9 (4.8;4.9)	5.3 (5.2;5.4)	<.0001↓	4.4 (4.3;4.6)	4.4 (4.3;4.5)	0.6	7.6 (7.4;7.8)	5.7 (5.6;5.9)	<.0001↑
Correct Go	91.6 (91.6;91.7)	92.9 (92.8;93.0)	93.3 (93.2;93.4)	<.0001	93.3 (93.2;93.48)	93.1 (93.0;93.3)	0.03	88.7 (88.5;88.9)	90.1 (89.9;90.3)	<.0001
Response time (ms)		576.3 (574.3;578.4)	557.7 (555.8;559.7)	<.0001↓	582.2 (579.9;584.5)	600.3 600.3;597.7)	<.0001↑	562.5 (560.1;564.8)	622.0 (619.2;624.8)	<.0001↑

[1]0.58% of go trials preceding a correct go response are pre-pushes. Each column sums to 100%.

[2]The percentage of incorrect go responses on go trials (5.5%) is significantly lower (p<.0001) than the percentage of incorrect go responses, 8.2% (95%CI: 8.1; 8.4%, not shown in table) across all stop-respond trials.

[3] p-values refer to within trial type comparisons of pre and post event type percentages. Non-significant (unadjusted p-values) post-pre differences are shaded. Where significant (p <.0001) differences are observed, the potential association with response time difference score is indicated by an arrow. ↓ Indicative of speeding; ↑ Indicative of slowing e.g.: 1.7% of go trials preceding a correct go response are no-response trials, compared to 1.1 % of go trials following a correct go response, a significant (p<.0001) decrease in no-response trials. Pre correct go response times appear to be shifted towards longer response times leading to a greater probability of no responses compared to the post correct go response time distribution. This is consistent with post correct go speeding.

Table 3: Response time adjustment association (*beta coefficient*) with other SST variables.

	ITSSRT	**Mean correct go response time**	**Correct go response time standard deviation**
Adjustment Index	*Beta Coefficient (95%CL)[1]; p value*		
Correct go	-0.06 (-0.14; 0.01) 0.1	0.03 (-0.14; 0.19) 0.8	-1.6 (-1.8; -1.3) < .0001
Stop-inhibit	0.17 (0.07; 0.26) 0.0006	0.09 (-0.07; 0.26) 0.3	3.4 (3.1; 3.7) < .0001
Stop-respond	-0.20 (-0.27; -0.12) < .0001	0.80 (0.63; 0.97) < .0001	3.7 (3.4;4.0) < .0001

[1]A positive beta coefficient corresponds to greater slowing/reduced speeding with greater values of SST variables, with the opposite direction for negative coefficients. For ease of presentation, beta coefficients are shown for a 10 ms difference in SST variables. For example, for a 10 ms difference in ITSSRT, there is an estimated 0.17 ms difference in post stop-inhibit slowing such that individuals with longer stop signal reaction times are estimated to demonstrate greater post stop-inhibit slowing.

26 Development of response time adjustment in the SST.

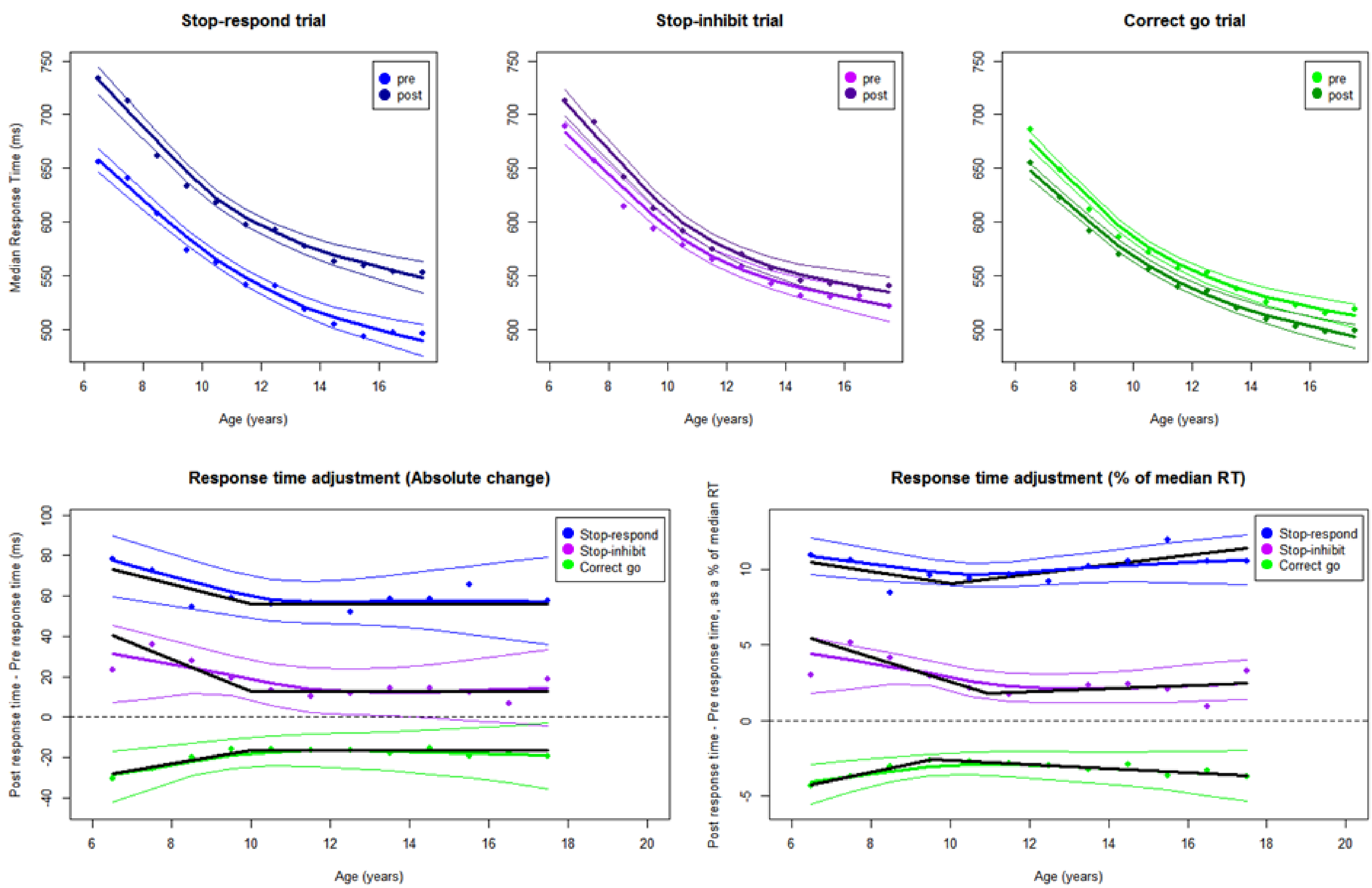

Figure 1: Median response time preceding and following each adjustment index (stop-inhibit, stop-respond, correct go) and response time difference scores (post-pre change in response time) across age. Predicted values in a model of integer age categories are represented by points, and locally weighted regression smoothing curves of the predicted values and their 95%CI are shown. Piecewise regression estimates of response time adjustment values (panels 4 and 5) are shown in a darker color superimposed over the nonparametric curves. Note: it was not possible to estimate equivalent response time adjustment for go errors because there were too few such errors.