Fall 2018

Development of Adaptive Coordination for Proactive and Reactive Control and the Influence of Worry on this Process

Shadi Sharif
Shadi.Sharif@Colorado.EDU

Development of Adaptive Coordination for Proactive and Reactive Control and the Influence of Worry on this Process

Shadi Sharif

Psychology, University of Colorado Boulder

October 29, 2018

Dr. Yuko Munakata, Department of Psychology and Neuroscience

Defense Committee:

Dr. Yuko Munakata, Department of Psychology and Neuroscience

Dr. Eliana Colunga, Department of Psychology and Neuroscience

Dr. Nancy Guild, Department of Molecular Cellular & Developmental Biology

Abstract

Young children transition from engaging cognitive control reactively in the moment to proactively planning ahead as they develop. Reactive control has been suggested as the adaptive control mode for young children because it allows them to learn and take in information while proactive control is likely a more effortful process. Children's sensitivity to control modes and ability to adapt accordingly is not well known. This study explores whether children coordinate their behavior and adapt towards well-rehearsed cognitive control practices. In addition, trait worry was examined to see its influence on cognitive control mode processes. We investigated these relationships in children and adults using a demand selection task in which cues were available either before or after target onset and participants chose which mode they preferred; then, levels of worry were tested using established measures. Five-year-olds coordinated their behavior to avoid the proactive deck, whereas 10-year-olds did not have a distinct preference and adults preferred the proactive deck. Trait worry did not influence cognitive control processes. These results highlight adaptive coordination in response to control demands across development.

Keywords: Cognitive Control, Adaptive Coordination, and Worry

Introduction

Control over one's thoughts is a critical skill for leading a successful life, influencing health and work outcomes (Monttiff, Arseeault, Belsky, Dickson, Hancox, Harrington, Sears, 2011). This executive control can be engaged at different times. For example, when driving to a new location, one can engage in proactive control by preparing the directions beforehand or one can engage in reactive control by finding directions while driving (Chevalier, Martis, Curran, & Munakata, 2015). Proactive control requires sustained representation of task goals to promote preparatory attentional bias. In contrast, reactive control recruits attention transiently, in a "late correction" manner. Children transition from engaging cognitive control reactively in the moment to proactively planning ahead around the age of 6 (Chatham, Frank, & Munakata, 2009; Munakata, Snyder, & Chatham, 2012; Braver, 2012).

Ten- and 5-year old children's ability to engage reactively and proactively was observed in a task-switching game where children had to switch between sorting pictures by color or shape in different conditions (Chevalier et al., 2015). Two conditions made proactive control either possible or impossible by having the rule (i.e., sorting by color or shape) available either before or at the same time as the picture. A third condition encouraged proactive control by not only making it possible, but also by making reactive control more difficult (Chevalier et al., 2015). Pupillometric data was used as a measure of cognitive effort; greater pupil dilation indicated greater cognitive effort, and this dilation was compared to the time-point it was engaged. If pupil dilation was greatest *before* picture onset, then it would indicate proactive control mode because they prepared beforehand, whereas, if pupil dilation was greatest *after* picture onset it would indicate reactive control mode because cognitive effort was engaged in a "late-correction" manner. Ten-year-olds engaged in proactive control whenever possible, as indexed by faster response times in all conditions proactive control was possible and pupillometric data, which demonstrated greater pupil dilation *before* picture onset in the all conditions proactive preparation was allowed (Chevalier et al., 2015). Conversely, 5-year-olds did engage in proactive control, but only when utilizing reactive control was made more difficult and they showed greater pupil dilation before picture onset *only* when they had to engage proactively (Chevalier et al., 2015).

Reactive control has been suggested as the adaptive control mode for 5-year-olds because it allows them to constantly learn and take in information while proactive control is likely a more effortful process and less practiced (Chevalier et al., 2015). Conversely, proactive control is suggested as more adaptive for 10-year-olds and adults because it is more practiced and worth the effort to prepare beforehand when there is a predictable outcome (Chevalier et al., 2015). Whether 5-year-olds can coordinate their behavior in response to temporal control demands (proactive/reactive control) and adaptively prefer a reactive task is unclear. In addition, whether 10-year-olds and adults coordinate their behavior to enable proactive control is less clear. Discerning this sensitivity to cognitive control demands and adaptive behavior is critical to understanding how cognitive control develops.

Adults and 11-12-year-olds have been shown to adapt their behavior to avoid unnecessary cognitive effort (Kool, McGuire, Rosen, & Botvinick 2010; Niebaum, Chevalier, Guild, & Munakata, 2018). Both Kool et al. (2010) and Niebaum et al. (2018) examined adaptive behavior using a task-switching game in which participants had to switch between two rules. The rules came from one of two decks: an easy deck and a hard deck. The hard deck matched the rule to the previous trial only 10% of the time, whereas the easy deck matched the rule to the previous trail 90% of the time (Kool et al., 2010; Niebaum et al., 2018). Six-7 year olds were not aware of the difference in the decks nor did they choose the easier deck (Niebaum et al., 2018). However, both studies found that adults and 11-12-year-olds favored the easy deck and coordinated their behavior towards the easier task (Kool et al., 2010; Niebaum et al., 2018). Not only that, adults that struggled more with the task and experienced greater costs avoided the task with frequent rule switches and chose the less cognitively demanding task more often (Kool et al., 2010). This result demonstrates that adults choose to adaptively coordinate behavior to avoid cognitive effort especially when they struggle with the task. Although both adults and 11-12-year-olds adaptively coordinate behavior to avoid cognitive effort, different signals are driving their behavior because adult's easy deck selection was based on costs in response time (choosing the deck they were fastest on), while 11-12 year-olds easy deck selections were based on accuracy switch costs (choosing the deck they were most accurate on). These results suggest that signals driving adaptive behavior change through development.

The current study explored whether younger children, older children, and adults adapt their behavior to avoid cognitive effort associated with proactive versus reactive control modes. To test adaptive choices of proactive and reactive control across development and the factors that influence these choices, we utilized a demand selection task with decks that differed in proactive reactive control demands. We predicted that 5-year-olds would preferentially choose the reactive deck, whereas 10-year-olds and adults would preferentially choose the proactive deck, and these choices would be influenced by response time and accuracy on the decks as in prior work.

Anxiety has also been shown to influence cognitive processing (Moran, Bernat, Aviyente, Schroder, & Moser, 2015; Fales, Barch, & Burgess, 2008; Moser, Moran, Schroder, Donnellan, & Yeung, 2013). There are two main forms of anxiety: anxious arousal, which is characterized by a physiological response to a clear and present threat, and anxious apprehension/ worry which is characterized by verbal rumination and a response to an ambiguous threat. Prior work has associated anxious apprehension/ worry with an enlarged Error Related Negativity (ERN), which acts as an alarm system, indicating when there is a greater need for increased cognitive control processes (Moran et al., 2015). Adults with a high-level of worry demonstrated an increased ERN and poorer post-error behavior as indicated by response time (Moran et al., 2015). As a result, adults high in worry have greater error monitoring but this is not translated into adaptive behavior in response to control demands (Moran et al., 2015). High worry individuals also show greater transient activation of cognitive control regions and reduced sustained activation (Fales et al., 2008). This result is important because while proactive control is characterized by a sustained activation of control areas, reactive control is characterized by transient activation (Braver, 2012). As a result, adults high in trait worry may implement reactive control and chose a reactive task option and a similar relationship may exist in children.

The current study examined whether 5-year-olds, 10-year-olds, and adults have a preference for control modes and adapt their behavior based on control demands. We predicted that 5-year-olds would preferentially choose to be reactive whereas 10-year-olds and adults would preferentially choose to be proactive. We also predicted that adults and children high in trait worry would preferentially select the reactive deck, given that anxious adults show a greater transient pattern of working memory recruitment (Fales et al., 2008) and have reduced active maintenance of goal-relevant information.

Methods

Participants

Thirty-nine 5-year-olds, twelve 10-year-olds, and forty-three adults were recruited to participate. Six 5-year-olds were excluded due to fussing resulting in thirty-two 5-year-olds (mean age = 5.5, range = 5.08 - 6.08, 17 girls, 15 boys), twelve 10-year-olds (mean age = 10.83, range = 10.25 - 11, 6 girls, 6 boys), and forty-three adults (mean age = 20.92, SD = 3.62). Child participants were recruited from the participant database that is maintained by the Department of Psychology and Neuroscience at the University of Colorado Boulder. Adult participants were recruited from the Department of Psychology and Neuroscience subject pool at the University of Colorado Boulder for partial course credit.

Most children were Caucasian and from middle to high socioeconomic status. Before participation, parental informed consent was obtained for all children. Five-year-olds gave verbal assent, and 10-year-olds also signed an informed assent. Informed consent was also obtained for all adults. All children who completed the study received a small prize and their parents/guardians received $5 in travel compensation. Adults who completed the study were granted partial course credit. All study procedures were approved by the local institutional review board.

Procedure

A trained experimenter tested all participants individually in a single 60-min session at the laboratory. Participants completed the demand selection task (DST). After task completion, participants complete a post-task questionnaire. Subsequently, adults completed the Penn State

Worry Questionnaire (PSWQ) and children completed the Penn State Worry Questionnaire-Child (PSWQ-C) and Revised Child Anxiety and Depression Scale (RCADS).

Materials

Participants completed a demand selection task (DST). After task completion, participants completed a post-task questionnaire as well as the Penn State Worry Questionnaire and Revised Child Anxiety and Depression Scale.

Demand Selection Task. The DST was computer based and programmed in PsychoPy (v1.91) to be similar to the proactive/reactive conditions of Chevalier et al. 2015 and to the child adapted DST of Niebaum et al. 2018. A computer monitor displayed two decks (digitized image of blue squares) (.5"w x .75"h), symmetrically positioned to the left and right of center. Participants used a button box that had four options on it, each button with a picture of its icon above it (a blue square, a green circle, an orange triangle, and another blue square), and used it to choose either the left or right deck and then subsequently to sort the toy. After sorting each toy feedback was given on whether it was sorted correctly or not. Correct responses received a smiling face picture (.5" x .75") and incorrect responses received an angry face picture (.5" x .75"). In addition, correct responses received a piece of digital candy (.1", 1.1") shown at the bottom right of the screen; a candy piece was removed after incorrect responses. The candy count gave long-term feedback on performance and gave motivation for good performance through out the task.

Not explicitly stated to participants, in one deck (referred to as the proactive deck) participants were presented the rule for 1.5 seconds, and then, the rule was covered and they were presented with the picture to sort. On the other deck (referred to as the reactive deck), participants were presented with the rule at the same time as the picture and both remained visible until the participant made a decision. The DST task is depicted in Fig. 1.

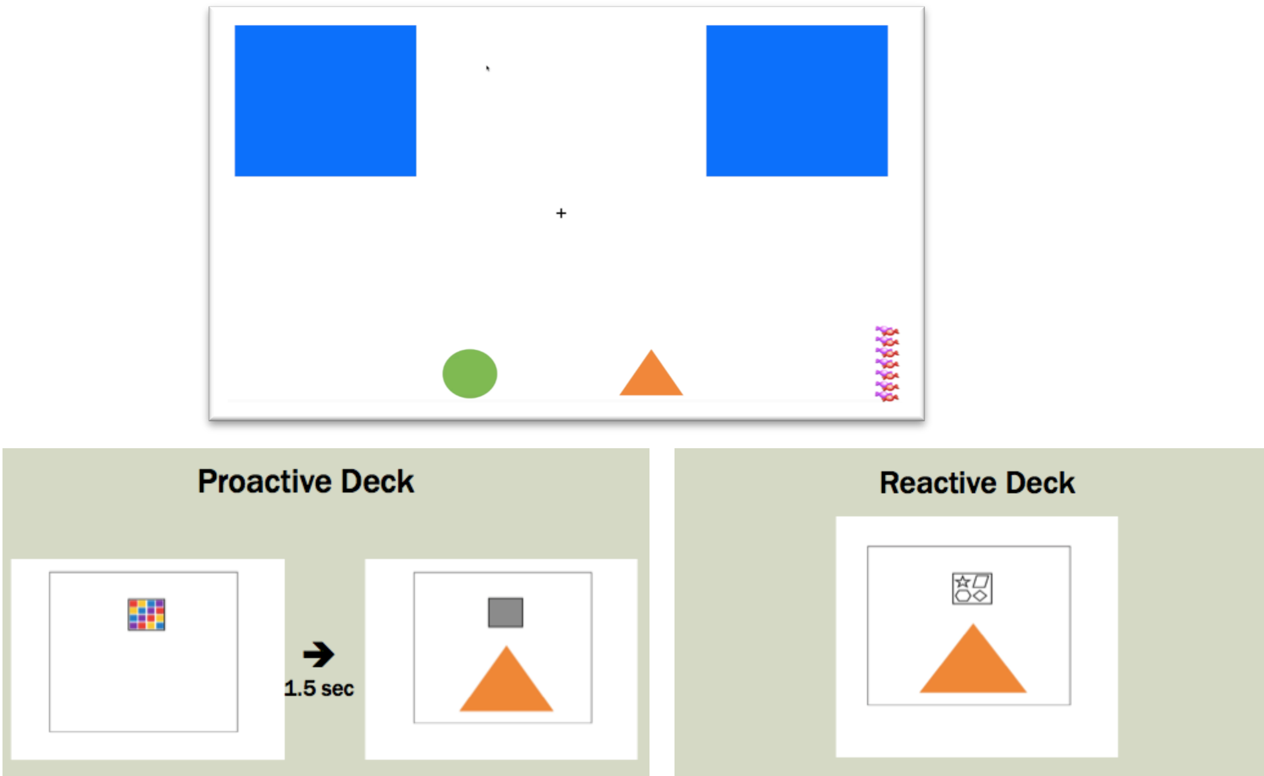


Fig. 1. The demand selection task had participant's choice between the two decks. One deck allowed for proactive control, whereas the other deck only allowed for reactive control.

Participants initially practiced how to sort toys according to each of the dimensions (color and shape) in 4 practice trails each. Then participants were instructed that they would play both games (color and shape) at the same time and completed 4 practice trials. In the deck familiarization phase, participants were introduced to the left and right decks and continued to play both games; pictures came from either the left first or the right then alternated across 60 trials. After, participants practiced choosing the left and the right decks themselves in 5 trials each. Verbal guidance and feedback were provided during these trials by the experimenter that could be repeated if necessary. Subsequently, participants completed the DST where they could choose the deck they wanted across 50 trials.

Post-task questionnaires

DST post-task questionnaire. After completing the DST participants were asked to complete a post-task questionnaire. The questionnaire consisted of 6 questions aimed at measuring participants' metacognitive awareness of the differences between the decks and their preferences. Responses to these questions are not included in these analyses because they were not relevant to the current study hypotheses.

Penn State Worry Questionnaire (PSWQ). The PSWQ measures trait worry. It has high internal consistency and good test-retest reliability (Meyer, Miller, Metzger, and Borkovec, 1990). The PSWQ consists of 16 statements and utilizes a 5-point numerical Likert scale from "*not typical of me at all*" to "*very typical of me*". Item scores are summed to give a total score, with higher scores indicating higher worry. Adults completed the PSWQ on their own and the experimenter left the room to allow for privacy.

The child-adapted version of the PSWQ (Chorpita, Tracy, Brown, Collica, & Barlow, 1997) has had conflicting results in its validity; some argue that it should be condensed to remove reverse scored items whereas others argue that the full model is better (Muris, Meesters & Gobel, 2001; Pestle, Chorpita, & Schiffman, 2008). In addition, its use in children below the age of 8 has not been fully explored. We choose to keep the full model, since it has been the most tested.

The PSWQ-C consists of 14 statements and utilizes a 4-point Likert scale of how true the statement is about the person ranging from *never, sometimes, mostly*, to *always*. Similarly, item scores are summed to give a total score, with higher scores indicating higher worry. Five-year-olds and 10-year-olds completed the PSWQ-C. The experimenter administered the PSWQ-C verbally. Children were shown a thumb version of the Likert scale that they used as a guide to answer and verbally told the experimenter their answer or pointed to the thumbs.

Revised Child Anxiety and Depression Scale (RCADS). The Revised Child Anxiety and Depression Scale (RCADS) is a validated measure of anxiety and depression in children (Chorpita, Moffitt, & Gray, 2005). The full measure consists of 47 statements, and they have multiple shortened versions looking at specific facets. We utilized the RCADS panic subscale to look at the facets of anxiety. Although the RCADS does not specifically look at trait worry, it is the most validated measure for anxiety in children and we wanted to use it as a comparison to the PSWQ-C, which has had conflicting results.

Parents of the 5-year-olds completed the RCADS and 10-year-olds completed the RCADS themselves. It consists of 9 statements and uses a 4-point Likert scale of how true the statement is about the person, ranging from *never, sometimes, often*, to *always*.

Children were again shown a thumb version of the Likert scale that they used as a guide to answer and verbally told the experimenter their answer or pointed to the thumbs.

Statistical Analysis

All statistical tests were conducted using the open-source R software. We used two-tailed t-tests within each group to determine whether each group significantly differed in accuracy or response times on correct trials between deck options. We anticipated, based on prior work, that the proportion of proactive deck selections would not be normally distributed and confirmed that in the current sample; we thus used the non-parametric Kruskal-Wallis test to test for omnibus group differences in the proportion of proactive deck selections and Wilcoxon signed-rank tests to assess whether groups differed from chance deck selections. We tested for group differences in responses to each post-task question using chi-square tests.

Results

We first present accuracy and response time results from the deck familiarization phase. Then, we examine differences from chance for control mode preference, age differences for control mode preference, predictors of control mode preference, and the effect of trait worry on predictors and preferences. Response times were examined for correct responses after discarding outliers; values greater than M +3 SD and values lower than 200 msec or M − 3 SD (1.6%) were excluded, as in previous work (Chevalier et al., 2015). Two additional 5-year-old participants were also excluded for mean response time across conditions longer than 10s after the above filtering, as in previous work (Niebaum et al., 2018). All participants' relative response times on the proactive and reactive decks were log-transformed by log transforming each deck and then subtracting to reduce skew.

Deck familiarization baseline performance

As expected, age groups differed in their overall accuracy ($F_{(2,84)} = 8.4591$, $p < .001$). Five-year-olds had lower accuracy rates (M = 89.29%, SD = 6.4%) than 10-year-olds (M = 91.97%, SD = 6.4%) and adults (M = 94.46%, SD = 4.2%). Age groups also differed in their relative accuracy on the proactive and reactive decks ($F_{(2,84)} = 5.987$, $p = .003$). Five-year-olds were more accurate on the reactive deck (M = 91.37%, SD = 8.61%) than on the proactive deck (M= 86.11%, SD = 7.59), while 10-year-olds and adults did not significantly differ in their accuracy rates on the proactive (10-year-olds: M = 91.81%, SD = 5.84%; adults: M = 94.96%, SD = 4.00%) or reactive deck (10-year-olds: M = 92.12%, SD = 9.22%; adults: M = 93.95%, SD = 6.48%), (t = -1.71, p = 0.091).

As expected, age groups differed in their overall response time ($F_{(2, 84)} = 101.59$, $p < .001$). Five-year-olds had slower response times (M = 3.35 msec, SD = 1.20) than both 10-year-olds (M = 1.31 msec, SD = 0.20) and adults (M = 0.89 msec, SD = 0.17). Participants were faster on the proactive deck (M = 1.62 msec, SD = 1.35) than on the reactive deck (M= 2.14 msec, SD = 1.45), (t = -10.17, p < .001). This was true of all age groups (proactive RT - reactive RT) (5-year-olds: M = -0.63, p < .001; 10-year-olds: -0.51, p < .001; adults: M= -0.44, p < .001). Descriptive performance statistics are presented in Table 1. Overall, baseline performance was consistent with previous work in that 5-year-olds were slower and less accurate than 10-year-olds and adults and that all groups were faster on the proactive deck.

Table 1

Deck familiarization performance across age groups and proportion of proactive deck selections

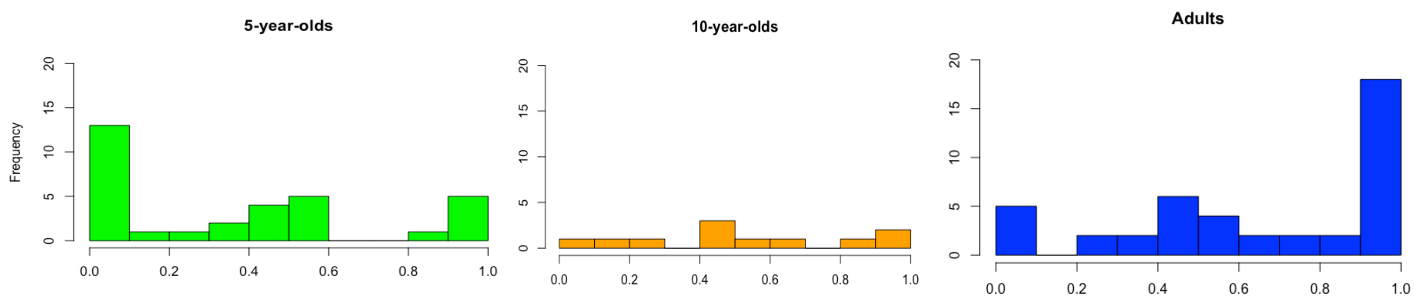
	5-year-olds	10-year-olds	Adults
Overall Accuracy ^	89.29% (6.4%)	91.97% (6.4%)	94.46% (4.2%)
Relative Accuracy ^ (proactive acc- reactive acc)	-0.05 (0.09)	-0.003 (0.09)	0.01 (0.07)
Overall Response Time (in msec) ^	3.35 (1.20)	1.31 (0.20)	0.89 (0.17)
Relative Response Time (in msec) (proactive log rt- reactive log rt)	-0.63 (0.72)	-0.51 (0.25)	-0.44 (0.18)
Proportion of Proactive Deck Selection ^	38% (35.8%)	54.36% (33.1%)	66.12% (33.7%) *

Data presented as mean (SD); * indicates significance from chance at $p < .05$;

^ indicates main effect group differences.

Control mode preference by age

We examined how often participants chose the proactive deck to test for control mode preferences. Age groups differed in how often they chose the proactive deck (Kruskal Wallis chi-squared = 8.66, p= .01). Adults chose the proactive deck significantly more often than chance (V = 692, p-value = .01; M = 66.12% SD = 33.7%) (Fig. 2). Ten-year-olds did not show a clear preference for either deck (V = 33, p-value = .61; M = 54.36%, SD = 33.1%), and 5-year-olds had a non-significant preference for the reactive deck (V = 146, p-value = 0.124; M = 38%, SD = 35.8%) (Fig. 2).



Proportion of Proactive Deck Selections

Fig. 2. The proportion of proactive deck selections is represented across age groups. Five-year-olds may avoid the proactive deck and instead prefer the reactive deck. Ten-year-olds did not show a clear preference in either direction. Adults had a clear and significant preference for the proactive deck option.

Accuracy and response time as predictors for deck preference

We examined predictors of how often participants chose the proactive deck option to their accuracy and response times. Relative accuracy (proactive acc - reactive acc) did not predict proactive deck selection (r = 0.202, p = 0.064) (Fig. 3). Relative response time (proactive log RT - reactive log RT) did not predict proactive deck selections (r = -0.147, p = 0.179) (Fig. 4). Overall, neither accuracy nor response time predicted proactive deck selections.

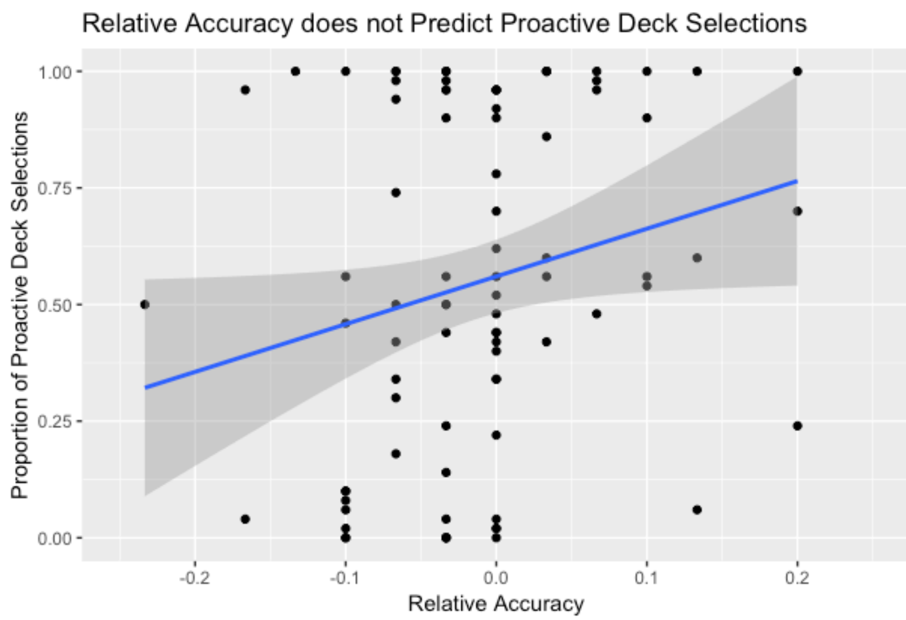


Fig. 3. Relative accuracy (proactive acc - reactive acc) was not associated with the proportion of proactive deck selections.

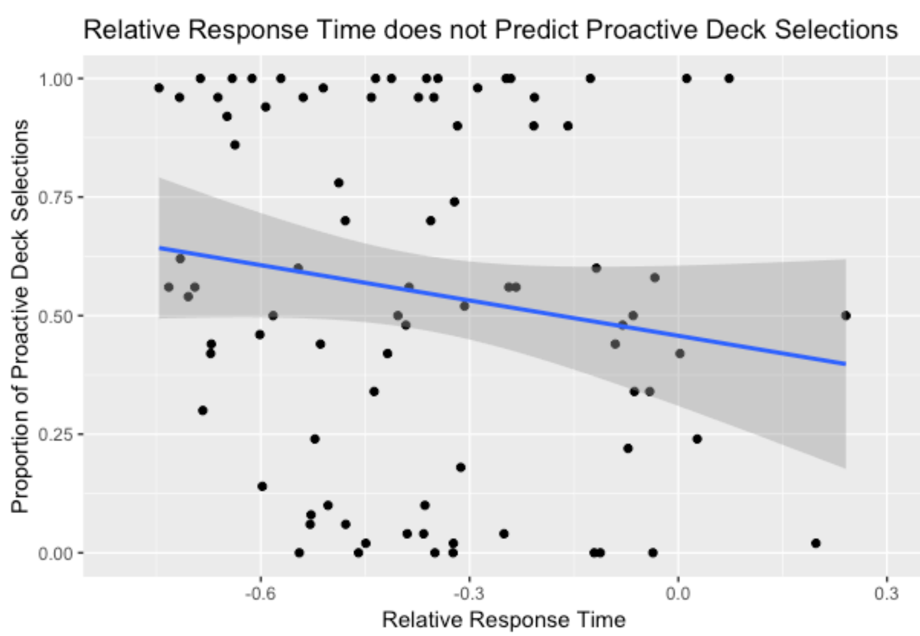


Fig. 4. Relative response time (proactive log RT- reactive log RT) was not associated with the proportion of proactive deck selections.

Trait worry and predictors of accuracy and response time

The effects of trait worry on predictors of accuracy and response time were examined to determine whether those high in trait worry benefit less from the proactive deck option. A correlation was first run to compare PSWQ-C score to RCADS score ($r = .166$, $p = 0.288$) (Fig. 5), which exposed that these measures do not associate with each other. When administering the PSWQ-C to children, especially to 5-year-olds, it was evident many of them struggled with the questionnaire and did not understand all the statements. As a result, only the RCADS scores were used for further analyses.

Trait worry did not predict relative accuracy (proactive acc - reactive acc) in either adults ($r = -0.094$, $p = 0.550$)(Fig. 6.A) or children ($r = -0.153$, $p = 0.333$) (Fig. 6.B). Trait worry also did not predict relative response time (proactive RT - reactive RT) in either adults ($r = -0.158$, $p = 0.311$) (Fig. 7.A) or children ($r = -0.204$, $p = 0.196$) (Fig. 7.B). Overall, no significant associations were found between high-level worry and accuracy or response time.

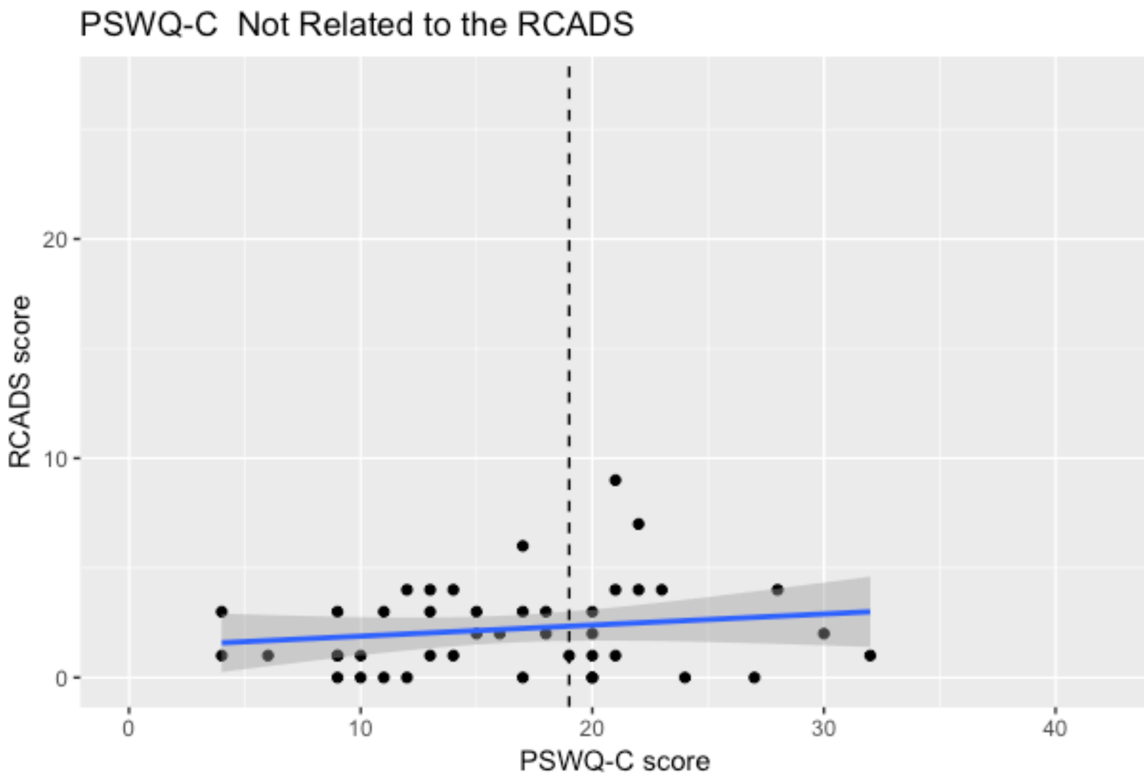


Fig. 5. PSWQ-C scores were compared to RCADS scores. The full score ranges of both scales are shown. A score of 19+ on the PSWQ-C indicates clinical levels of anxiety and is shown with the vertical dotted line. A score of 13+ on the RCADS indicates clinical levels of anxiety. PSWQ-C scores were not associated with RCADS scores.

A) Adults B) Children

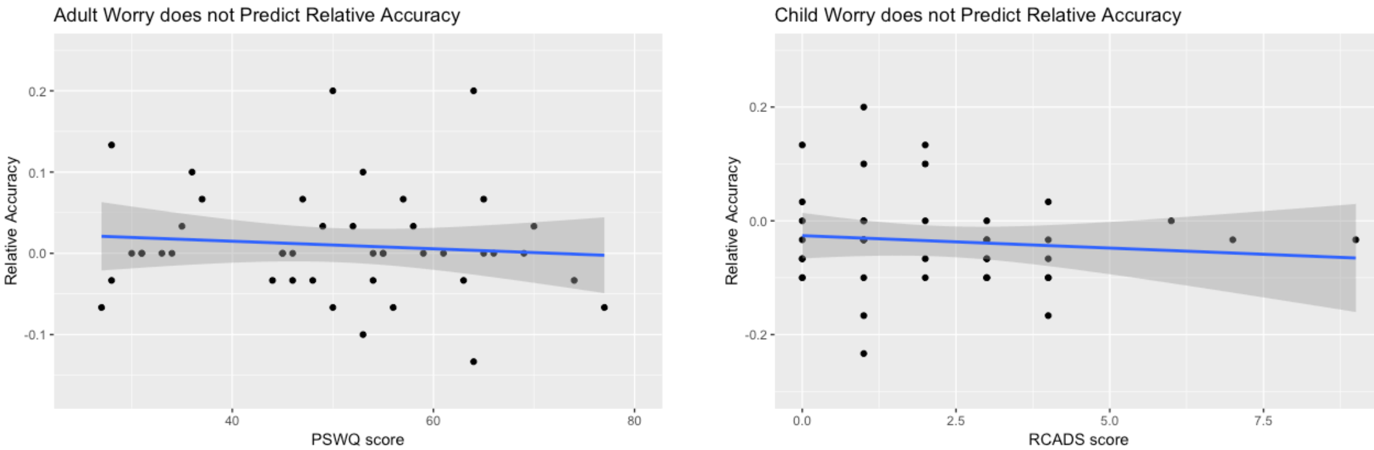


Fig. 6. A) Adults level of worry did not predict their relative accuracy (proactive acc- reactive acc). B) Children's level of worry also did not predict their relative accuracy.

A) Adults B) Children

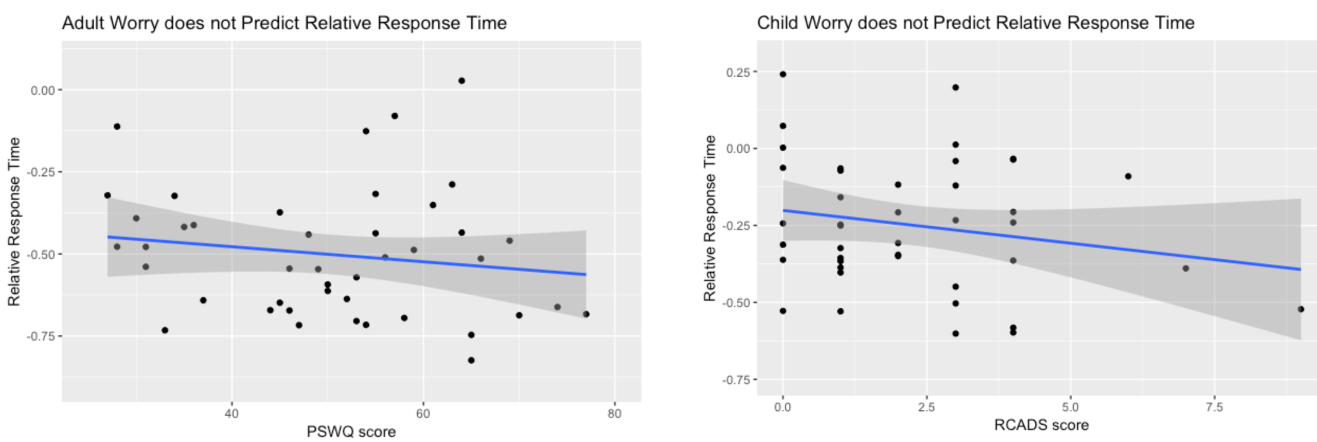


Fig. 7. A) Adults level of worry did not predict their relative response time (proactive log RT - reactive log RT). B) Children's level of worry also did not predict their relative response time.

Control mode preference as a result of trait worry

The influence of trait worry on control mode preference was examined using correlations between trait worry scores and the proportion of proactive deck selections. Adult's level of trait worry was not related to the proportion of proactive deck selections (r = 0.148, p = 0.345) (Fig. 8). Five-year-olds and 10-year-olds level of trait worry was also not related to the proportion of proactive deck selections (r = 0.174, p = 0.265) (Fig. 9).

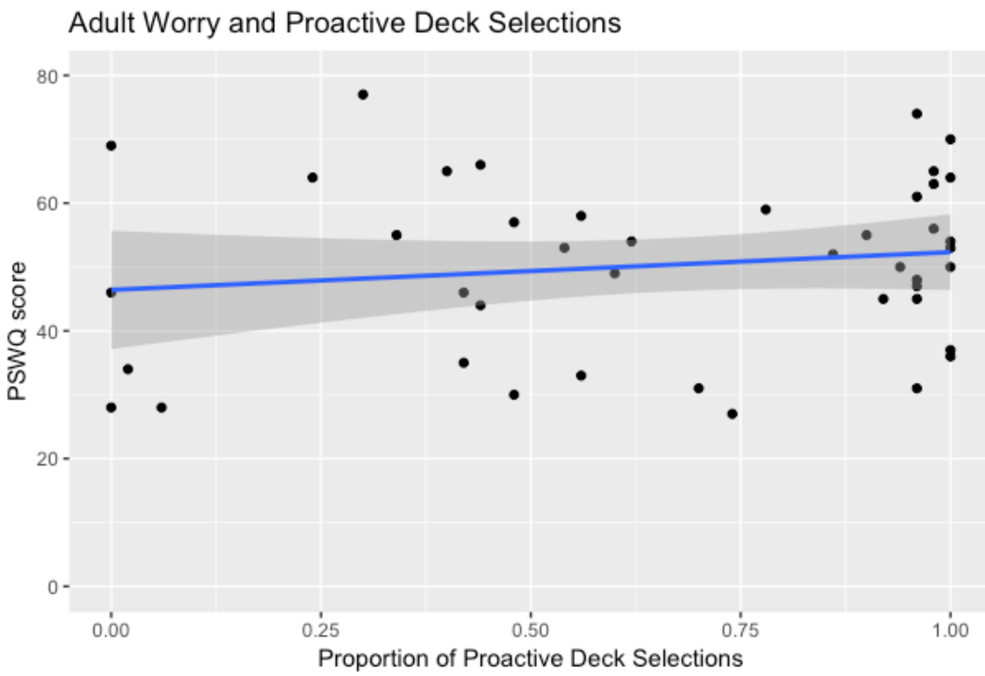


Fig. 8. No association was found between level of worry and proactive deck selections in adults.

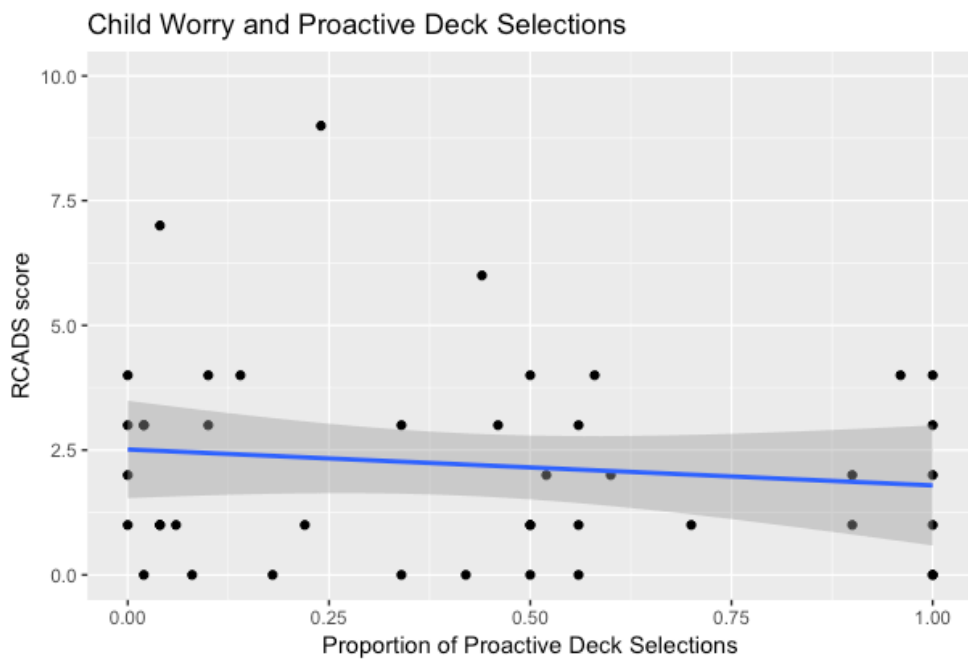


Fig. 9. No association was found between levels of worry and proactive deck selections in children.

Discussion

Younger children, older children, and adults demonstrated distinct preferences for engaging reactive versus proactive control. All age groups were faster on the proactive deck, similar to previous work (Chevalier et al., 2015). In addition, 5-year-olds had a non-significant preference for the reactive deck, whereas 10-year-olds did not show a distinct preference for either deck option and adults had a significant preference for the proactive deck.

Younger children and adults demonstrated adaptive behavior to control demands. Reactive control is more adaptive for younger children because it allows them to constantly learn and take in information, whereas proactive control is likely a more effortful process and less practiced (Chevalier et al., 2015). Five-year-olds coordinated their behavior based on temporal control demands and made the adaptive choice of preference for the reactive deck. This suggests younger children seem to have an implicit coordination in response to different temporal control demands (Chevalier et al., 2015) and that they are more sensitive to temporal control demands than to switch cost demands (Niebaum et al., 2018). Adults were also able to coordinate their behavior based on temporal control demands and made the adaptive choice for themselves. Although adults preferred the proactive deck, which is typically described as requiring greater cognitive effort, it is more practiced and due to their good working memory, active maintenance of goal-relevant information in this simple task may be relatively easy (Chevalier et al., 2015). In addition, the benefit of utilizing proactive control for adults seems to outweigh the cost because they can reliably predict outcomes (Chevalier et al., 2015).

Trait worry was not associated with control mode preference or with less benefit from the proactive deck option, as seen through predictors of accuracy and reaction time. Although high worry individuals show greater error monitoring (Moran et al., 2015), this did not seem to influence their preferred cognitive control mode or their accuracy and response time. This may be because accuracy did not differ between the proactive and reactive decks in older children and adults. As a result, the greater error monitoring which is prevalent in high worry individuals (Moran et al., 2015) may not have been as enhanced and that might be why no association between high worry and cognitive control mode preference was observed. Future research could create a paradigm where accuracy rates between the decks are greater; for example, by making the proactive deck harder and inserting a greater delay between rule and picture onset. By potentially increasing errors on the proactive deck we might see if high worry influences preferred cognitive control modes. In addition, future research could examine the role feedback plays in accuracy and coordinating behavior. It may be the case that more aversive feedback to wrong responses could also cause greater error monitoring in high worry individuals and lead them to coordinate behavior in response to accuracy costs.

The PSWQ-C and RCADS measures did not correspond with each other, providing conflicting scores for the same individual. This is problematic because both measures are looking at the same constructs of anxiety and therefore should correspond. In addition, PSWQ-C scores suggested that almost forty percent of the sample was at clinical levels of anxiety. Knowing that this was a representative sample of children and that anxiety disorder rates are prevalent in less than 1% of children (Beesdo & Knappe, 2009), suggests it may be problematic for use in our sample. An important issue in the PSWQ-C measure is that a great deal of introspection is required. Younger children especially may not yet have the cognitive capacity to be introspectively aware of their behaviors and emotions and to then be able to self-report it. As a result, further research on testing worry levels in children must be conducted, creating measures that are more reliable. A possible alternative is to utilize parent-adapted versions, like the RCADS, where the parent reports their child's behavior. This could counter the issue of introspection, especially for young children.

A limiting factor in our study was the small sample size for 10-year-olds. Being so underpowered prevented us from seeing large-scale trends and making definitive conclusions from the 10-year-old group. Future research should include larger and more representative sample sizes to make more definitive conclusions. Another limiting factor was the low variance in child anxiety levels. Future research could compare a non-clinical sample to a clinical sample of anxious children to see whether a relationship exists between high anxiety and control mode preference.

Overall, 5-year-olds and adults coordinated their behavior based on control modes. While 5-year-olds coordinated their behavior towards the reactive deck, 10-year-olds did not show a clear preference for either deck and adults coordinated their behavior towards the proactive deck. This exposes that not only are young children capable of engaging in proactive control, but that they also seem to have an implicit coordination to avoid it demonstrating they are capable of adaptive behavior in response to temporal control demands. Similarly, adults are capable of adapting behavior in response to temporal control demands. Trait worry was not found to be associated with control modes or with less benefit from the proactive deck option as measured by response time and accuracy. Future research could examine the role of greater accuracy difference or feedback to accuracy and how trait worry might influence those relationships.

References

Beesdo, K., Knappe, S., & Pine, D. S. (2009). Anxiety and Anxiety Disorders in Children and Adolescents: Developmental Issues and Implications for DSM-V. *The Psychiatric Clinics of North America*, *32*(3), 483–524. http://doi.org/10.1016/j.psc.2009.06.002

Braver, T. S. (2012). The variable nature of cognitive control: A dual-mechanisms framework. *Trends in Cognitive Sciences*, *16*(2), 106–113. http://doi.org/10.1016/j.tics.2011.12.010

Chatham, C. H., Frank, M. J., & Munakata, Y. (2009). Pupillometric and behavioral markers of a developmental shift in the temporal dynamics of cognitive control. Proceedings of the National Academy of Sciences, 106(14), 5529-5533.

Chevalier, N., Martis, S. B., Curran, T., & Munakata, Y. (2015). Metacognitive processes in executive control development: The case of reactive and proactive control. Journal of Cognitive Neuroscience, 27(6), 1125-1136.

Chorpita, B. F., Tracey, S. A., Brown, T. A., Collica, T. J., & Barlow, D. H. (1997). Assessment of worry in children and adolescents: An adaptation of the penn state worry questionnaire. Behavior Research and Therapy, 35, 569–581.

Chorpita, B.F., Moffitt, C.E., Gray, J., (2005) Psychometric properties of the Revised Child Anxiety and Depression Scale in a clinical sample. Behavior Research and Therapy, 309-322

Fales, C.L., Barch, D.M., Burgess, G.C. et al. Anxiety and cognitive efficiency: Differential modulation of transient and sustained neural activity during a working memory task. Cognitive, Affective, & Behavioral Neuroscience (2008) 8: 239.

Kool, W., McGuire, J. T., Rosen, Z. B., & Botvinick, M. M. (2010). Decision making and the avoidance of cognitive demand. Journal of Experimental Psychology: General, 139(4), 665.

Meyer, T.J., Miller, M.L., Metzger, R.L., & Borkovec, T.D. (1990). Development and validation of the Penn State Worry Questionnaire. Behaviour Research and Therapy, 28(6), 487-495.

Munakata, Y., Snyder, H. R., & Chatham, C. H. (2012). Developing cognitive control: Three key transitions. Current directions in psychological science, 21(2), 71-77.

Moser J.S. Moran T.P. Schroder H.S. Donnellan M.B. Yeung N. (2013). On the relationship between anxiety and error monitoring: A meta-analysis and conceptual framework. Frontiers in Human Neuroscience, 7, 466 .

Moran, T.P., Bernat, E.M., Aviyente, S., Schroder, H.S., Moser, J.S. (2015) Sending mixed signals: worry is associated with enhanced initial error processing but reduced call for subsequent cognitive control, *Social Cognitive and Affective Neuroscience*, Volume 10, Issue 11, Pages 1548–1556.

Muris, P., Meesters, C., & Gobel, M. (2001). Reliability, validity, and normative data of the penn state worry questionnaire in 8- to 12-year-old children. Journal of Behavior Therapy, 32, 63–72.

Pestle, S.L., Chorpita, B.F., Schiffman, J. (2008). Psychometric Properties of the Penn State Worry Questionnaire for Children in a Large Clinical Sample. Journal of Clinical Child & Adolescent Psychology, 37:2, 465-471