Targeting the dynamics of cognitive control across development: Evidence from reaching behavior in the Simon task

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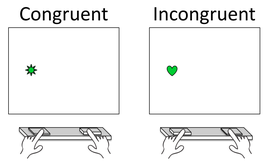
Introduction

Cognitive control is commonly assessed with button-press congruency tasks such as the Simon (1969) task

- Incongruent trials generate conflict between a prepotent response (*respond on same side*) and a control-demanding response (*respond based on stimulus identity*)



Congruency Effect

Difference in average performance on incongruent and congruent trials (e.g., $RT_{Incongruent} - RT_{Congruent}$)

- Decreases until mid-thirties (Waszak, Li, & Hommel, 2010)

Multiple dissociable processes have been proposed to underlie cognitive control (Shenhav, Botvinick, & Cohen, 2013)

- **Response Threshold Adjustment (RTA)** process puts the "brake" on motor output when conflict is detected
- **Controlled Response Selection (CRS)** process directs top-down support to "steer" response activations in favor of the correct response

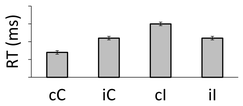
Reach tracking proposed to reflect how these processes function (Erb Moher, Sobel, & Song, 2016; Erb, Moher, Song, & Sobel, 2017)

- **Initiation Time** (*time elapsed from stimulus onset to response onset*) reflects the **RTA** process by indexing how long the "brake" is put on motor output
- **Curvature** (*degree to which a movement deviates from a direct path to the selected target)* reflects when the **CRS** process marshals sufficient top-down support to "steer" activation in favor of the correct response

***Q1**: How do the **RTA** and **CRS** processes contribute to age-related reductions in the congruency effect?*

Gratton Effect

Faster RTs on congruency repeat trials (cC & iI) than congruency switch trials (iC & cI)



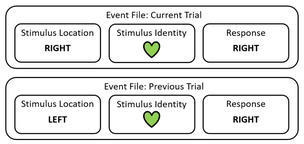
Conflict Adaptation Account (Botvinick et al., 2001)

Cognitive control is upregulated on incongruent trials

- Performance is facilitated on iI trials (easier to focus on stim. identity)
- Performance is impaired on iC trials (automatic response is correct, controlled processing delays responding)
- **Reach trajectories should not be pulled toward incorrect response on iC trials**

Feature Integration Account (Hommel, 2004)

On congruency switch trials, the stimulus and response features of the current trial conflict with those of the previous trial, resulting in the activation of the incorrect location



- **Reach trajectories should be pulled toward incorrect response on iC trials**

***Q2**: Are reach trajectories on iC trials pulled toward the incorrect response?*

Methods

Participants

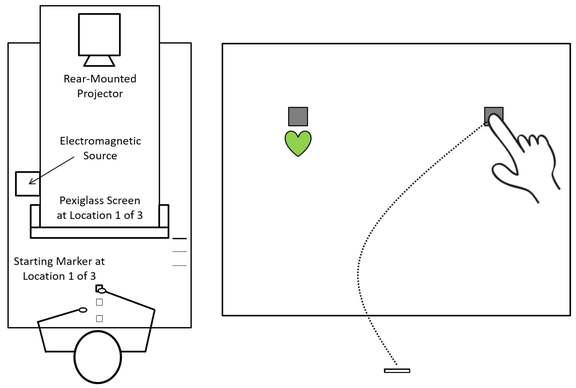
- 36 right-handed participants in each of three age groups
  - Children: 6- to 8-year-olds (18 females)
  - Pre-adolescents: 10- to 12-year-olds (15 females)
  - Adults: 18- to 23-year-olds (20 females)

Materials

- Liberty electromagnetic position and orienting system (Polhemus Inc.), digital projector, Plexiglass screen

Task

- 9-point calibration, followed by 16 baseline trials
- **4 blocks of 40 trials** (20 congruent, 20 incongruent)
  - Heart = Left, Sun = Right (counterbalanced)

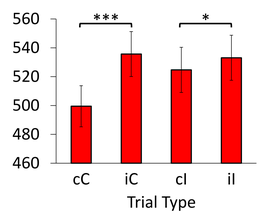


Results

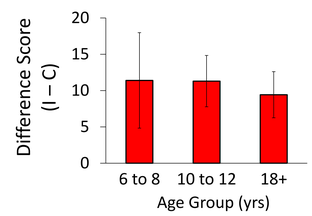
Analyses

- 2 (Current Congruency: C vs. I) x 2 (Prev. Congruency: c vs. i) x 3 (Age Group: Children, Pre-adolescents, Adults) ANOVAs
- Only accurate trials preceded by an accurate trial included in analyses, except for Error Rate measure

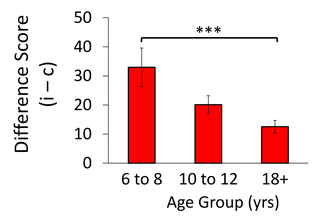
Initiation Time (ms)



- CI: $F(1, 105) = 15.4$, $p < .001$, $\eta_p^2 = 0.13$
- CI x ci: $F(1, 105) = 25.9$, $p < .001$, $\eta_p^2 = 0.19$

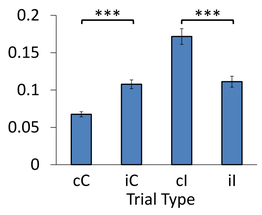


- CI x Age Group: $F(2, 105) = 0.11$, $p = .90$

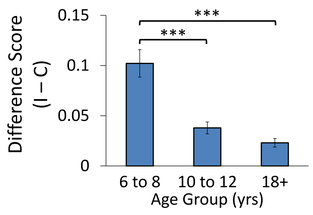


- Age Group x ci: $F(2, 105) = 6.89$, $p = .002$, $\eta_p^2 = 0.12$

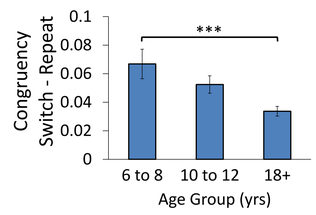
Curvature (ratio)



- CI: $F(1, 105) = 109$, $p < .001$, $\eta_p^2 = 0.51$
- CI x ci: $F(1, 105) = 148$, $p < .001$, $\eta_p^2 = 0.59$

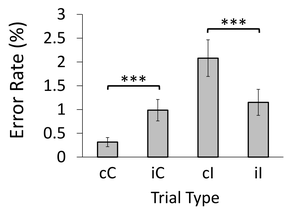


- CI x Age Group: $F(2, 105) = 21.6$, $p < .001$, $\eta_p^2 = 0.29$

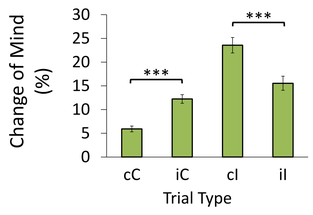


- CI x ci x Age Group: $F(2, 105) = 4.88$, $p < .01$, $\eta_p^2 = 0.09$

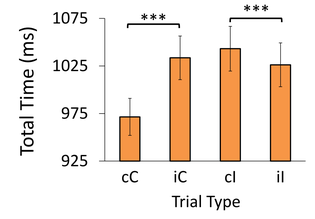
Additional Measures



- CI x ci: $F(1, 105) = 17.7$, $p < .001$, $\eta_p^2 = 0.14$
- CI x ci x Age Group: $F(2, 105) = 9.18$, $p < .001$, $\eta_p^2 = 0.15$



- CI x ci: $F(1, 105) = 138$, $p < .001$, $\eta_p^2 = 0.57$
- CI x Age Group: $F(2, 105) = 19.71$, $p < .001$, $\eta_p^2 = 0.27$



- CI x ci: $F(1, 105) = 160$, $p < .001$, $\eta_p^2 = 0.60$
- CI x ci x Age Group: $F(2, 105) = 17.3$, $p < .001$, $\eta_p^2 = 0.25$

Discussion

***Q1**: How do the **RTA** and **CRS** processes contribute to age-related reductions in the congruency effect?*

Initiation Times and **Curvatures** revealed distinct patterns of effects, consistent with claim that these measures reflect the **RTA** and **CRS** processes, respectively

- **Initiation Times** were elevated on incongruent trials and trials preceded by an incongruent trial; age-related gains only observed in the effect of previous congruency
- **Curvatures** revealed the Gratton effect; age-related reductions observed in both the congruency effect and the Gratton effect

***A1**: Age-related reductions in the congruency effect are driven primarily by changes in the functioning of the **CRS** process*

***Q2**: Are reach trajectories on iC trials pulled toward the incorrect response?*

Systematic differences in performance on iC relative to cC trials:

- Larger **Curvatures** on iC than cC trials
  - This difference does not require that trajectories were pulled toward the incorrect location on iC trials because movements may simply have been more direct on cC trials
- **Change of Mind** measure used to determine whether participants began a response in a manner characteristic of a reach to the incorrect target
  - More frequent **Changes of Mind** on iC trials relative to cC trials, indicating that reach trajectories were initially pulled toward incorrect response

***A2**: Reach trajectories on iC trials reveal strong evidence of pull toward the incorrect response, consistent with the Feature Integration Account*

Conclusions

Relative to button-press measures, reach tracking provides a more detailed view of how the processes underlying cognitive control function across different timescales

- Within a trial, across multiple trials, and across development

Reach tracking presents new opportunities to assess developmental and individual differences, and to compare competing theoretical accounts

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