Is the Antisaccade Task a Unicorn Task For Measuring Cognitive Control?

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Author Note

Author Contributions: JNR conceived the project, programmed the experiment, and wrote the paper. AFCdlP performed the latent variable analysis in JAGS and edited the paper.MSP performed the complementary latent-variable analysis in lavaan and co-wrote the paper. VMR provided the adaptive staircase algorithms and analysis, and edited the paper. AT conceived the project, set up the experiments, organized the running of participants, and edited the paper.

Open Science Practices: All code used in performing this research are publicly available at https://github.com/PerceptionAndCognitionLab/inh-newtasks/blob/public/papers/as/v1/p.Rmd. The links therein refer to raw data, which are curated github.com/amthapar/data-east/tree/main/antiSaccade/as12

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Abstract

One of the most popular measures of cognitive control is the antisaccade accuracy task (Kane et al., *J Exp Psychol General*, 2001) where briefly presented and subsequently masked targets at a peripheral location are identified. Prior to mask presentation, there is a cue at an opposing location that must be suppressed. We assess to what degree this antisaccade accuracy measure reflects cognitive control vs. general speed by comparing perforance to a prosaccade accuracy condition. Target durations in both tasks are adjusted with an adaptive 2-down/1-up staircase to produce constant accuracies. Individual target durations in the antisaccade condition are highly correlated to those in the prosaccade condition(r = .83). With a series of hierarchical models, we show there is but a single source of systemic variation across the conditions—a factor of general speed. We conclude that the antisaccade accuracy measure indexes general speed rather than cognitive control.

Keywords: cognitive control, inhibition, antisaccade task, general speed

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In psychology it is common to use the related concepts of *cognitive control*, *inhibition*, *executive function*, and *self regulation* to construct theories of attention, intelligence, working memory, development, aging, and psychopathology. The *structure* of cognitive control, therefore, has been a central, cross-domain topic for over three decades. There have been a number of competing views of cognitive control. One popular position is that cognitive control is a common, domain-general, unified concept that is engaged in many tasks (Engle, Tuholski, Laughlin, & Conway, 1999; Kane, Bleckley, Conway, & Engle, 2001). Alternatives to this position come in two varieties. One is a finer subdivision of these general abilities including the proactive-vs-reactive dual-process model of Braver (2012), and the exceedingly popular three-factor model of Miyake et al. (2000). The other variety is that cognitive control does not exist in a general form; instead it is comprised of several, independent, domain-specific abilities (Rey-Mermet, Gade, & Oberauer, 2018).

One main-line behavioral approach to exploring the structure of cognitive control is to apply latent variable models to individual performance scores. A brief summary is as follows: Individuals complete a battery of cognitive control exercises such as the Stroop task (Stroop, 1935), the flanker task (Eriksen & Eriksen, 1974), the anti-saccade task (Kane, Bleckley, Conway, & Engle, 2001), the N-back memory task (Cohen et al., 1994), and the stop-signal task (Logan & Cowan, 1984; Verbruggen et al., 2019). Then, the covariation across scores is decomposed into latent variables (Bollen, 1989; Skrondal & Rabe-Hesketh, 2004). The relations among these latent variables purportedly reveal the underlying structure of cognitive control processes.

Results from latent-variable analyses have not been as conclusive or convincing as one might hope. The problem is that several of the experimental tasks which purportedly measure cognitive control do not correlate well with each other. For example, the correlation between flanker and Stroop effects in large studies is often near zero and never greater than .25 (Rouder, Haaf, & Kumar, in preparation). It is difficult to determine whether these low correlations reflect a true lack of underlying correlation or attenuation from excessive measurement error (Hedge, Powell, & Sumner, 2018; Rouder & Haaf, 2019). Additionally, extant latent-variable analyses with cognitive-control tasks have been shown to be computationally unreliable (Karr et al., 2018).

Why are the correlations so low across scores? It is useful to partition cognitive control scores into those from *tasks* and those from *measures*. Tasks are true experiments where Donders' subtractive logic (Donders, 1868) is used to localize a process of interest. Two conditions are constructed where the only difference between them that is that the process of interest loads more highly on to one than the other. The contrast of the conditions allows for a measure of the process free from nuisance factors. An example is the Stroop task where cognitive control is needed more for the incongruent than the congruent condition, and the subtraction provides a measure of cognitive control free from factors such as overall speed or motivation. Measures are instruments that do not have conditions or use Donders subtraction method. Cognitive-control measures include antisaccade accuracy, card-sorting performance and working-memory span. Performance typically reflect the composite of several skills and processes including but not limited to cognitive control.

The problem in measuring cognitive control has been with tasks. As several researchers have shown, the resulting difference scores are excessively variable even when there are 100s of trials per condition per participant (Draheim, Mashburn, Martin, & Engle, 2019; Hedge, Powell, & Sumner, 2018; Rouder, Haaf, & Kumar, in preparation). The statistical bright spot has been with measures. Because measures do not involve a subtraction, they tend to have higher reliability in typically-sized sample (Draheim, Mashburn, Martin, & Engle, 2019). The problem with measures, however, is their interpretation. Whether measures index cognitive control is more-or-less asserted *prima facie* without recourse to experimental-manipulation logic. Researcher who use measures rely on their correlations with other purportedly similar measures to bolster their interpretability. For example, the correlation between working-memory span and antisacade accuracy is interpreted as coming from a shared factor of cognitive control (Unsworth, Robison, & Miller, 2021).

A laudable goal in our view is to find a unicorn task or measure for cognitive control. Such a task or measure would have high reliability in reasonable sample sizes and clearly index cognitive control. Perhaps the best candidate is the antisaccade accuracy measure (Kane, Bleckley, Conway, & Engle, 2001; Unsworth, Robison, & Miller, 2021). Individual differences in antisacadde accuracy are known to have good reliability and correlate moderately well with working memory, problem-solving ability and other cognitive control measures (Chuderski & Jastrzębski, 2018; Friedman & Miyake, 2004; Unsworth, Robison, & Miller, 2021).

The paradigm for obtaining an antisaccde accuracy measure is shown in Figure 1. Here, the cue precedes the target, and cues and targets are presented on opposite sides of fixation. There is an automatic orientation to the cue (Guitton, Buchtel, & Douglas, 1985), and this orientation response must be successfully controlled to process the target before it is masked. Accuracy, then, reflects the degree of control.

We emphasize that the antisaccade accuracy measure is a measure rather than a task as there is often no manipulation or contrast. It is possible to construct a task with both antisaccade and prosaccade conditions. The prosaccade condition, where the cue and target would be at the same location, serves as a baseline where cognitive control is not needed as the automatic orientation to the cue aids in target processing. Individual variation in prosaccade accuracy reflects individual variation in *general speed* (Salthouse, 1996) , where general speed in this setup is the speed to process briefly flashed stimuli. The antisaccade accuracy presumably indexes not only general speed but cognitive control as well. The contrast between the prosaccade and antisaccade condition then may be used to isolate the cognitive control component much the same way that the contrast between incongruent and congruent conditions are used to isolate cognitive control in Stroop tasks.

Researchers occasionally run prosaccade and antisaccade accuracy conditions in their experiments with the former serving as practice or filler. Importantly, contrasts are not constructed from the conditions (e.g., Kane, Bleckley, Conway, & Engle, 2001; Unsworth, Robison, & Miller, 2021). The exception is Rey-Mermet, Gade, and Oberauer (2018) who tuned stimulus target duration for each participant in their antisaccade task from an adaptive staircase in a preceding prosaccade task. This tuning serves as a control for individual differences in the ability to identify briefly flashed targets.

Constructing a contrast between prosaccade and antisaccade conditions is beset with the following practical problem: There is no single target duration that works well for both prosaccade and antisaccade conditions. If the target duration is tuned for the prosaccade condition, then performance is at floor in the antisaccade condition, and, the target duration is tuned for the antisaccade condition, then performance is at ceiling for the prosaccade condition. To mitigate this problem, we used a simple adaptive staircase procedure to adjust the target duration for each individual separately in the prosaccade and antisaccade conditions. With the 2-down/1-up procedure (Levitt, 1971; Treutwein, 1995), we were able to ascertain a characteristic target duration that corresponded to 71% accuracy for each individual in each condition. The duration in the prosaccade condition indexes a general speed component without cognitive control; the duration in the antisaccade condition indexes a combination of general speed and cognitive control; and, perhaps, the contrast may serve as a suitable measure of cognitive control alone.

The key prediction is about the correlation among the prosaccade and antisaccade condition. Of course we expect some correlation as both the prosaccade and antisaccade task tap many of the same processes including how well individuals can process quickly flashed targets with backwards masking. But we should not expect too high of a correlation if only the antisaccade task taps cognitive control and the cognitive-control component is the dominant in accounting for individual differences. What is the correlations is quite high? Then the antisaccade performance can be well predicted from the prosaccade performance. In this case, it is difficult to interpret antisaccade performance as localizing cognitive control; instead the antisaccade measure should be thought of as tapping the same processes as the prosaccade condition.

Method

Subjects. Twenty-six students from Brywn Mawr College participated in exchange for course credit or $10. This sample was the largest one we could obtain before the semester ended. Although a sample size of 26 is not recommended for between-subject designs, it is plenty powerful for the current within-subject design where each participants runs for 300 trials (Rouder & Haaf, 2018; Smith & Little, 2018).

Apparatus. Participants were run individually on a PC running Windows. The experiment was controlled by a Python 3.6 program using Psychopy 3 libraries. The display was an ordinary 19" LCD running with a resolution of 1440 × 900 pixels[2] at a refresh rate of 75hz.

Design. The main dependent measure of interest is the stimulus duration obtained in an adaptive staircase procedure. The main independent variable is whether the cue is located around the target (prosaccade condition) or whether the cue is located 180° from the target (antisaccade condition). This variable was manipulated within participant and was blocked so that the participant always knew whether the trial in the prosaccade or antisaccade condition.

Procedure. Participants were flashed either X or M as a target on each trial, and they had to indicate whether this target was an M or an X by depressing the corresponding key on a computer keyboard. The structure of an antisaccade trial is shown in Figure 1.

The target was placed at a certain angle relative to fixation, with all angles equally likely. In the antisaccade task, the cue consisted of two radial segments at an angle 180° from the target (as shown). For the prosaccade trials (not shown), the cue was presented at the same angle as the target. In pilot work, we confirmed that cues were sufficiently separated from targets as to not cause any meta-contrast masking effects. Timing of the events are shown in Figure 1 with the last blank lasting until response. After that, participants were provided feedback. They heard a pleasant 2-tone sequence for correct responses and a longer, lower tone for error responses.

Staircasing followed a 2-down/1-up procedure where the increments were single refreshes at 75hz (13.3 ms). Experimental blocks were comprised of 50 trials. The initial target duration in antisaccade blocks was 120ms (9 frames); that in prosaccade blocks was 66.7 ms (5 frames). The first two blocks were designed as practice blocks to familiarize the participant with the task. They consisted of only 10 trials and the target duration was started at 267 ms (20 frames). The first of these was a prosaccade block; the second was an antisaccade block. These 2 practice blocks were followed with the six experimental blocks of 50 trials each described above. The order of these 6 blocks followed an ABBAB design: some participants performed an antisaccade block; other performed a prosaccade block first.

Results

Cleaning Steps

One participant was discarded because their staircases across all blocks increased without reaching any steady-state. This participant may have reversed the key mappings.

In the staircasing procedure, the goal is to describe the steady-state value after a transitory period from the initial value. There are a number of choices and we tried several options including discarding a fixed number of initial trials or discarding trials before a set number of reversals (Levitt, 1971). None of these choices had more than a marginal effect on the results. Herein, we discarded the first 15 trials of each 50-trial block and averaged the duration values on the remaining 35 trials to form a block score. Additionally, the first experimental block in each condition was discarded because learning effects were apparent for some participants. The results change only marginally if we include these two blocks.

Observed Relationships

Mean individual staircased durations for prosaccade and antisaccade tasks are shown as a scatter plot in Figure 2A. Times for the antisaccade task were about twice as great as those for the prosaccade task reflecting the additional time needed to fixate the target's location when it was opposite the cue. There is a strong degree of correlation between the prosaccade and antisaccade task , $r = 0.83$.

The relationship between the prosaccade duration and the contrast is shown in Figure 2B. There is a large degree of correlation here as well, $r = 0.65$. To the degree that this contrast localizes a cognitive-control process, it too is well predicted by general speed in the prosaccade task. The remaining scatter plot, that between the contrast and the antisaccade duration performance is shown in Figure 2C, and the exceedingly high correlation, $r = 0.97$, shows that the variability in the contrast reflects the variability in the antisaccade task more than variability in the prosaccade task.

Mixed Linear Model Analysis

The above results show that about 70% of the variation in the antisaccade task may be accounted by variation in the prosaccade task. The question then is whether the remaining 30% of unaccounted variance is measurement error or systematic variation across individuals. We construct a series of hierarchical models to account for measurement error and various systematic structures. The first model, $\mathcal{M}_1$, is an unstructured model to separate the two sources of variation. This first model is followed by two others were we add successive degrees of structure. The residual variabilities from the three models are compared much like one compares reduction in R^2 from adding more covariates in linear models.

The unstructured model, $\mathcal{M}_1$ is:

$$\begin{aligned}\mathcal{M}_1: \quad & Y_{ijk} \sim \mathrm{N}(\mu_{ij}, \sigma_j^2)\\ & \mu_{ij} \sim \mathrm{N}(\nu, \delta^2)\end{aligned}$$

Y_{ijk} is the staircased duration for the ith person in the jth condition (prosaccade/antisaccade) in the kth block. The latent variable μ_{ij} is the "true" duration for the ith participant in the jth condition after measurement error, σ_j^2 is accounted for. Mean ν is a grand mean, and variance δ^2 is the unaccounted variance at the participant-by-condition level after measurement error (σ^2) is modeled. We expect δ^2 to be large in Model $\mathcal{M}_1$ as there is no condition or participant effects are specified on μ_{ij}. Indeed, under Model $\mathcal{M}_1$, $\delta^2 = 1112\text{ms}^2$, or, there is about 33 ms of deviations after modeling measurement error.[1]

To assess how much of this variance is accounted for by condition effects, we add condition effects to the model onμ_{ij}:

$$\begin{aligned}\mathcal{M}_2: \quad & Y_{ijk} \sim \mathrm{N}(\mu_{ij}, \sigma_j^2)\\ & \mu_{ij} \sim \mathrm{N}(\nu_j, \delta^2)\end{aligned}$$

Under Model $\mathcal{M}_2$, $\delta^2 = 136.30\text{ms}^2$. Model $\mathcal{M}_2$ accounts for about 87.70% of the variance in μ_{ij}. Indeed, there is a large difference in overall performance between the prosacade and

[1] All models are implemented as a Bayesian model in JAGS (Denwood, 2016) using conventional hierarchical-modeling techniques (Rouder & Province, 2019). We used weakly-informative priors that convey a minimum of information for this class of models (Haaf & Rouder, 2017; Rouder & Lu, 2005). For $\mathcal{M}_1$: $\sigma^2 \sim$ Inv-χ^2; $\delta^2 \sim$ Inv-χ^2; $\nu \sim \mathrm{Norm}(50, 75^2)$, where the normal is parameterized in mean and variance. For $\mathcal{M}_2$: $\sigma^2 \sim$ Inv-χ^2; $\delta^2 \sim$ Inv-χ^2; $\nu_j \sim \mathrm{Norm}(50, 75^2)$. For $\mathcal{M}_3$: $\sigma^2 \sim$ Inv-χ^2; $\delta^2 \sim$ Inv-χ^2; $\nu_j \sim \mathrm{Norm}(50, 75^2)$; $\lambda_j \sim \mathrm{Norm}^+(30, 50^2)$ where Norm^+ is a normal truncated below at 0. MCMC chains were comprised of 20,000 iterations per model.

antisaccade conditions; accounting for this large difference reduces the residual variance substantially.

How much of this remaining variance may be accounted for by a one-factor structure? The one-factor model is:

$$\begin{aligned}\mathcal{M}_3: \quad & Y_{ijk} \sim \mathrm{N}(\mu_{ij}, \sigma_j^2)\\ & \mu_{ij} \sim \mathrm{N}(\nu_j + \lambda_j \phi_i, \delta^2)\\ & \phi_i \sim \mathrm{N}(0,1)\end{aligned}$$

In additional to condition means, there is a standardized characteristic duration for each person, ϕ_i, and condition loadings, λ_j. To make the model identifiable, we restrict the loadings to be positive. This model is a hierarchical version of a standard one-factor model where cell means μ_{ij} exhibit hierarchical shrinkage to the one-factor structure.

Under Model $\mathcal{M}_3$, $\delta^2 = 3.20\text{ms}^2$. Model $\mathcal{M}_3$ accounts for about 99.71% of the unaccounted variance after modeling measurement error (that is, compared to Model $\mathcal{M}_1$), and 97.66% of the unaccounted variance after modeling measurement error and condition effects (that is, compared to Model $\mathcal{M}_2$). These results provide strong support for the one-factor structure. Once general speed is accounted for, there is just a tiny smudge of systematic variance remaining that could possibly be accounted for by additional factors.

As an additional check, we ran a confirmatory two-factor analysis with separate factors for the prosaccade and antisaccade conditions with durations from separate blocks entering into the analysis as separate manifest variables to enhance identifiability. The model converged well in Laavan (Rosseel, 2012), but resulted in a Heywood case (Rindskopf, 1984) where the resulting covariance matrix between the latent factors was not positive definite. The variances were too low for the degree of covariance indicating that the two latent factors had a correlation that approached 1.0 and that the two-factor model was inappropriate. In summary, antisaccade and prosaccade performance is driven to high precision by a single factor.

Conclusions

Because only a single factor is needed to account for over 97% of the systematic individual variation across the two tasks, it seems unreasonable to interpret the antisaccade performance as reflecting any process that is not shared with the prosaccade performance. Given that the prosaccade performance does not reflect cognitive control, we conclude that antisaccade performance does not as well. There certainly is suppression of the orienting response to the cue in the antisaccade task, but this process too reflects general speed rather than an independent cognitive control construct.

Antisaccade accuracy our view is not a unicorn task for measuring cognitive control. It may be, however, a unicorn task for measuring general speed. Covariation across prosaccade performance, antisaccade performance, and the contrast indicate that prosaccade and antisaccade tasks index a general speed factor reflecting how fast people are in performing and surpressing simple eye movement and visual tasks, and how quickly they can identify briefly masked targets.

The staircased antisaccade task is particularly attractive from a psychometric viewpoint. Because individual's durations vary to a far greater degree than the measurement error, highly reliable scores may be obtained in reasonably-sized samples. A single long block of 100 trials comprised of two interleaved staircases should be sufficient to provide a highly reliable antisaccade accuracy score (Draheim, Tsukahara, Martin, Mashburn, & Engle, 2021). Such a block takes only 5 minutes to run and may be used in clinical as well as experimental settings. Researchers who use antisaccade accuracy measures should not interpret them as cognitive control scores but rather as general speed scores.

References

Bollen, K. A. (1989). *Structural equations with latent variables.* Wiley.

Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences*, *16*(2), 106–113.

Chuderski, A., & Jastrzębski, J. (2018). Much ado about aha!: Insight problem solving is strongly related to working memory capacity and reasoning ability. *Journal of Experimental Psychology: General*, *147*(2), 257–281. doi:10.1037/xge0000378

Cohen, J. D., Forman, S. D., Braver, T. S., Casey, B. J., Servan-Schreiber, D., & Noll, D. C. (1994). Activation of the prefrontal cortex in a nonspatial working memory task with functional MRI. *Human Brain Mapping*, *1*(4), 293–304. doi:10.1002/hbm.460010407

Denwood, M. J. (2016). Runjags: An R package providing interface utilities, model templates, parallel computing methods and additional distributions for MCMC models in JAGS. *Journal of Statistical Software*, *71*, 1–25.

Donders, F. C. (1868). Die schnelligkeit psychischer processe: Erster artikel. *Archiv für Anatomie, Physiologie Und Wissenschaftliche Medicin*, 657–681.

Draheim, C., Mashburn, C. A., Martin, J. D., & Engle, R. W. (2019). Reaction time in differential and developmental research: A review and commentary on the problems and alternatives. *Psychological Bulletin*, *145*(5), 508.

Draheim, C., Tsukahara, J. S., Martin, J. D., Mashburn, C. A., & Engle, R. W. (2021). A toolbox approach to improving the measurement of attention control. *Journal of Experimental Psychology: General*, *150*(2), 242.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working Memory, Short Term Memory, and General Fluid Intelligence: A latent variable approach. *Journal of Experimental Psychology: General*, *128*, 309–331.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, *16*, 143–149.

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology: General*, *133*, 101–135.

Guitton, D., Buchtel, H. A., & Douglas, R. M. (1985). Frontal lobe lesions in man cause difficulties in suppressing reflexive glances and in generating goal-directed saccades. *Experimental Brain Research*, *58*(3), 455–472.

Haaf, J. M., & Rouder, J. N. (2017). Developing Constraint in Bayesian Mixed Models. *Psychological Methods*, *22*(4), 779–798.

Hedge, C., Powell, G., & Sumner, P. (2018). The reliability paradox: Why robust cognitive tasks do not produce reliable individual differences. *Behavioral Research Methods*.

Kane, M. J., Bleckley, M. K., Conway, A. R. A., & Engle, R. W. (2001). A controlled-attention view of working-memory capacity. *Journal of Experimental Psychology: General*, *130*(2), 169–183. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=psyh&AN=2001-17501-002&loginpage=Login.asp&site=ehost-live&scope=site

Karr, J. E., Areshenkoff, C. N., Rast, P., Hofer, S. M., Iverson, G. L., & Garcia-Barrera, M. A. (2018). The unity and diversity of executive functions: A systematic review and re-analysis of latent variable studies. *Psychological Bulletin*, *144*(11), 1147.

Levitt, H. (1971). Transformed Up-Down Methods in Psychoacoustics. *The Journal of the Acoustical Society of America*, *49*, 467–477. doi:10.1121/1.1912375

Logan, G. D., & Cowan, W. B. (1984). On the ability to inhibit thought and action: A theory of an act of control. *Psychological Review*, *91*(3), 295.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D.

(2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100.

Rey-Mermet, A., Gade, M., & Oberauer, K. (2018). Should We Stop Thinking About Inhibition? Searching for Individual and Age Differences in Inhibition Ability. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. Retrieved from http://dx.doi.org/10.1037/xlm0000450

Rindskopf, D. (1984). Structural equation models: Empirical identification, Heywood cases, and related problems. *Sociological Methods & Research*, *13*(1), 109–119.

Rosseel, Y. (2012). Lavaan: An R package for structural equation modeling. *Journal of Statistical Software*, *48*, 1–36.

Rouder, J. N., & Haaf, J. M. (2018). Power, Dominance, and Constraint: A Note on the Appeal of Different Design Traditions. *Advances in Methods and Practices in Psychological Science*, *1*(1), 19–26. Retrieved from https://journals.sagepub.com/doi/pdf/10.1177/2515245918801915

Rouder, J. N., & Haaf, J. M. (2019). A psychometrics of individual differences in experimental tasks. *Psychonomic Bulletin and Review*, *26*(2), 452–467. Retrieved from https://doi.org/10.3758/s13423-018-1558-y

Rouder, J. N., Haaf, J. M., & Kumar, A. (in preparationin preparation). *Why Most Studies of Individual Differences With Cognitive Tasks Are Bound To Fail*.

Rouder, J. N., & Lu, J. (2005). An Introduction to Bayesian Hierarchical Models with an Application in the Theory of Signal Detection. *Psychonomic Bulletin and Review*, *12*, 573–604.

Rouder, J. N., & Province, J. M. (2019). Bayesian Hierarchical Models in Psychological Science: A Tutorial. *New Methods in Cognitive Psychology*, 32–66.

Salthouse, T. A. (1996). The processing speed theory of adult age differences in cognition. *Psychological Review*, *103*, 403–428.

Skrondal, A., & Rabe-Hesketh, S. (2004). *Generalized Latent Variable Modeling: Multilevel, longitudinal, and structural equation models*. Boca Raton: CRC Press.

Smith, P. L., & Little, D. R. (2018). Small is beautiful: In defense of the small-N design. *Psychonomic Bulletin & Review*, *25*(6), 2083–2101.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*, 643–662.

Treutwein, B. (1995). Adaptive Psychophysical Procedures. *Vision Research*, *35*, 2503–2522.

Unsworth, N., Robison, M. K., & Miller, A. L. (2021). On the relation between working memory capacity and the antisaccade task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*.

Verbruggen, F., Aron, A. R., Band, G. P., Beste, C., Bissett, P. G., Brockett, A. T., … Boehler, C. N. (2019). A consensus guide to capturing the ability to inhibit actions and impulsive behaviors in the stop-signal task. *eLife*, *8*, e46323. doi:10.7554/eLife.46323

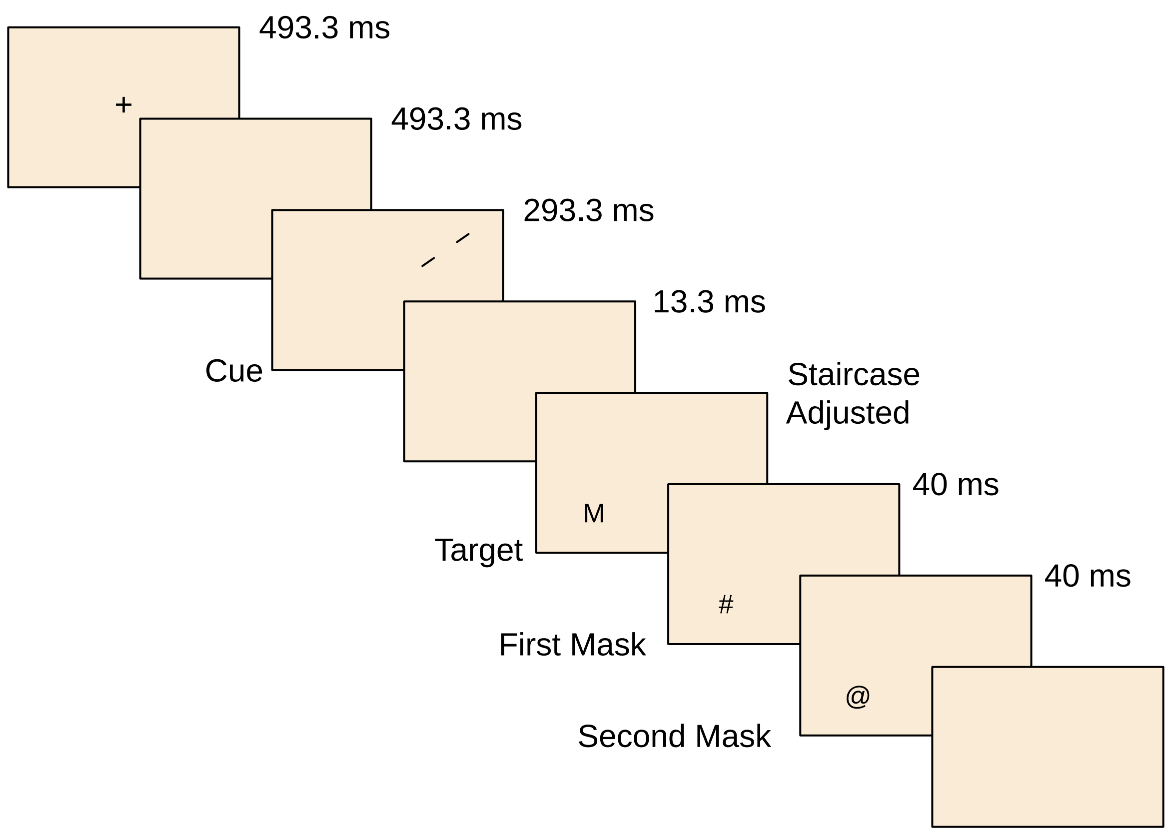

Figure 1. The structure and timing of an antisaccade trial. The cues were radial line segments at a certain angle relative to fixation. The targets were either X or M, and in the antisaccade trial, appeared opposite from the cue. The duration of the target was staircase adjusted, and the target was followed by a sequence of two masking displays. This sequence was highly effective and induced little response bias toward either target. Prosaccade trials were the same with the exception that the cue and target appeared at the same angle relative to fixation.

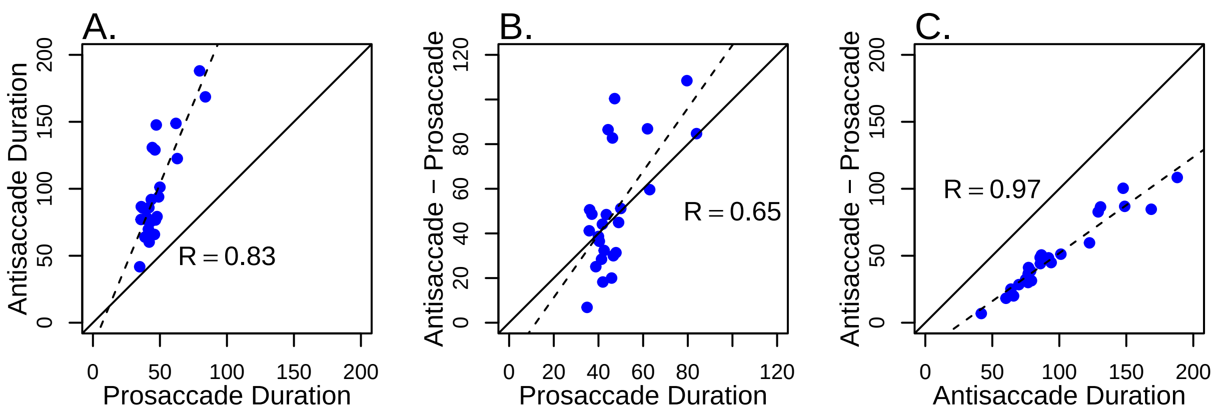

Figure 2. Relationship between prosaccade and antisaccade characteristic durations. A. Scatter of anti-sacade duration as a function of prosaccade duration. The high correlation is indicates that the antisaccade task is well predicted by the prosaccade task and likely reflects general speed to a large degree. B. Scatter of the difference in durations across conditions as a function of prosaccade task duration. The positive correlation indicates that a cognitive-control component (defined as the contrast) is not independent from a general-speed component. C. Scatter of the difference as a function of anti-saccade duration suggests that the tasks and the differences among them reflect a single factor.