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Variation in antisaccadic response latencies investigated with the hierarchical LATER process model

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ABSTRACT

The antisaccade paradigm is frequently applied to measure inhibitory control. Typically, simple, perceptually neutral stimuli are used as cues. Recently, emotional versions of this paradigm have also been employed. In our study, we used both versions of the paradigm. In addition, scrambled faces served to control for stimulus size and emotional valence. We applied a hierarchical extension to the Linear Approach to Threshold Ergodic Rate (LATER) process model, which allows the estimation of two latent cognitive parameters: speed of information accumulation (accretion rate) and the amount of information needed before a saccadic movement (caution threshold). We hypothesized a faster accretion rate and lower caution threshold for circular and scrambled compared to emotional face stimuli as well as meaningful differences between individual emotions. Our results showed a faster accretion rate and lower caution threshold for emotional compared to circular stimuli, though. In contrast, scrambled faces had a lower accretion rate and lower caution threshold. Furthermore, the LATER model uncovered subtle differences between different emotions. Happy faces tend to receive a faster accretion rate and higher caution threshold than neutral ones, while for fearful faces it was the other way around. Our results contradict earlier research on emotional stimuli interfering inhibitory control.

1. Introduction

The antisaccade task is a very popular tool for measuring inhibitory control processes. There are different kinds of versions of this paradigm, which all roughly follow a methodological standard (Antoniades et al., 2013), but apply different kinds of stimuli e.g., white geometric shapes or emotional faces. During antisaccade execution, reaction times (RTs) are much longer than the actual nerval transmission. Therefore, research suggests that different underlying cognitive processes cause this difference in actual RT and nerval transmission itself (Noorani & Carpenter, 2016). The frontal eye field (FEF) is crucial for antisaccade generation (Connolly et al., 2002), although neurons in the lateral intraparietal area are also needed for the sensorimotor transformation for antisaccades (Zhang & Barash, 2000). Moreover, neurons in the FEF and superior colliculus are responsible for the inhibition of saccades as well as direction errors during antisaccade execution (Everling & Munoz, 2000). These areas receive their signal from the supplementary motor area (Stuphorn et al., 2010) and the dorsolateral prefrontal cortex (Munoz & Everling, 2004). Different neuronal populations in the basal ganglia facilitate prosaccades as well as antisaccades, which are connected to higher cortical areas, which provide the necessary input (Ford & Everling, 2009).

One way of modeling two of these cognitive processes is through accretion rate and caution threshold. The accretion rate quantifies the amount of information a person needs until making an antisaccadic eye-movement. Hence, it constitutes the extent of information accumulation. The caution threshold describes how careful a specific person is when making the decision of an oculomotor movement away from a stimulus. We estimate these two parameters with the Linear Approach to Threshold Ergodic Rate (LATER) model (e.g., Carpenter et al., 2009; Noorani, 2014; Noorani & Carpenter, 2013, 2016). The focus of the classic LATER model is the comparison of accretion rate and caution threshold across different conditions. Oravecz et al. (2016) and Roberts et al. (2019) extended this model hierarchically, which allows variation within and between persons as well as within conditions. This is important because we expect a trial-to-trial random rate i.e., subjects respond differently in each trial. In previous studies, the extended LATER model has already been applied to a Go/No-Go task, but not yet to antisaccade tasks (Roberts et al., 2019). We claim that combining hierarchical process modeling with experimental parameters (i.e.,

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different kinds of stimuli) can provide a deeper understanding of how emotional valence and stimulus size affect antisaccade performance. Conventional frequentist analyses are based on averaging task performance across individuals per experimental condition and thus reducing the amount of information by which the model is informed, which might lead to insufficient results (e.g., Aichert et al., 2013); when there are not enough valid trials, RTs cannot be interpreted as such, which was the case in this research.

By applying hierarchical LATER modeling, latent parameters instead of mean RTs are estimated. Thus, it might be possible to capture intra-individual cognitive processes, which in turn facilitate condition-specific differences to be not biased by averaging raw performance values. Fig. 1 illustrates the concept of the LATER model as well as the estimated variations in information accumulation and caution threshold. In the antisaccade task, we define RTs as the interval between stimulus onset and the first saccadic response. In the LATER model, accretion rate ν_p marks the linear rate of information accumulation, while the caution threshold θ_p represents the information amount needed to respond. A person p accumulates information until reaching a threshold, which then leads to a saccade. Recently, Oravecz et al. (2016) introduced a Bayesian hierarchical LATER model, where not only the accretion rate ν_p, but also the caution threshold θ_p is allowed to vary across subjects. Note that RT distributions are positively skewed. Since we are interested in the underlying mechanism for the variability and not the effect itself, we use the inverted (reciprocal) RT as the dependent variable. If the reciprocal RTs are plotted cumulatively, it will result in a straight line. Thus, this rate (not effect) modeling the decision process follows a Gaussian distribution (Noorani & Carpenter, 2016). To include both person-specific and condition-specific covariates, all persons p have to be stacked under one another, so that the vector of individual RTs y_n, where $n = (1, 2, \cdots, N)$ with N as the total number of RTs and n as a specific trial, is then given by

$$y_n \; N\left(\frac{\nu_n}{\theta_n}, \frac{1}{\theta_n^2}\right).$$

Let the covariate for every data point be denoted as $g_{n,c}$, where $c = (1, 2, \cdots, C)$ with C representing the number of dummy-coded conditions minus 1 (baseline). For the paradigm comparison, this means that the emotional and scrambled paradigm is compared to the baseline of the classic paradigm. In the emotional paradigm itself, neutral faces are the baseline to which happy, fearful, and sad faces are compared to. The corresponding regression coefficients are denoted as $\delta_{\nu,c}$ for the accretion rate and $\delta_{\theta,c}$ for the caution threshold. Hence, the accretion rate is given by

$$\nu_n = \nu_p + \boldsymbol{g}\delta_\nu,$$

while the caution threshold is given by

$$\theta_n = \theta_p + \boldsymbol{g}\delta_\theta.$$

For a thorough introduction of the hierarchical extension of the LATER model, see Oravecz et al. (2016) and Roberts et al. (2019). We fit the hierarchical LATER model to data from antisaccade trials of three different antisaccade paradigms (classic/scrambled/emotional) performed by a psychologically healthy sample. While the antisaccade paradigm is typically used for measuring inhibitory control (Antoniades et al., 2013; Noorani & Carpenter, 2016), it can also be highly informative about general alertness and cognitive processing speed as measured by prosaccades. Notably, prosaccades are usually a control condition and therefore tested less frequently than antisaccades. Prior studies found only modest effects of stimulus size in the antisaccade paradigm (Fischer & Weber, 1997), when using varying sizes of neutral white stimuli. Yet to date, no one compared stimuli that are more complex, e.g. emotional faces to smaller and simpler geometrical stimuli in terms of cognitive processing parameters. Nevertheless, task-evoked potentials have been found to be directly related to stimulus size (Busch et al., 2004). However, none of these studies has demonstrated differences in reaction times between different kinds of paradigms nor examined the underlying mechanisms of RTs that affect different kind of stimuli. As a result, it remains unknown whether stimulus size or emotional valence affect specific components of cognitive functioning in healthy subjects. Our goal is to apply the hierarchical LATER model and explore intra-individual differences among healthy adults in their information accumulation and caution processes.

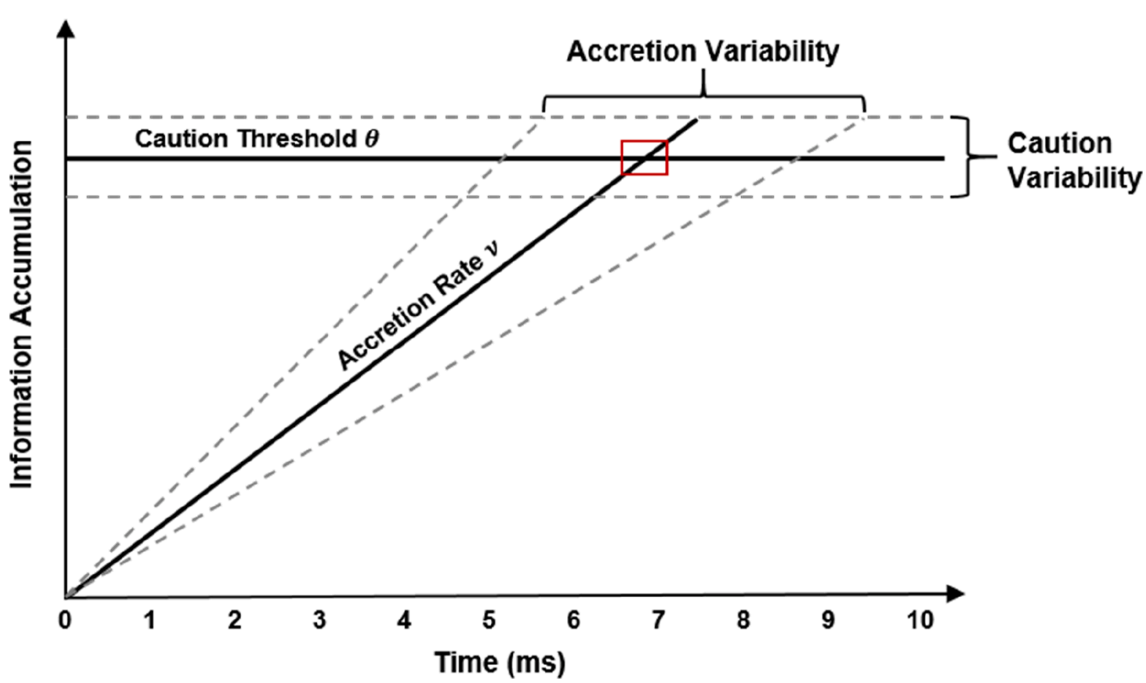

Fig. 1. Visual representation of the cognitive processes (accretion rate and caution threshold) examined in the hierarchical Linear Approach to Threshold with Ergodic Rate (LATER) model. The red rectangle illustrates the end of the decision process. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

First, we expect size and complexity to affect cognitive processes important for response execution during antisaccades, as emotional valence was shown to interfere with inhibition capacities (Schimmack & Derryberry, 2005; Verbruggen & De Houwer, 2007; Herbert & Sütterlin, 2011; Rebetez et al., 2015). Therefore, we would assume slower accretion rates and higher caution threshold in emotional compared to scrambled or classic, circular stimuli. As emotional faces contain more information than scrambled or circular stimuli and are bigger in size, this seems to be a plausible conclusion. Second, given widespread effects of emotional content on eye-movement patterns (Mogg & Bradley, 1999; Calvo et al., 2006; Khalid et al., 2017), we hypothesize that displayed emotions will affect cognitive processes important for response execution during antisaccades. We assume that these effects may be hidden, when analyzing RTs via traditional mean scores.

2. Materials and methods

2.1. Participants

Thirty-seven volunteers (M_{age} = 21.78, SD_{age} = 1.89) participated with informed consent in the present study, which was conducted in line with the guidelines of the Declaration of Helsinki. Exclusion criteria were visual impairment corrected with glasses or any current psychological problem. Therefore, we applied the DIA-X-SSQ (Wittchen & Perkonigg, 1996) to ensure our subjects' psychological health, and only invited participants without reporting any current psychological issues. We recruited our participants from an experimental seminar from a bachelor degree program in psychology; they were rewarded with course credits, which they needed to collect within their studies. Furthermore, they had the possibility to cancel their participation at any moment with not negative consequences. Thirty-five subjects (27 female) were entered into the final analyses, as we had to exclude two subjects because of too much data loss due to blinking during data acquisition. As this study is exploratory and meant to illustrate the implications of a new approach for data analysis, it is difficult to define a practically relevant effect size for power planning. Therefore, we chose the sample size ad hoc with the assumption that 3,150 replications per participant and 35 participants yield sufficiently precise estimates and good credible interval coverage. This assumption is based on prior research with comparable or smaller sample sizes where LATER modeling was applied (e.g., Carpenter et al., 2009; Burrell et al., 2012; Domenech & Dreher, 2010; Noorani & Carpenter, 2013; Roberts et al., 2019).

2.2. Data collection

We used a Tobii TX-300 eye-tracker to collect eye-movements binocularly (Tobii AB, Danderyd, Sweden). With a sampling rate of 300 Hz, this infrared-based eye-tracking system is able to quantify horizontal eye-movements up to +/-25°. Before data acquisition, the eye-tracker was calibrated and validated with a 5-point calibration procedure.

For artifact correction and calculation of saccade parameters, we used a custom developed interactive analysis software, which allowed evaluating RTs based on a linear regression as well as eye-movement interval classification. Within the tool, the automated detection was adjusted manually and directly exported into Excel files for further statistical analyses. The tool is a stand-alone application developed in F#. It reads in the TSV-ASCII output from the Tobii TX-300 eye-tracker. Target positions and timestamps of the experimental setup must be configured in a separate ASCII-file. Each target event can be filtered (e.g., by its name) and visualized. The visualization shows the error (or angle) towards the target over time separated in X and Y direction (see Fig. 2). An angle is computed between the vector mean gaze point - mean 3D eye position and the vector target point − 3D eye position. In this experiment the 3D eye position was not included in the output file by the scanner, and was estimated as [259, 207.25, 601.35] (RCSmm), which was taken from an identical experimental setup (fixed head position). As the experiment focuses on the X-error, this is used for further analysis. A linear regression is computed directly on the input stream, by matching a line

($y = \mathbf{k}{*}x + \mathbf{d}$) onto the so far processed X-error values. If a new data sample is more than 0.3° apart from the line, a new interval and line matching is started. Fig. 2 shows the linear regression lines as striped-blue lines.

Additionally, intervals are illustrated by colored and labelled bars at the bottom of the plot in green (fixation), yellow (decreasing X-error value) and light blue (increasing X-error value). An interval is classified as fixation if $|\mathbf{k}| < 0.006$. The speed of the eye-movement is shown as bar plots in grey (°/4ms), and the RT marked by the black bars. RT is measured in milliseconds from the target change event of the experiment to the start of a saccade. The automatically detected RT can be overridden via user interaction. Data corrected by the user are stored in a separate ASCII file. Target events can also by classified by the user as bad data to be excluded from further processing and export. A text field allows setting up a wild-card inclusive filter. Navigation through the filtered events is also supported. Once the events have all been verified and corrected, the exported Excel table includes event name, event type, emotion label, RT, and time to the first target fixation.

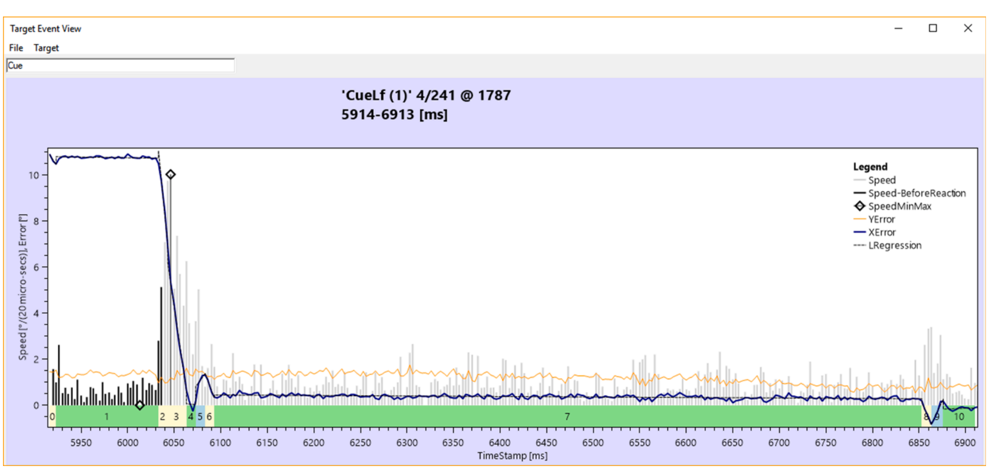

Fig. 2. Custom interactive analysis software for evaluating RTs in the antisaccade task.

2.3. Antisaccade paradigms

In the classic antisaccade paradigm, we presented a neutral cue (white circle, 1° diameter, line thickness 0.3°) in the center of the display for a variable interval of 1000 – 2000 ms (Tobii TX-300 screen-unit; resolution: 1920x1080; refresh rate: 60 Hz; viewing distance: 60 cm; Dell Precision T-5610). We kept the viewing distance stable via a chin rest. After the variable interval, the cue moved 12° either left or right from the center, where it stayed for 1000 ms, before it moved back to the center (no gap or overlap). The task sequence followed methodological standards (Antoniades et al., 2013) and was further based on the design from another antisaccade study applying the LATER model (Noorani & Carpenter, 2013). Similar to Noorani & Carpenter (2013), our task sequence minimized the production of early or express saccades e.g., by applying a step task instead of a gap, because we wanted clear distributions of antisaccades and errors that were not interfered by express saccades, therefore enabling the development of a robust model of the data. Each position appeared equally often (randomized order). We instructed our subjects to fixate on the central cue and further as soon as it moved to another location, to fixate as fast as possible on the mirror position of the respective target without looking in direction of the target. As a second condition, subjects performed prosaccades, where they had to follow the stimulus as fast as possible and fixate it. We presented pro- and antisaccades in separate blocks. We applied the exact same task with emotional (happy, fearful, sad) and neutral faces with facial stimuli from the FACES database (Ebner et al., 2010). All non-facial features (e.g., hair, neck) were removed and the faces were resized to 6°x8°. For each expression, we used five different black and white pictures that were balanced for gender (50% male faces); all faces were Caucasian. Emotions were presented randomized within blocks. As a third condition, we used scrambled faces in order to control for stimulus size and complexity (one male/one female face); we applied a Photoshop scrambling filter to make those faces and emotions unrecognizable (see Fig. 3). All blocks were preceded by 10 practice trials, from which the data were discarded. After each 75 trials, subjects got the possibility to take an individual break. We randomized the order of the blocks across participants. In sum, we recorded over 100,000 saccades and the experimental session took about 3 to 3.5 h per participant, depending on individual breaks.

Block 1 (classic prosaccades): 150 trials

Block 2 (classic antisaccades): 375 trials

Block 3 (scrambled faces prosaccades): 150 trials

Block 4 (scrambled faces antisaccades): 375 trials

Block 5–6 (emotional faces prosaccades): 600 trials (150 per emotion)

Block 7–10 (emotional faces antisaccades): 1500 trials (375 per emotion)

As central performance indicators, we chose (1) saccade RTs and (2) error rates (ER; saccades in direction of the target cue or corrective saccades). The applicability of those parameters has been validated both in healthy and clinical samples (Ettinger et al., 2003). Saccadic and antisaccadic eye-movements were defined by criteria of amplitude ≥ 1.5°, velocity ≥ 30°/s and latency between 100 and 900 ms. Trials with RTs faster than 100 ms were excluded from analyses to avoid the inclusion of potentially premature or artifact-bearing responses (e.g., blinks). This threshold was set to ensure that the response was in fact a reaction to the stimulus as well as a saccadic eye-movement. Choosing this threshold is well documented in the literature (Ettinger et al., 2003). For the calculation of RTs, we used the onset of a saccade and removed all artifact-affected trials (e.g., blink saccades, measurement failures; ~0.02% in each paradigm). RTs were calculated only on correct responses.

2.4. Data analysis

We estimated our parameters in a Bayesian framework as it provides a convenient way to estimate all parameters at once. Hence, it reduces potential bias while still being computational feasible. We used flat (uninformative) priors since there was no specific prior knowledge. The posterior means are estimated over 6 Markov Chains with 2,000 iterations each (1,000 samples as burn-in). Two models are fitted separately: The comparison of the classic paradigm with the emotional and scrambled paradigm as covariates and the emotional paradigm itself with happy, fearful, and sad emotions as covariates compared to neutral faces. Model convergence was tested by the $\widehat{R}$ statistic ($\widehat{R} < 1.1$; Gelman & Rubin, 1992) and posterior predictive checks (PPC). The latter simulates new data from the estimated coefficients and compares it to the observed RT distribution. We conducted all statistical analyses in R 4.0.4 or later and Stan (R Core Team, 2021; Carpenter et al., 2017). Our scripts and data set are openly available at https://osf.io/s3ega/.

3. Results

3.1. Individual differences in the decision on antisaccades

Accretion rate and caution threshold parameters were estimated for each person individually (see Fig. 4). Caution parameter estimates ranged from 1 to 3, while accretion rate was between 0.7 and 1.6. To relate these two scales, a subject with caution parameter 3 and accretion rate 2 would need 666 ms to perform an antisaccade. As can be seen, various combinations of accretion rates and caution thresholds can lead to similar RTs.

3.2. Task- and emotion-specific differences in the decision on antisaccades

We were interested in capturing differences in the decisions on antisaccade trials depending on the applied stimulus and emotion. These

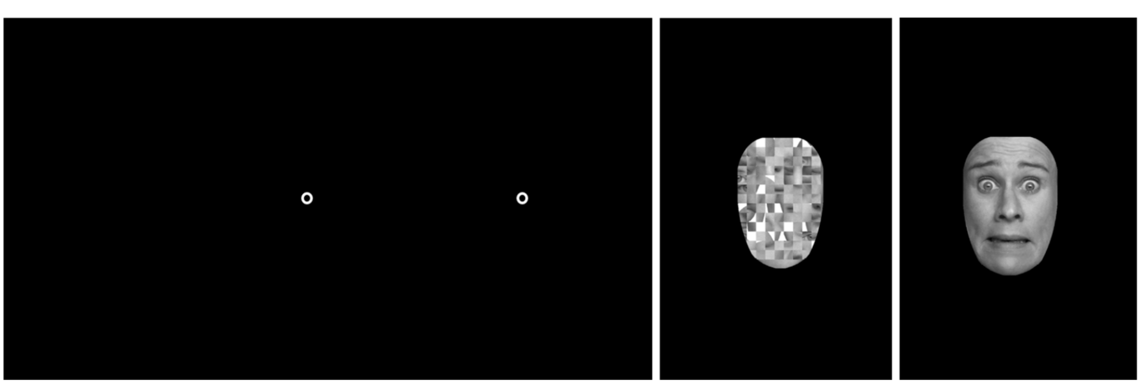

Fig. 3. Stimuli as presented in the three different pro- and antisaccade paradigms applying classic circles (A), emotional (B) and scrambled faces (C) as target cues.

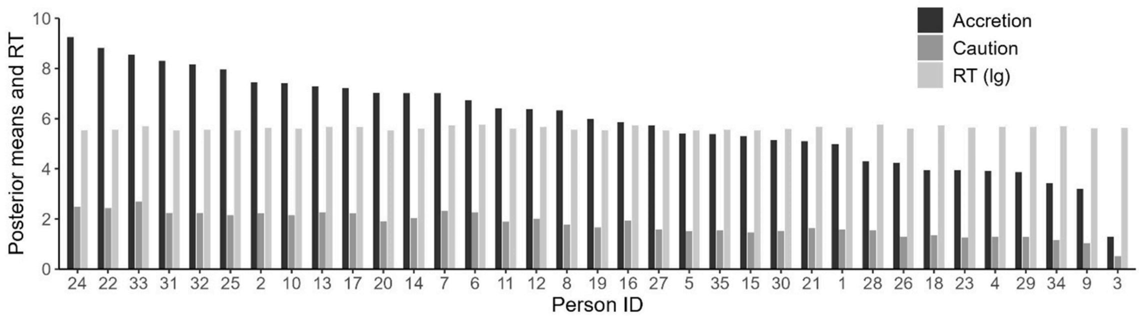

Fig. 4. Posterior mean estimates of accretion rate and caution threshold when comparing the different paradigms for every person. To illustrate the different combinations of accretion and caution, the log-transformed RT is included, additionally.

conditions were modelled individually for each subject. We chose the classic circular stimuli as our baseline, and modeled the differences in the scrambled and emotional paradigms in terms of accretion rate and caution threshold (see Table 1). Both accretion parameters have a strong positive (emotional paradigm) or negative (scrambled paradigm) difference to the baseline (classical paradigm), since the 97.5% credible interval does not contain 0. Accretion parameters reveal that emotional stimuli received faster information accumulation compared to classic, circular stimuli, while scrambled faces were processed slower than circles. Compared to the baseline condition, subjects had a lower caution threshold when performing antisaccades with emotional and scrambled faces, relative to the baseline condition (white circles).

Differences between emotions are in general smaller, which means that these results need to be interpreted more carefully. We found a tendency towards faster accretion rate and higher caution threshold for happy faces, which was statistically not meaningful, though. For fearful faces, a slower accretion rate and lower caution threshold were observed. No meaningful difference exists between neutral and sad face stimuli, as both parameters had a 97.5% credible interval containing 0.

3.3. Model fit

In addition to model convergence, we tested how well the LATER model fits the actual observed data by performing posterior predictive checks (PPCs). For this, we generated 100 new data sets from the posterior distributions of the LATER model parameters. Fig. 5 shows blue density curves of these generated datasets overlaying the observed data (bars). The PPC shows a good posterior fit to the observed data in the comparison of paradigms (see Fig. 4A). The fit of the emotional paradigm is not optimal (see Fig. 4B). Underestimating the actual distribution is common, if there are other associations involved, which were not modeled. Thus, it is probably the case that other covariates are responsible at least for parts of the variation in RTs within the emotional paradigm.

Table 1
Posterior mean estimates (M), standard deviation (SD), and credible interval (CI) for accretion rate and caution threshold.

Regressand	Mean (SD)	$CI_{2.5\%}$	$CI_{97.5\%}$
Paradigm Comparison			
Accretion Emotional ($\delta_{\nu,1}$)	0.50 (0.04)	0.43	0.58
Accretion Scramble ($\delta_{\nu,2}$)	−0.75 (0.04)	−0.84	−0.67
Caution Emotional ($\delta_{\theta,1}$)	−0.10 (0.01)	−0.12	−0.08
Caution Scramble ($\delta_{\theta,2}$)	−0.29 (0.01)	−0.32	−0.27
Emotion Comparison			
Accretion Happy ($\delta_{\nu,3}$)	0.10 (0.05)	0.003	0.21
Accretion Fearful ($\delta_{\nu,4}$)	−0.09 (0.05)	−0.19	0.005
Accretion Sad ($\delta_{\nu,5}$)	−0.03 (0.05)	−0.13	0.08
Caution Happy ($\delta_{\theta,3}$)	0.03 (0.01)	−0.0004	0.05
Caution Fearful ($\delta_{\theta,4}$)	−0.02 (0.01)	−0.05	0.003
Caution Sad ($\delta_{\theta,5}$)	−0.01 (0.01)	−0.03	0.02

Negative Posterior Means indicate faster accretion rates and lower caution thresholds; positive values indicate slower accretion rates and higher caution thresholds. Mean and SD are posterior mean and standard deviation.

4. Discussion

In this paper, we used the hierarchical LATER model (Roberts et al., 2019), which decomposes RTs into two separate components of cognitive processing i.e., accretion rate and caution threshold. This model extension makes it possible to account for and compare differences in sources of variation related to experimental conditions as well as person-specific differences in accretion rate and caution threshold. We demonstrated the applicability and benefits of this model by applying it to eye-tracking RT data from a group of healthy subjects, identifying condition and trial level effects during antisaccade execution. We further show the strength of this approach by demonstrating what researchers can learn about different kind of stimuli and the influence of stimulus size, complexity, and emotional valence utilizing this modeling approach.

Our findings demonstrate differences in both cognitive parameters underlying RTs concerning different emotions. In the current analyses, the baseline (or comparative) condition was the classic antisaccade task applying circular stimuli. Our results demonstrated the following: relative to our baseline condition, we observed faster accretion rates in the emotional antisaccade paradigm, but slower accretion rates in the paradigm applied with scrambled faces. Moreover, subjects utilized a lower caution threshold in emotional and scrambled stimuli relative to the baseline condition.

Our study is the first to apply advanced process modeling to examine the effects of stimulus size and emotional valence on inhibitory control. Understanding how stimulus size and emotional valance affect inhibitory control is important, as problems in executive functioning, especially with emotional stimuli, are a common finding in psychological disorders, e.g. major depression (Hoffmann et al., 2019), anxiety (Chen et al., 2014), and bipolar disorder (García-Blanco et al., 2013). Our findings demonstrate differences in both accretion and caution parameters in emotional relative to neutral circle stimuli: we found faster accretion rates and lower caution thresholds in emotional face stimuli, while for scrambled faces both accretion rate and caution threshold were lowered compared to circular stimuli. This overall main finding contradicts other studies demonstrating a negative influence on inhibitory control performance due to emotional content (Schimmack & Derryberry, 2005; Verbruggen & De Houwer, 2007; Herbert & Sütterlin, 2011; Rebetez et al., 2015), and thus promotes the notion that performance deficits in the emotional antisaccade paradigm mark solely a symptom of affective disorders as mentioned above.

Interestingly, emotional trials produced faster accretion rates and lower caution thresholds than classic trials. This finding suggests that

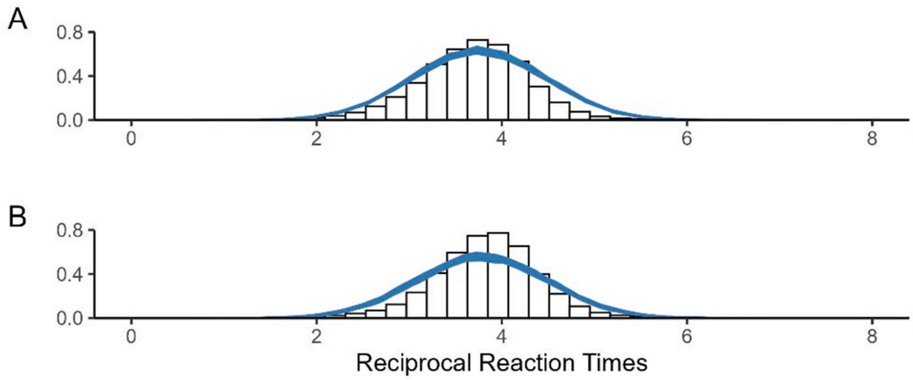

Fig. 5. PPCs for (A) paradigm comparisons and (B) emotion comparisons. The histogram shows the observed distribution, while the blue lines illustrate 100 samples from the posterior distribution. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

during the processing of emotional faces, participants seemed to be less careful in their decision time. In contrast, Rebetez et al. (2015) reported prolonged response latencies when examining the stop trials of the stop-signal task in emotional vs. neutral trials, which is not in line with our results. Our results support the notion that accretion rate i.e., the speed of information accumulation, is not affected by emotional content. Of note, the opposite is the case for scrambled faces as they received slower accretion rates than classic circular stimuli, which points to the fact that information about emotional stimuli is acquired faster than information about less complex and smaller stimuli. Indeed, an event-related potential study could show that emotional faces affect earlier stages of emotion processing when being compared to emotional words (Frühholz et al., 2011); emotional value is detected at early stages of emotional processing in the visual cortex. Moreover, the fusiform face area is involved here (Ganel et al., 2005), which might play a role in the faster accretion rates.

The distinction of the antisaccade task from other tasks applied in earlier studies might be crucial here. Inconsistent results may have occurred because different cognitive mechanisms were involved (Friedman & Miyake, 2004), which might be either pre-potent response inhibition, resistance to distractor interference, or resistance to proactive interference. The antisaccade task mainly involves pre-potent response inhibition (Noorani & Carpenter, 2013). Moreover, the stop signal task for example involves a motoric component for response execution. Therefore, it is impossible to separate motoric and cognitive processes from each other. A major advantage of the antisaccade task is that it only involves eye-movement, which is not intermingled with motoric processes during the cognitive processing of stimuli. Moreover, as we used a blocked design, we were able to investigate the inhibition of pre-potent responses solely. In the stop signal task, stop and go trials are interleaved, and thus it is likely that not only inhibitory control, but also shifting is involved (Friedman & Miyake, 2004).

Nevertheless, the caution threshold was lower for emotional and scrambled stimuli than for small circles, indicating that stimulus size matters for caution before response execution. Therefore, less processing demands, and time might be needed to integrate information about emotional faces into the decision process. To the best of our knowledge, a LATER process model has never been applied to different versions of the antisaccade paradigm to examine underlying mechanisms of response latencies. Most importantly, our findings partially contradict prior research attempting to examine the influence of emotional content on underlying mechanisms of inhibitory control.

Differences between emotions are in general smaller concerning effect sizes, which is why we interpret these results more carefully. Happy faces tend to receive a faster accretion rate and higher caution threshold than neutral ones, which means that information is accumulated faster, while responses are executed more carefully. This might be interpreted as happy faces attracting more attention than neutral ones and thus being harder to avoid. For fearful faces, it was the other way around i.e., slower accretion rate and lower caution threshold. This result is interesting insofar, as evolutionary psychology suggest that humans are prone to detect fear faster than any other emotion, as it is relevant for our survival (Boll et al., 2011; Khalid et al., 2017). Our results suggests that information accumulation is slower compared to neutral faces, although responses are executed less carefully, which means that fearful faces are processed longer than neutral ones, but easier to avoid.

There are notable limitations in the current study: first, we only examined antisaccade performance more closely and not prosaccades. The experiment already took 3 to 3.5 h per participant with 150 trials per prosaccade condition, which was insufficient for parameter estimation. So second, the duration of the experiment is another limitation of the study, as 3 to 3.5 h of eye tracking are quite exhausting and tiring. Nevertheless, we included breaks within blocks (every 75 trials), which participants could take individually. In addition, subjects could take a break between the blocks, where we opened the window, and they could stand up from the chin rest. We analyzed whether RTs differed across this 75-trial blocks by applying an analysis of variance and found no significant difference concerning the processing speed of our subjects ($F(1, 29) = 0.99$, $p = 0.47$). Third, we had a relatively small and young sample with unbalanced gender, which comprised of bachelor psychology students only; this is not representative at all. However, as described by Roberts et al. (2019), the implementation of a process model that utilizes a sequential sampling method as well as hierarchical modeling can handle small sample sizes better than traditional approaches. Nevertheless, the application in older and cognitively more diverse samples would be important for future studies.

Taken together, the hierarchical LATER model (Oravecz et al., 2016) is able to describe antisaccadic RTs with two parameters, while simultaneously accounting for stimuli differences. Thus, we gained insight into subtle effects of stimulus-type and emotional valence on performance that might be hidden when analyzing mean RTs by applying traditional frequentist analyses. Modeling performance in emotional eye-tracking paradigms in disordered samples would be another target worthwhile to address in future studies. The applied model examined differences across individuals together with stimulus-specific differences. This is an important extension as it enables researchers to examine both between- and within-subject differences during various experimental conditions. For the antisaccade paradigm measuring inhibitory control without motoric response processes, emotional faces seem to facilitate inhibitory control, as information about faces is accumulated faster than for smaller circular stimuli. As consequence, emotional faces are easier to avoid. Moreover, when controlling for stimulus size, emotional valence, and complexity by applying scrambled faces, we find that information about scrambled face stimuli is accumulated slower than in circular stimuli. This gives rise to the notion that not size or emotional valence, but complexity plays a major for information accumulation. For both emotional and scrambled faces, the caution threshold was lower than for classic circular stimuli, which indicates that the size of the stimulus influences the cautiousness of the response more than emotional valence or complexity do.

Moreover, researchers might apply the hierarchical LATER model in future studies to investigate potential factors influencing antisaccadic RTs in individuals suffering from affective disorders like major depression, bipolar disorder, or anxiety. Moreover, saccadic reactions during prosaccades with respect to different kinds of stimuli should be investigated, as this might yield different insights than the inhibitory mechanisms in antisaccades.

5. Ethics statement

The Ethical Review Board of the University of Innsbruck reviewed and approved the study protocol. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data** availability **statement

The data that support the findings of this study are openly available in open science framework at https://osf.io/s3ega/, doi:10.17605/OSF.IO/S3EGA. The source code of the custom developed interactive analysis software is available on GitHub at https://github.com/gileoo/Eye-TrackingFS. The present research did not receive any funding.

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