Distinct inhibitory control systems underlie individual differences in dynamic responses to an ultimatum game: A preliminary investigation

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Abstract

Adult participants were asked to accept or reject third-party distributions that were fair or unfair in ways that created advantageous or disadvantageous inequities while their manual responses were tracked. Reach tracking measures how participants resolve conflict between alternate options and the timing of that resolution. Participants were less likely to accept disadvantageous inequities than fair distributions or advantageous inequities. Participants showed greater deviance in their curvature towards the alternative option when they rejected the distribution than when they accepted it. However, they resolved their deviance towards the alternate option faster when they rejected a distribution. This suggests a new way of considering the role of inhibitory control in economic decision making: Participants more quickly detect conflict when rejecting distributions, but the act of costing oneself resources requires more inhibitory processes related to conflict resolution.

Keywords: Reach Tracking; Inhibitory Control; Ultimatum Game

Introduction

Measures of social decision-making investigate the ways in which human beings navigate a complex environment. One such example is the ultimatum game (Güth et al., 1982), which investigates the extent to which participants will incur costs to achieve fair behavior. In one version of this game, participants choose to accept or reject a proposed distribution of resources (made by a third party) between themselves and another person. Participants typically accept fair (or near fair) offers. Rejection rates increase as their share becomes lower; participants often reject offers below some minimally acceptable value (usually 20-30% of the distribution, see Camerer, 2003). These results – that participants will forgo resources if the offer has too much of a disadvantageous inequity – are considered problematic for the hypothesis that participants only try to maximize gains; rather, they are taken as evidence that a fundamental motivation for decision-making is a preference for fairness (e.g., Fehr & Fischbacher, 2004; Glimcher et al., 2009).

To understand how fairness influences social decision-making, numerous neuroimaging studies of performance on the ultimatum game have posited roles for distinct neural systems in evaluating the decision to accept or reject an offer. The insula shows greater activation when processing unfair distributions. This activation has initially been considered to reflect negative emotions towards unfair distributions (e.g., Hsu et al., 2008; Sanfey et al., 2003; Tabibnia et al., 2008). However, others have suggested that this activation results from participants detecting deviation from an expected outcome, by showing similar patterns of activation for disadvantageous and advantageous inequities (e.g., Civai et al., 2012). These results suggest that one process involved in deciding whether to accept or reject others' offers incorporates evaluating the social nature of the task, and the perception of fairness of the offer.

Many of these studies group activation of the medial prefrontal cortex and anterior cingulate together; these regions show greater activation when participants decide to reject rather than accept the offer, particularly when the participant themselves is the responder (e.g., Corradi-Dell'Acqua et al., 2013). This activation is thought to reflect participants monitoring the conflict between the more rational desire to gain resources and the more irrational desire (from an economics standpoint) to preserve fairness when receiving an unfair offer. Higher activation indicates more inhibition of the rational action in favor of the irrational one.

A fundamental question involves the role of these latter neural circuits in monitoring, evaluating, and resolving the conflict inherent in rejecting unfair distributions of resources. That is, these neural circuits are engaged in distinct processes involved in cognitive control. Shenhav et al. (2013) proposed a three-component model of cognitive control based on the function of these neural circuits. The first component, more associated with dACC (dorsal anterior cingulate cortex) activation, monitors conflict that stems from competing activations. Such a mechanism is used to register the unfair distribution with the possibility of rejecting it. The second component registers the appropriate course of action given one's goal, which would involve deciding to accept or reject

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the distribution. The third component generates a response. The latter components recruit medial prefrontal areas, through which signals of conflict from the first component raise one's threshold to respond by adjusting motor responses (e.g., Munakata et al., 2011).

The majority of research that examines the role of the medial prefrontal cortex and anterior cingulate use fMRI to detect differential patterns of activation among trials. Although this method has shown dissociable patterns of responses between the neural circuity involved in the emotional evaluation of the offer and the cognitive control involved in acceptance or rejection, these findings have not isolated the facets of cognitive control involved in that decision-making. Here, we use a different method – 3D reach tracking – to examine the manual responses of participants as they accept or reject distributions in an Ultimatum game. This measure uses the temporal dynamics of behavior to provide insight into the neural systems involved in decision making; such temporal information is often not accessible via the fMRI method, making reach tracking a way of supplementing conclusions obtain by this method.

Reach tracking has been used to study dissociable processes in cognitive control in various nonsocial cognitive measures. Evidence from reach tracking provides information about the role of the neural circuits involved in cognitive control as a decision unfolds over time. Previous reach tracking research has shown that the degree of curvature in a participant's reach movement indicates how co-active competing responses are over the course of a trial (e.g., Song & Nakayama, 2008). When given a two-alternative forced-choice, participants who reach more directly to a target response show lower influence from the alternate option when deciding. This work suggests that the deviance in curvature towards the competing outcome can be used to target how conflict resolution involving competitive inhibition unfolds over the course of a trial *in situ*. Applied to the decision to accept or reject a distribution, curvature deviance can be seen as the extent to which participants are affected by other possible action, and such processes have been shown to reflect medial prefrontal function.

In addition to the amount of curvature deviance participants generate, that deviance unfolds over time. Previous reach tracking findings have also shown that the point during the trial that participants reach their maximum deviance in the curvature of their reach and then become more direct in their reach indicates the point at which participants have identified and resolved the conflict presented to them (Menceloglu et al., 2021; Song & Nakayama, 2008), which involves more functioning of anterior cingulate. Reaching maximal deviance earlier in the trial might reflect registering the conflict between the unfair distribution and the lack of resources gained by rejecting it.

Sobel et al. (2024) studied children's performance on an ultimatum game within a reach tracker environment. They found that children showed longer response times when faced with a disadvantageous inequity, indicating more monitoring resources were needed. Between the ages of 5-8, children developed adult-like responses regarding the resources needed to reject advantageous inequities, in which they did not accept a sure gain. The adult sample present in that study was small, and only one advantageous and disadvantageous distribution was presented.

In the present study, adult participants sat at a reach tracking apparatus in which they wore an electromagnetic sensor on their finger as they interacted with information projected on a Plexiglass screen. (As shown in Figure 1). After a set of baseline trials, in which they reached directly to individual target locations on the screen, they could accept or reject a distribution by touching locations on the screen. They were then given a set of trials in which they had to accept or reject fair distributions (5 resources to them, 5 to another) or unfair distributions of large (9-1 or 1-9) or small (6-4 or 4-6) inequities that were advantageous or disadvantageous to the participant. They were told that the distributions were generated by a third party, and that they were playing against a fictional, third-party other, and that this was their only interaction. This way, they did not have to be concerned about their reputation for fairness or possible retribution from other players. This removed some of the emotional components of deciding whether to accept or reject a distribution, and focused more on the cognitive control involved in making the tradeoff between maximizing resources and a sense of fairness in accepting the distribution. We tracked not only whether participants accepted or rejected the distribution on each trial, but also the nature of the trajectory with which they made these responses.

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Methods

Participants

A sample of 40 college-age students were recruited through the University participant pool. All participants were right-handed and tested in the laboratory (M_{age} = 19.5 years; SD = 1.9 years; 24 identified as women, 17 identified as men). Sample size was determined using G-power software through determining the post hoc effect size from previous reach tracking studies with adult participants (Erb et al., 2016), assuming $\alpha = .05$ and $\beta = .20$.

Stimuli and Procedure

Stimuli were presented via MATLAB (Version 2015b; Mathworks) and Psychtoolbox (3.0.11; Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997, and projected onto a Plexiglass display (44cm x 33cm) from behind. The display was arranged upright on a table, perpendicular to the participant's line of vision at 48 cm from the edge. The 3D finger position was recorded at approximately 240Hz using an electromagnetic position and orientation recording system (Liberty, Polhemus) with a measuring error of 0.03 cm root mean square. We secured a motion-tracking marker (2.26 x 1.27 x 1.14 cm) weighing 0.13 oz with a Velcro strap near the tip of the right index finger of the participant. Participants rested their index finger on a Styrofoam block (2 × 2× 2 cm) placed at 27 cm from the screen along the z-dimension (i.e., the distance between the participant and the display screen).

At the beginning of the experiment the tracking system was calibrated using a nine-point calibration process, in which participants were asked to touch nine equally spaced points on the screen sequentially. Each participant performed two baseline blocks (40 trials/block) each before and after the main experimental block (200 trials) (Figure 1). Ten practice trials were provided at the beginning of the main block to familiarize participants about the task.

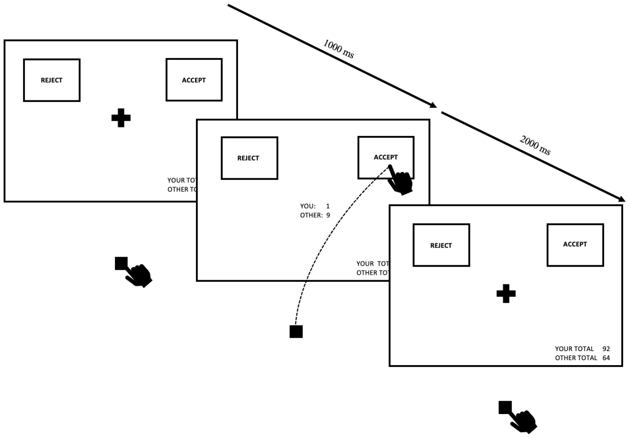

Figure 1. Illustration of a trial sequence in the main experiment block. It shows an example trial with a 1-9 distribution. Participants reached and touched one of the options to indicate their choice ("accept" or "reject") for a given distribution

In the main experiment, participants were informed that they would play a game with someone in the lab. Then they would be presented with distributions that designated points to the participant and their fictional partner. There were five distributions: 5 (five points for the participant) - 5 (five points for the partner), 6-4, 9-1, 4-6, and 1-9. They were instructed to either *accept* or *reject* a presented distribution by touching a corresponding response box (see Figures 1 and 2). They were also informed that if they accepted, both participant and their partner would receive those points, whereas if they rejected, neither of them would receive the points.

Each trial began with a central crosshair (2 cm x 2 cm) on the screen. Participants had to place their index finger in the starting position for 1000ms. If participants moved earlier, the participant was shown the frame with the fixation cross, and they could continue to the experimental frame by returning to the starting block only until they rested on the experiment block for a continuous 1000ms. The two response boxes (3cm x 2cm), one labeled "Accept" and the other labeled "Reject", appeared on upper right and upper left side of the screen (10 cm diagonally from the crosshair). Whether Accept or Reject was displayed on the right or left side was counterbalanced across participants. On each trial, participants saw one of five possible distributions (e.g., You: 1 Other: 9) on the screen center (see Figures 1 and 2). Participants were asked to respond quickly and accurately by reaching towards one of the two response boxes. Total points accumulated for participants and their counterparts were updated in the bottom right corner of the screen after each choice. Participants had to complete their responses within two seconds, otherwise the data for that trial was excluded. Auditory feedback was given to indicate successful completion of reach (Accept was a 600 Hz tone and Reject was a 200 Hz tone) if they responded within the time limit, and 400 Hz tone if their response was slow and did not count.

In the baseline block, designed to control for individual differences in participants' kinematics for each chosen location, the procedure was similar to the main experimental block, except there was no central decision choice. Only one of the response boxes was presented on each trial (without the "Accept" or "Reject" being present). Thus, participants were simply instructed to reach and touch the presented response box.

Data Processing

Data analysis procedures for reach movements were adapted from previous studies (e.g., Moher et al., 2015; Menceloglu et al., 2021). We conducted offline analysis on continuous reach movement data using a custom MATLAB (2022a; Mathworks) software. Movement velocity was calculated from the 3-D position traces after filtering with a second-order low-pass filter (cutoff frequency of 10 Hz). A velocity threshold of 10 cm/s was used to mark the movement onset and movement offset time. Each 3-D trajectory was then normalized across the distance (z-axis) dimension using the functional normalization procedure to give 100 points equally spaced in distance space.

To determine how reach deviated, we calculated an *Alternative Attraction Score (AAS)* for each trial by subtracting the corresponding mean trajectory separately from the functionally normalized horizontal lateral deviation (x-dimension) for each of the left and right choice locations within each participant. This controlled for differences in participants' kinematics for the chosen location. Positive AAS represents a deviation toward an alternative response box (i.e., curved towards a "Reject" box when the "Accept" box was touched). In contrast, negative AAS represents a deviation toward a selected response. These individual scores were then averaged to get the mean alternative attraction score per participant for each distribution. AAS were also plotted for their maximal value in time.

Results

Figure 2 shows the continuous nature of an individual participants' data in response to a particular distribution. In this way, we were able to analyze the percentage of trials on which participants accepted or rejected a distribution, the maximal deviance of their reach to indicate the choice, compared to baseline (their Alternate Attraction Score) and the timing of that attraction score.

Raw data and analysis code can be found at: https://osf.io/p7cye/?view_only=e2543ddb360a4b269e93831b9fc83825. We first analyzed the decision to accept or reject each distribution over the trials. We excluded the trials in which participants timed out on their response or where the tracker could not record participants' reach (437 of the 8000 trials under consideration or 5.5%). To account for the repeated nature of responses, we constructed a General Linear Mixed Model with a robust covariation matrix, assuming a binary response on the choice participants made on each trial. Distribution was the fixed factor. Participant and trial number were random factors.

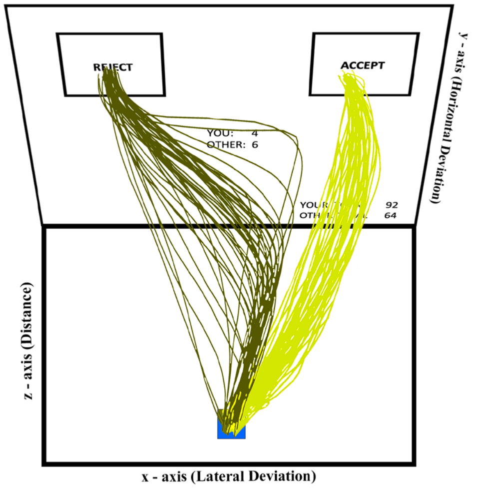

Figure 2. Example of reach trajectories from a single participant. Dark green traces represent rejections and light green represent acceptance.

This analysis revealed a main effect of distribution, *F*(4, 7558) = 383.07, *p* < .001. Participants accepted the distribution in which they were given 1 and the other person received 9 less frequently (15% of the trials) than the 4-6 distribution (41%, B= -1.94, SE = 0.13, 95% CI [-2.19, -1.69], *t* = -15.07, *p* < .001), the 5-5 distribution (80%, B = -4.16, SE = 0.14, 95% CI [-4.44, -3.87], *t* = -27.75, *p* < .001), the 6-4 distribution (94%, B = -5.75, SE = 0.18, 95% CI [-6.10, -5.39], *t* = -31.57, *p* < .001), and the 9-1 distribution (90%, B = -5.10, SE = 0.16, 95% CI [-5.41, -4.78], *t* = -31.47, *p* < .001). Participants similarly accepted the 5-5 distribution more frequently than the 4-6 distribution, B = 2.22, SE = 0.11, 95% CI [2.00, 2.44], *t* = 19.68, *p* < .001, and less frequently than the 6-4 distribution, B = -1.59, SE = 0.16, 95% CI [-1.89, -1.28], *t* = -10.22, *p* < .001, and the 9-1 distribution, B = -0.94, SE = 0.13, 95% CI [-1.20, -0.68], *t* = -7.09, *p* = .001. In general, as participants were offered more resources on a trial, they were more likely to accept the distribution, except for the difference between the 6-4 and 9-1 distributions, which were accepted at near-ceiling levels.

We next considered alternative attraction scores for each trial. The scores for the five distributions are shown in Figure 3. To analyze these data, we constructed a General Linear Mixed Model, assuming a linear response on the average alternative attraction score for each distribution. Distribution and participants' choice (whether they accepted or rejected the trial) were the fixed factors. Participant and trial number were random factors. This model revealed a significant effect of choice, with participants showing lower attraction scores (i.e., deviance in their curvature compared to baseline) when they accepted (overall ~12% deviant) an offer than when they rejected one (overall, ~19% deviant), B = -0.07, SE = 0.005, 95% CI [-0.08, -0.06], *t* = -13.21, *p* < .001. There was also a main effect of distribution, such that children were more deviant when presented with an advantageous inequity than a fair trial, B = 0.05 and 0.06, both SEs = 0.02, *t*-values = 2.87 and 2.79, *p* = .004 and .005 for the 9-1 and 6-4 distributions respectively. There was also a significant distribution x choice interaction, which indicated that the difference between rejecting a distribution and accepting it was greater for the two advantageous inequities, B = -0.04 and -0.04, both SEs = 0.02, *t*-values = -2.21 and -1.89, *p* = .03 and .059 for the 9-1 and 6-4 distributions respectively.

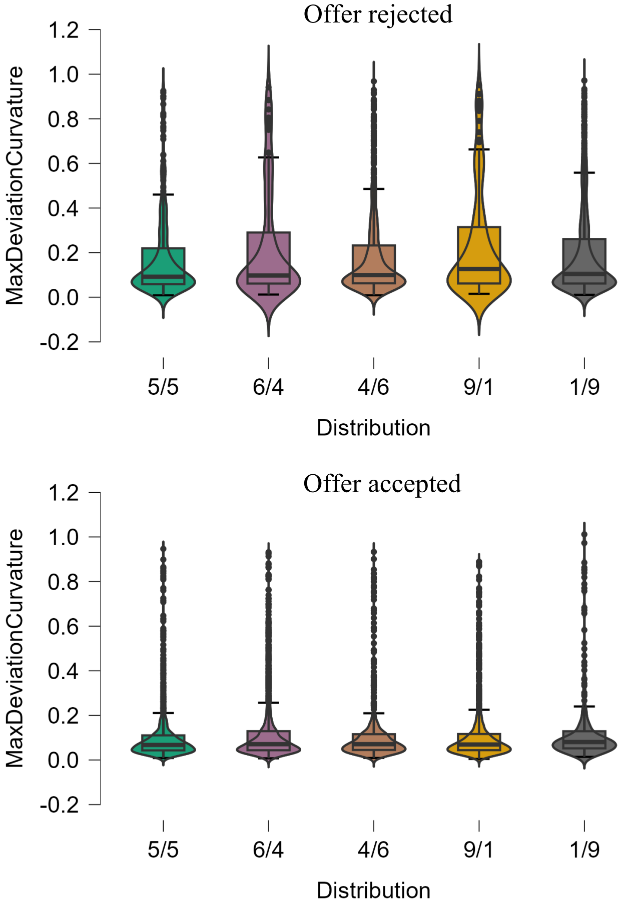

Figure 3. Alternate Attraction Scores for each distribution when distribution was rejected (top figure) or accepted (bottom figure).

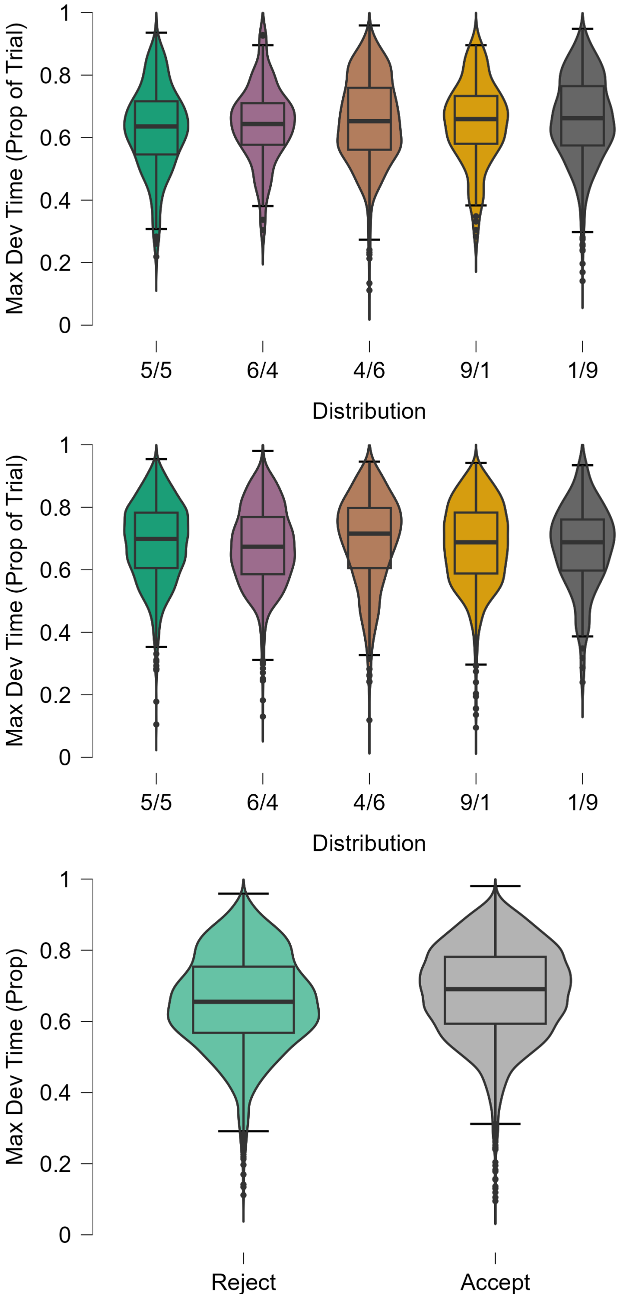

Figure 4. Proportion of response time when participant showed maximal AAS value for each distribution when distribution was rejected (top figure) or accepted (middle figure). Overall data across the distributions are shown in the bottom figure

Finally, we analyzed when participants' attraction score peaked during the trial. That is, at what percentile during the time of the trial does the participant show their maximum alternative attraction score? These data are shown in Figure 4. Lower percentiles indicate that participants detected that conflict resolution was necessarily earlier in the decision-making process. We conducted the same kind of GLMM analysis with a robust covariation matrix. Distribution and participants' choice (whether they accepted or rejected the trial) were the fixed factors, considering a factorial model. Participant and trial number were random factors.

This model revealed only a main effect of choice, with participants resolving conflict more quickly (i.e., earlier in the reach) on average when they rejected the distribution than when they accepted it, B = 0.02, SE = 0.008, 95% CI [0.002, 0.03], $t = 2.28$, $p = .02$. This suggests that rejecting distributions in general required fewer inhibitory control resources dedicated to monitoring for a conflict between gaining resources and acting fairly. This is not completely surprising, given that rejecting distributions might involve no conflict with the appearance of fairness.

Discussion

This study examined the inhibitory control processes involved in deciding to accept or reject a distribution in an ultimatum game, using a measure designed to isolate distinct inhibitory control processes. Participants were given a set of distributions that were either fair (a 5-5 split of 10 resources), or unfair to their benefit or detriment by a small or large amount (1-9, 4-6, 6-4, and 9-1 distributions of 10 resources). Participants mostly accepted fair distributions, as well as distributions in which they were given more resources than a fictional other. The lack of advantageous inequity aversion is consistent with our measure of distributions being generated by a third party, so that participants were not required to be concerned about their reputation or the social consequences of their actions (e.g., Fehr & Gachter, 2002). Within the trials in which the offer was less than half, participants were more likely to accept distributions that were closer to fair (4 vs 6) than distributions that were not (1 vs. 9). This is consistent with participants accepting distributions above a minimally accepted value (Camerer, 2003).

The dependent measures collected by reach tracking provide insight into the processes behind social decision making. When participants accepted a distribution, their alternative attraction score was less deviant – that is, they were less swayed by the other alternative. This indicates that regardless of the distribution (and controlling for the distributions they observed), the decision to accept the distribution, and thus gain resources, required less of the response selection process than rejecting the distribution. Accepting a distribution always involves some kind of gain; the decision to do so uses fewer cognitive control resources that involve resolving conflict between performing the action and the decision to do so. This was most prominent when participants were presented with advantageous inequities. Rejecting such inequities involved more resources dedicated to conflict resolution, more so than when the distribution was fair or involved rejecting a disadvantageous inequity.

In contrast, the decision to accept a distribution in general was made at a later point in the decision-making process than the decision to reject a distribution. That is, the decision to gain resources, regardless of the distribution offered, required more cognitive control involved in monitoring for conflict (between the desire to gain resources and a norm of fairness). That is, when participants accept resources in an ultimatum game, they might need more inhibitory control resources to monitor whether they are acting fairly. This suggests the possibility that if the stakes were higher (e.g., if participants were accepting/rejecting real money), their responses might be different as rejecting distributions might involve monitoring for conflict with the desire to gain resources.

These results suggest distinct roles of the anterior cingulate and medial frontal cortex in making these decisions, similar to findings that use nonsocial cognitive control measures that require monitoring, evaluation, and resolution of conflict between prepotent actions and rule-based responses, such as performance on a Stroop or Flanker task (e.g., Erb et al., 2016). The latter system, which is indicated by the AAS scores, is more involved with the decision to reject the distribution, regardless of whether the offer is fair or unequal. That is, rejecting a distribution, particularly when it is advantageous (presumably to appear fairer), requires more of this latter system. In contrast, the former system, which is operationalized by when participants' AAS score peaked, is more involved with the timing of how the conflict posed by accepting or rejecting the distribution is resolved.

This conclusion is consistent with cross-cultural developmental data; using a modified version of an ultimatum game for children, Blake et al., (2015) showed disadvantageous inequity aversion across many different cultures, but advantageous inequity aversion only in a small select group. If fewer cognitive control resources are required to process disadvantageous inequities, reasoning about such distributions might be the basis of concepts of fairness

More generally, the pattern of results generated by reach tracking can supplement neuroscientific evidence, while also providing enhanced evidence over other forms of behavior data, such as reaction time. Reach tracking offers the opportunity to dissect manual responses to behavioral measures into distinct inhibitory control processes. This allows researchers to enhance what we have learned about the role of the neural systems involved in social decision-making.

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