The relationship between fairness, cognitive control, and numerical encoding

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Abstract

Fairness, or the ability to distribute resources in a manner that accords with societally recognized principles of justice, is a hallmark of human cooperation. Young children rapidly develop the ability to enact fairness, but the cognitive underpinnings of this ability remain unknown. The present study investigated 4-7-year-olds' acquisition of three principles of fairness -- equality (the principle that all parties should have the same), merit (the principle that those who work harder should get more), and starting opportunity (the principle that those who started with less should get more) -- in relation to their emerging cognitive control and memory for numerical information (numerical accuracy). Cognitive control predicted children's equal sharing, whereas numerical accuracy predicted merit-based sharing. Children up through the oldest age we tested ignored starting opportunities. The results suggest that different principles of fairness may be underpinned by distinct cognitive processes.

Keywords: fairness; cognitive control; resource distribution; children; social and cognitive development

Introduction

Fairness, or the ability to distribute resources in a manner that accords with societally recognized principles of justice, serves as a foundation for human cooperation and is a critical cognitive achievement of early childhood. In spite of the fact that the concept of fairness itself is ubiquitous, its specific manifestation varies across individuals, cultures, and social groups (Schafer, Haun, & Tomasello, 2015). Even within a given cultural group, many possible principles of fairness exist. For example, people endorse the idea that principles of equality and merit are both fair. The key empirical question is how people shift between different potential principles of fairness and what accounts for the acquisition of these different forms of fairness. In this work, we explored the cognitive predictors of young children's fairness behavior in a third-party resource allocation task.

Recent work in developmental psychology finds that even infants possess rudimentary concepts of fairness (Sloane, Baillargeon, & Premack, 2012; Schmidt & Sommerville, 2012). Throughout preschool and middle childhood, children appreciate at least three distinct principles of fairness: equality (Rakoczy, Kaufmann, & Lohse, 2016; Smith, Blake, & Harris, 2013), merit (Baumard, Mascaro, & Chevallier, 2012; Damon, 1975; Jara-Ettinger, Gibson, Kidd, & Piantadosi, 2015; Kanngiesser & Warneken, 2012), and starting opportunity (McCrink, Bloom, & Santos, 2010; Ng, Heyman, & Barner, 2011). However, children do not always use these principles consistently. For example, although 3-year-olds pay attention to merit-based information (Baumard et al., 2012) and are able to incorporate it into their resource allocation decisions even when doing so is costly (Hamann et al., 2011; Kanngiesser & Warneken, 2012), they often ignore information about merit and enact equal distributions instead (Baumard, Mascaro, & Chevallier, 2012; Damon, 1975; Rizzo, Elenbaas, Cooley, & Killen, 2016).

One possibility for these discrepant results may be that different principles of fairness are underpinned by unique cognitive processes. In this work, we investigated two potential cognitive processes underlying children's resource distribution: children's memory for numerical information and children's cognitive control. Accurately encoding quantitative information is essential for both equality-based and merit-based allocation. Numerical skills operate at two levels for resource distribution tasks. First, a *general numerical ability* is necessary for children to execute even a simple division into two equal subsets that are matched on cardinal equivalence (see Muldoon, Lewis, & Freeman, 2009; Sarnecka & Wright, 2013). Indeed, counting abilities have been proposed and also recently found to relate to children's abilities to share resources equally (Chernyak, Sandham, Harris, & Cordes, 2016; Frydman & Bryant, 1988; Squire & Bryant, 2002).

Merit-based distribution also requires attending to quantitative information about relative effort (i.e., that one person worked twice as hard as another) and subsequently incorporating that information into decisions about resource allocation (i.e., that the harder worker must therefore receive twice as much). Similarly, information about starting opportunities must be encoded in order to be used. Thus, sharing between two recipients based on merit or starting opportunity requires *trial specific numerical encoding.* In this work, we looked at whether children encoded exact numerical information for each trial or whether the information was encoded only approximately.

Finally, we looked at children's emerging cognitive control. Distributing resources according to merit or starting opportunity requires holding in mind multiple -- and often conflicting -- pieces of information and "rules" regarding resource distribution (Zelazo, Helwig, & Lau, 1996). For example, a child must keep in mind that one person worked harder, but also that that person had a greater starting opportunity to begin with (McCrink et al., 2010). Prior work has found relationships between children's inhibitory control and their abilities to execute the normatively appropriate resource allocation in costly first-party tasks (Blake, Piovesan, Montinari, Warneken, & Gino, 2015; Steinbeis & Over, 2017). In third-party tasks of the type that we investigated, cognitive control may serve as a behavioral tool through which they may control their behavioral responses and implement a target distribution.

In this study, we presented 4-7-year-old children with a series of trials in which children were presented with stories about animal characters that had expended either equal or unequal amounts of work in order to acquire resources that would be jointly sold. Each character also had either equal or unequal amounts of starting opportunities. After hearing each story, children were provided with a set of resources to split between these characters. We tested children's memory for numerical information by asking children to recall the amounts of work and starting opportunities for each character after each trial. We also tested children's cognitive control by administering the Happy/Sad Stroop task (Lagattuta, Sayfan, & Monsour, 2011).

Method

Participants

Participants were 67 children (35 female, 32 male) between the ages of 4 and 7. This age-range included a younger age group of 33 4-5-year-olds (*Mean age* = 5.00; *Range* = 4.11 - 5.82) and an older age group of 34 6-7-year-olds (*Mean age* = 7.10, *Range* = 6.00 - 8.03). Children were tested either in the laboratory or at a local preschool or elementary school.

Materials

Materials were 12 sets of storybook panels (described below), 8 sets of plastic cookies for the resource allocation tasks, and a set of 24 black and white pictures of smiley faces (12 representing sad faces and 12 representing happy faces) for the Happy/Sad Stroop Task.

Procedure

Children completed 3 pretest trials, followed by 8 focal resource allocation trials, followed by the Happy/Sad Stroop Task. All children were tested in a quiet room in the laboratory or at their local school by an experimenter. All children were videotaped with the exception of 6 children whose parents did not provide video consent and 4 due to technical issues. The experimenter or a trained research assistant also transcribed answers as children during test.

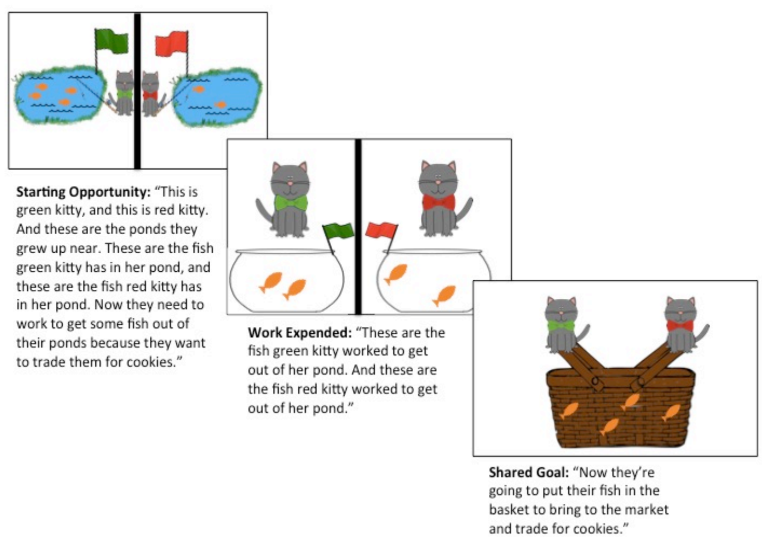
Pretest Trials All children began were introduced to the structure of the storybook task via 3 pretest trials aimed at making children understand the relevant components of each story. In the first panel, the experimenter showed the child two dinosaurs and said that sometimes in the stories some characters will have different amounts. She then indicated that one dinosaur had way more candy than another, and asked the child to recount which dinosaur had more. In the second panel, the experimenter showed the child two dinosaurs and said one worked harder than another and asked the child to recount which one worked harder. Finally, in the last panel, the experimenter showed the child two dinosaurs and said both had the same and worked the same amounts. She then asked the child to recount whether either of the dinosaurs had more and also to recount if one had worked harder. Incorrect responses were followed with corrective feedback and re-prompts.

Test Trials In each resource allocation trial, children were presented with two animal characters (e.g., two cats) who each acquired resources to achieve a shared goal (e.g., catching fish to sell at the market). The characters contributed either equal or unequal amounts of work towards the shared goal (e.g., one cat caught 4 fish the other caught 2). The characters also had either the same or different starting opportunities (e.g., one cat fished from a pond with 4 fish whereas the other cat fished from a pond with only 2 fish).

An example of the materials and wording of the task is shown in Figure 1 below.

We used a 2 (Starting Opportunity: Equal or Unequal) x 2 (Work Expended: Equal or Unequal) design in which we presented each child with 4 different trial types (2 of each type totaling 8 trials per child): (a) *all equal trials* (i.e., trials in which characters had exactly the same starting opportunity and expended the same amounts of effort); (b) *equal opportunity, unequal work trial*, (c) *unequal opportunity, equal work trials* (e.g., a trial in which two cats both obtain 2 fish, but one started with a pond that only had 2 and another started with a pond that had 4), and (d) *unequal opportunity, unequal work trials.* In these last trials, characters produced unequal amounts of work, but also had different starting opportunities. For example, one cat caught 2 out of 4 fish and another caught 1 out of 2 fish. The ratio of opportunity to work expended was thus equal.

Figure 1: Example of a Resource Allocation Trial



The types of trials and numbers used in each trial are summarized Table 1 below. As may be noted in this table, the work ratios between the two characters were 1:1 if equal and always 2:1 if unequal (i.e., the character who worked more obtained twice as much). Additionally, ratios between a given character's starting opportunity and work expended were also either 1:1 or 2:1.

Each of these four trial types were presented in 2 blocks: a large number block in which we used relatively large numbers of starting opportunities and work expended (e.g., 8 and 4 fish), and a small number block in which we used relatively small numbers of starting opportunities and work expended (e.g., 4 and 2 fish). Within each block, the presentation of the four different trial types were counterbalanced with a Williams Latin Square design. We also counterbalanced which block type (large vs. small) was presented first as well as whether the larger vs. smaller numbers appeared on the child's right or left side. Each trial used one of four possible animal pairs: cats that fished fish, rabbits that grew carrots, bears that picked apples, and monkeys that picked bananas. Presentation of animal types and colors of animal characters were fixed.

Resource Allocation After being read each scenario (trial type), children were shown 6 plastic cookies that the characters earned from their joint effort. Children were told that they had to decide which characters should get which cookies. Cookies were arranged in a linear array in between two cardboard boxes that depicted the two animal characters. We note that we used 6 cookies specifically because they enabled either distribution according to equality (i.e., 3 cookies to each character) or distribution according to a 2:1 merit ratio (i.e., 4 cookies to the harder worker and 2 to the less hard worker). We recorded the amount children gave to each character.

Table 1: Numbers used in each trial type

Trial Type	Starting Opportunity	Work Expended	Block Type
All equal	(8,8)	(4,4)	large
Equal opportunity, unequal work	(8,8)	(8,4)	large
Unequal opportunity, equal work	(8,4)	(4,4)	large
Unequal opportunity, unequal work	(8,4)	(4,2)	large
All equal	(4,4)	(2,2)	small
Equal opportunity, unequal work	(4,4)	(4,2)	small
Unequal opportunity, equal work	(4,2)	(2,2)	small
Unequal opportunity, unequal work	(4,2)	(2,1)	small

Numerical Accuracy Following resource distribution for each trial, boxes and materials were closed and put away, and children were asked four questions to assess their memories for the numerical information presented to them in the trial: two questions asking them to recall the characters' starting opportunities (e.g. "How many fish did green Kitty have in green Kitty's pond? How about red Kitty?") and two questions asking them to recall the characters' work expended (e.g., "And how many fish did green Kitty get out of green Kitty's pond? How about red Kitty?"). For each of these, we computed a continuous accuracy measure reflecting the Percent Absolute Error that children's answers displayed (Siegler & Booth, 2004). Percent Absolute Error (PAE) was calculated via the following formula:

$$\text{PAE} = \frac{|child's\ answer - correct\ answer|}{correct\ answer}$$

This score reflected the deviation of the child's answer from the correct answer. For example, a child who answered that there were 5 fish when the correct answer was 4 would receive a PAE score of |5-4|/4 = 25%. Thus, high PAE scores indicated lower accuracy, and low PAE scores reflected higher accuracy (with a score of 0 indicating having correctly recalled the exact number). On each trial, each child was given two scores assessing *trial specific numerical encoding:* a *Starting Opportunity PAE* reflecting the average PAE of the two opportunity questions, as well as a *Work Expended PAE* reflecting the average PAE of the two work expended questions on that trial. These are labeled as *trial specific* because they reflected children's accuracy for numbers on that specific trial only.

Additionally, children received an *Overall PAE* reflecting numerical accuracy average across all 32 questions asked (4 per trial), which reflected *general numerical memory*. This was referred to as *general numerical memory* because it reflected children's tendency to correctly estimate numbers *overall*, not on any given trial.

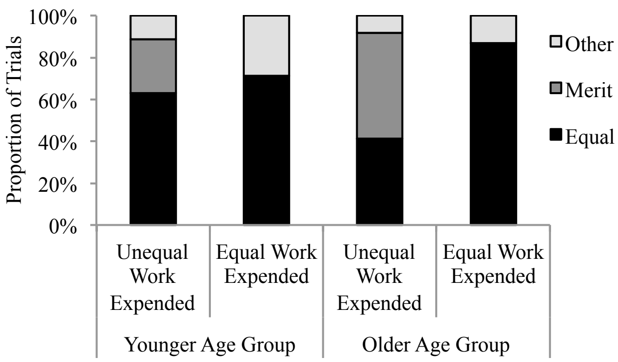
Cognitive Control After completion of all 8 resource distribution trials, children were administered a version of the Happy/Sad Stroop Task. Following procedures used in (Lagattuta et al., 2011), children were introduced to a happy and a sad face and asked to label them. They were then told they would be playing an "opposite" game in which they had to label happy faces as "sad" and sad faces as "happy". After ensuring all children understood task instructions, children completed 4 practice trials (corrective feedback was provided) followed by 20 test trials (no corrective feedback). Children were given a *Cognitive Control Score* between 0-20 reflecting the number of correct test trials.

Results

Preliminary results showed no effects of gender or block type, so we collapsed data across these variables. We first sought to characterize children's resource allocation decisions by coding the outcomes as equal, merit, or other (unequal for equal trials or against merit; see Figure 2).

We ran separate models predicting children's tendency to share resources equally. We ran a within-subjects mixed linear model using equal sharing allocation as the dependent variable and Age (entered continuously), Work Expended (equal or unequal), Initial Opportunity (equal or unequal) and all interaction effects as the predictors. There was a significant main effect of Work Expended, $F(1,528) = 9.102$, $p = .003$ a significant Age x Work Expended interaction, $F(1,528) = 18.07$, $p < .001$, and no other significant effects (p's > .15). Thus, equal allocations were predicted by age and whether the characters had expended equal amounts of work.

Figure 2: Allocation Types Across Trials



Note. Merit-based sharing is impossible in Equal Work Expended Trials

We also looked at predictors of merit-based sharing. Children were coded as having given a merit-based allocation if they had given more resources to the harder working character (i.e., one who produced a greater amount of resources). Because merit-based sharing was not possible in the All Equal trial, we excluded this trial from that analysis. There was a significant Age x Work Expended interaction, $F(1,396) = 4.81$, $p = 0.03$, and no other significant effects (all p's > .09). Thus, children made more merit-based allocations with age.

To better characterize these interactions, we explored how age impacted merit-based and equality-based sharing separately in each trial type. We thus ran follow-up models for equal work expended and unequal work expended trials using Age as a predictor. The results of these analyses are summarized in Table 2 (Model 1). We ran separate models using equal sharing as a response and then merit-based sharing as a response.

As shown in Table 2, Age predicted equal sharing in the trials in which characters produced equal amounts of work (top panel of Table 2; All Equal and Unequal Opportunity, Equal Work trials), whereas Age predicted merit-based sharing in trials in which characters produced unequal amounts of work (bottom panel of Table 2).

Therefore, confirming the previous analyses, all children ignored starting opportunities. However, age predicted children's likelihood of selecting the "correct" allocation type in each trial - equal-based sharing in the trials in which characters produced equal amounts of work, and merit-based sharing in the trials in which characters produced unequal amounts of work.

We next investigated whether these age-related changes were explained by numerical accuracy or cognitive control. In particular, we first looked at whether children's numerical accuracy predicted their resource allocation decisions. Recall that on each trial, each child was given two scores: a Starting Opportunity PAE and a Work Expended PAE. Preliminary analyses revealed no differences between the two PAE types, suggesting that children were equally adept at encoding both types of information.

We first looked at the predictors of each PAE type. For each model, we ran a mixed linear model using Age, Work Expended, and Initial Opportunity as predictors. We also included Cognitive Control Total Correct as a covariate to ensure that any potential age-related changes in encoding accuracy were not simply attributable to changes in cognitive control.

For Starting Opportunity PAE, there was a significant effect of Age, $F(1,464) = 93.71$, $p < .001$, with older children showing lower PAE (higher accuracy) for initial opportunity and no other significant effects (all p's > .25).

For Work Expended PAE, there was a significant effect of Age, $F(1,464) = 43.89$, $p < .001$, and a significant effect of Work Expended Trial Type, $F(1,464) = 20.05$, $p < .001$, with children showing worse encoding of work expended when the characters put in unequal amounts of work. Therefore, both age and trial type also predicted children's recall of the work expended. Children were better at encoding numerical information when characters had expended equal amounts of work.

Finally, we looked at predictors of Overall PAE. Age significantly predicted Overall PAE, $F(1,55) = 24.32$, $p < .001$, and Cognitive Control did not (once accounting for age; $p = 0.42$). Therefore, numerical accuracy and cognitive control were dissociable, despite both getting better with age.[1]

We next investigated whether these age-related differences in encoding accuracy might explain age-related changes in children's resource allocation decisions. Because children ignored starting opportunities, we do not further consider the Starting Opportunity PAE. Recall that each child could be coded as giving either an "equal split", "merit-based split", or neither split ("other"). For the separate analyses we coded these as equal split or not and merit-based split or not.

We first looked at predictors of equal sharing. Preliminary analyses revealed significant interactions between various predictors for the trial types. Therefore, we first considered the equal work trials only. We ran two mixed binary logistic regression models using equal sharing as a response variable and Age, Work Expended PAE, Overall PAE and Cognitive

[1] In order to avoid biasing the results with children who were responding with nonsensical numbers, we excluded responses on which PAE scores were over 500% ($n = 2$) for this analysis.

Control as the predictors.[2] The critical question was whether either Work Expended PAE or Cognitive Control might predict children's equal resource allocation.

As shown in Table 2, in the Equal Work Expended trials, Cognitive Control and Overall PAE (general numerical memory - the average error across the 32 questions asked) predicted children's equal sharing behavior. Once Cognitive Control and Overall PAE were accounted for, there was no longer any significant effect of age. Therefore, both cognitive control and *general* numerical memory explained age-related changes in sharing resources equally.

We then looked at predictors of merit-based allocation. As shown in Table 2, Work Expended PAE was related to the propensity to split resources meritoriously, but cognitive control and Overall PAE were not. Age continued to be related to the propensity to make merit-based splits.

Table 2: Beta Coefficients (and Standard Errors)

Response: Equal Sharing	Equal Work Expended	Unequal Work Expended
Model 1		
Age	**.40 (.13)****	**-.34 (.11)****
Model 2		
Age	-.22 (.18)	**-.50 (.14)****
Cognitive Control	**0.15 (.06)***	**.11 (.06)***
Work Expended PAE	-.46 (.35)	-.16 (.21)
Model 3		
Age	-.24 (.18)	**-.50 (0.14)****
Cognitive Control	**.14 (.06)***	**.13 (.05)***
Overall PAE	**-.28 (.13)***	-.08 (.12)

Response: Merit Sharing	Equal Work Expended	Unequal Work Expended
Model 1		
Age	–	**-43 (.11)*****
Model 2		
Age	–	**.35 (.15)***
Cognitive Control	–	.006 (.06)
Work Expended PAE	–	**-.89 (.40)***
Model 3		
Age	–	**.40 (.15)****
Cognitive Control	–	.006 (.06)
Overall PAE	–	.11 (.16)

p* < .05; ** *p* < .01; * *p* < .001

The Table 2 results suggest two things: first, cognitive control and *general numerical accuracy* predicted propensity to make equal splits. Second, *trial specific* numerical accuracy for work expended (ability to properly encode merit-based information specifically) predicted children's abilities to make merit-based splits on trials that called for merit-based splits (i.e., trials in which characters produced unequal splits). Both sets of results held when controlling for age, suggesting that age-related changes in equal sharing may be explained by changes in cognitive control and numerical accuracy, and that age-related changes in merit-based sharing may be partly explained by changes in encoding of merit-based information.

Discussion

Recent work has taken an interest in the cognitive predictors of fairness. Our findings are consistent with prior work showing a mostly equality-based principle during the preschool age shifting to a merit-based principle by middle childhood. We extend these findings by showing that 6 and 7-year olds actively create merit-based distributions even when making equal allocations is a viable alternative. Most importantly, we point to two cognitive predictors of sharing behavior: children's numerical encoding ability, and their emerging cognitive control, each of which exerted a unique effect on children's abilities to make resource allocations.

One possibility for why young children often do not employ merit-based resource allocations may be that they fail to encode trial-specific numerical information to begin with. Our findings show that this may be the case: encoding accuracy for the amount of work that each character expended predicted merit-based resource distribution on trials that called for such distribution. Interestingly, numerical encoding accuracy for starting opportunity information did not predict allocations based on this information. Thus, 6- and 7-year olds specifically encoded information about starting opportunity but did not use this information when allocating resources.

The effect of numerical accuracy held even when controlling for changes in age and cognitive control. Prior work has found that, in third-party unequal work tasks, younger children can and do distribute resources according to merit but under simplified conditions such as when an unequal allocation is the only option (Baumard et al., 2012). Three- and 5-year olds are also capable of using merit in first person distributions but the strategies used vary widely (Kanngiesser & Warneken, 2012).We propose that these individual differences may be explained by differences in the ability to accurately encode numerical information inherent in meritocratic situations.

In contrast to the cognitive processes for merit-based allocations, equal allocation decisions depended on general numerical encoding. This result falls in line with prior work finding that general numerical cognition (i.e., counting ability) predicts equal sharing among preschool-aged children (Chernyak et al., 2016). General numerical accuracy and counting ability may tap into the same underlying construct of numerical fluency and understanding of numbers, which may then help children with creating equal sets of resources.

We also found that children's emerging cognitive control predicted equal, but not merit-based, allocations across all trial types. This suggests that cognitive control serves as a general behavioral tool that allows children to choose equal outcomes in spite of inequalities present in the scenarios. One possibility for why this might be the case is that older

[2] Because Overall PAE and Work Expended PAE were highly collinear and conceptually and empirically confounded, we ran separate models using each PAE type (see Table 2).

children have acquired and might therefore need to inhibit other potential principles (e.g., merit) in order to enact the equality. Alternatively, cognitive control may simply help children ensure that two equal sets have been created. Most importantly, cognitive control failed to predict merit-based resource distribution, suggesting a dissociation between the types of cognitive mechanisms required for equality and merit-based resource allocation.

Few children used the information about starting opportunities, despite encoding this information. Although work has found that children are able to make evaluations of others' work based on their starting opportunity (McCrink et al., 2010; Ng et al., 2011), to our knowledge, there is no current work that has shown that children then use those evaluations to make resource allocation decisions. We therefore propose that children may be well aware of existing inequalities, but do not actively use such information when making resource allocation decisions.

Overall, our work points to two important cognitive predictors for different fairness principles. We propose that searching for individual differences in children's cognitive abilities may help account for and ultimately shape their social preferences.

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