

©American Psychological Association, 2020. This paper is not the copy of record and may not exactly replicate the authoritative document published in the APA journal. The final article is available, upon publication, at: <https://doi.org/10.1037/dev0001121>

Giving a Larger Amount or a Larger Proportion:
Stimulus Format Impacts Children's Social Evaluations

Michelle A. Hurst^{1*}, Alex Shaw¹, Nadia Chernyak², and Susan C. Levine¹

¹University of Chicago, Department of Psychology

²University of California-Irvine, Department of Cognitive Sciences

*corresponding author:

Michelle Hurst
5848 S University Ave
Chicago, IL 60615 USA
hurst.mich@gmail.com; hurstm@uchicago.edu

Author Note

Our study design, analysis plan, and hypotheses for all experiments were pre-registered and are available on aspredicted.com: Exp. 1 #9759: <https://aspredicted.org/r2wx2.pdf>; Exp. 2 #14205: <https://aspredicted.org/es7fq.pdf>; Exp. 3 #41511: <https://aspredicted.org/7g95k.pdf>. Additionally, all materials, data, analysis code, and time-stamped pre-registration documents are available on the on the Open Science Framework (<https://osf.io/5g34d/>).

Abstract

Young children show remarkably sophisticated abilities to evaluate others. Yet, their abilities to engage in *proportional* moral evaluation undergoes protracted development. Namely, young children evaluate someone who shares *absolutely* more as being “nicer” than someone who shares *proportionally* more (e.g., sharing 3-out-of-6 is nicer than sharing 2-out-of-3, because $3 > 2$, even though $3/6 < 2/3$), whereas adults think the opposite. We investigate the hypothesis that this prior work underestimates children’s proportional social reasoning by relying on discrete and spatially separated quantities (e.g., individual stickers), which can hinder proportional reasoning even outside social contexts. In three experiments we examine whether 4- and 5-year-old children’s social evaluations are impacted by the discreteness and spatial separation of the resource and compare their behavior to adults (18 to 63 years; across all samples: 38% girls/women, 62% boys/men; no other demographic data was collected). We find that children are sensitive to these features: when the resource was divided into discrete units (Experiment 1) or spatially separated (Experiment 2) children were more likely to use absolute amount, as opposed to proportion, relative to when the resources were not divided and remained spatially connected. However, adults were highly sensitive to proportion regardless of the display’s perceptual features (Experiment 3), and children’s use of proportion remained below adult-levels. These results suggest that perceptual features influence children’s use of absolute vs. proportional information in their social evaluations, which has theoretical and methodological implications for understanding children’s conceptions of fairness. All project components are available: <https://osf.io/5g34d/>.

Keywords: *proportion, number, resource distribution, social evaluation*

Giving a Larger Amount or Larger Proportion: Stimulus Format Impacts Children's Social Evaluations

There is substantial research investigating how young children think about what is fair (for reviews see Engelmann & Tomasello, 2019; Shaw, 2013). One question of particular interest is how children decide who is a better or nicer cooperative partner. By preschool age, children's judgements of partner choice reflect relatively sophisticated reasoning: they selectively prefer and share resources with those who have helped others (Dunfield & Kuhlmeier, 2010; Kenward & Dahl, 2011), those who work harder (Baumard et al., 2012; Jara-Ettinger et al., 2016; Kanngiesser & Warneken, 2012), and those who share more themselves (Warneken & Tomasello, 2013). In spite of this apparent sophistication, young children demonstrate relatively protracted development using *quantitative* information in their moral evaluations (Chernyak et al., 2019; McCrink et al., 2010). For example, in contrast to adults, 4 and 5-year-olds tend to judge someone who shared three-sixths of their resources as being nicer than someone who shared two-thirds, potentially because they are attending to absolute number shared ($three > two$) as opposed to the relative proportion ($three-sixths < two-thirds$; McCrink et al., 2010; Ng et al., 2011). However, this previous work investigating children's use of proportional information may underestimate children's social reasoning by using visual displays that interfere with children's tendency to use proportional information, regardless of the social context.

This hypothesis is consistent with research demonstrating that cognitive constraints, and in particular children's developing numerical abilities, can play a critical role in the development of fairness concerns (Chernyak et al., 2016, 2019; Frydman & Bryant, 1988; Hook & Cook, 1979; Jara-Ettinger et al., 2016; Posid et al., 2015; Squire & Bryant, 2002). In the current study, we are particularly focused on how perceptually available information may bias children's

attention to numerical versus proportional information, rather than on variations in numerical ability.

Although previous research suggests that infants as young as 6-months-old are able to track the ratio of two quantities and use this information to make quantity comparisons and probabilistic inferences (Denison et al., 2013; Denison & Xu, 2010; Duffy et al., 2005; McCrink & Wynn, 2007), by the age of 6-years, children make systematic errors with probability and proportion, such as deciding $2/3$ is less than $4/9$ (Boyer et al., 2008; Hurst & Cordes, 2018; Jeong et al., 2007). Over the last decade or so, researchers have investigated the causes of children's struggle with proportional information and have found that when the quantities are divided, and thus countable, children tend to focus on matching or comparing the absolute numerical information and ignore proportion (attending to $2 < 4$, even though $2/3 > 4/9$). In contrast, when the stimulus is continuous and not divided, meaning that countable numerical information is not available, children are more likely to attend to proportion (Boyer et al., 2008; Hurst & Cordes, 2018; Jeong et al., 2007). Notably, the error pattern children show when reasoning about divided quantities parallels the pattern found in children's social evaluations, which have almost exclusively relied on discrete and countable resources (e.g., stickers; tokens; cookies; toys).

In addition to being perceptually discrete, typical resource distribution scenarios result in the shared and unshared resources being spatially separated (i.e., 2 cookies that were shared and 4 that were unshared separate from each other), which may make it more difficult for children to integrate and compare these amounts in terms of overall proportion. Although there is less research on the role of spatially separating versus integrating the components that make up a proportion, there is some evidence that presenting these components as connected leads to better proportional reasoning in young children. In particular, a study investigating 8- to 10-year-olds'

performance with spatial proportions presented as a single rectangle containing each part (i.e., as part-of-a-whole) or as two separated components (two rectangles side-by-side, one for each part) found that children performed significantly worse when the parts were presented side-by-side compared to when they were stacked (Möhring et al., 2016). Additionally, children's performance on the side-by-side proportion task was significantly less related to their fraction knowledge than children's proportion performance with stacked pieces, suggesting that the spatially separated proportion task may not be eliciting the kind of part-whole reasoning that is important for fraction-based strategies or knowledge (Möhring et al., 2016). Thus, having spatially separated parts may make it more difficult to compare the components in a way that supports proportional reasoning about the integrated "whole".

Taken together, these findings suggest that the stimuli used in typical resource distribution scenarios may emphasize the absolute outcome of the scenario (i.e., that one character shared 3 stickers and the other shared 5), either through the discreteness and countability of the resources (Boyer et al., 2008) or the difficulty in trying to integrate both pieces of information when presented as spatially separated (Möhring et al., 2016).

In offering explanations for the developmental shift from relying on absolute amount versus proportional sharing in judgements of "niceness", prior work has focused on explanations that emphasize more social factors, such as valuing qualitatively different types of information. That is, one possibility is that younger children simply have different moral preferences than older children, they value the absolute outcome over relative proportion and older children and adults value proportions over outcomes. In line with the importance of social-cognitive factors in these kinds of judgments, prior work has found that introducing collaboration (i.e., manipulating the social structure) increases children's attention to proportion (Ng et al., 2011). In the current

study, however, we investigate another (not mutually exclusive) hypothesis: children's tendency to disregard proportion in resource distribution contexts is related to their more general tendency to disregard proportional information presented via particular types of stimuli with discrete and spatially separated components. If this is the case, then we would expect children's attention to proportional information to increase when the stimuli are continuous and spatially connected as part of a whole, relative to when they are discrete or spatially separated, in line with their behavior in proportional reasoning tasks more generally (Boyer et al., 2008; Hurst & Cordes, 2018; Jeong et al., 2007; Möhring et al., 2016). Alternatively, it may be that children will focus on the absolute outcome of sharing scenarios regardless of the display characteristics, in line with work in other domains such as goal directed events (Lakusta & Carey, 2015).

In three experiments, we investigated 4- and 5-year-old children's and adults' social evaluations based on resource distributions and separately manipulated two features of the stimuli. In Experiment 1, we compared children's evaluations when the resources were divided into discrete units compared to when they were continuous and not divided. In Experiment 2, we compared children's evaluations when shared and non-shared continuous resources were spatially separated versus connected. In Experiment 3, we measured adults' judgements in all conditions used in Experiments 1 and 2 in order to provide an adult comparison group to help contextualize children's performance. For all experiments we pre-registered our sample sizes, basic analysis plan for the primary task of interest, and our hypotheses on aspredicted.org (Exp. 1 #9759: <https://aspredicted.org/r2wx2.pdf>; Exp. 2 #14205: <https://aspredicted.org/es7fq.pdf>; Exp. 3 #41511: <https://aspredicted.org/7g95k.pdf>). In addition to the central task, in Experiments 1 and 2 we included two individual difference tasks for secondary exploratory analyses, a counting task and a spontaneous matching task. The additional analyses involving these tasks are included in

Supplemental Materials. All materials, data, and the time-stamped pre-registration documents are provided on the Open Science Framework (<https://osf.io/5g34d/>; Hurst et al., 2020).

Experiment 1

Method

Participants. Seventy-one¹ children were randomly assigned to one of two conditions: Discrete ($n = 36$; $M_{\text{age}} = 4.8$ years Range = 4.0 to 5.99 years; $n_{\text{males}} = 16$, $n_{\text{females}} = 20$) and Continuous ($n = 35$; $M_{\text{age}} = 4.9$ years Range = 4.0 to 5.99 years; $n_{\text{males}} = 21$, $n_{\text{females}} = 14$). An additional three children participated but were excluded and replaced because they watched another child complete the task prior to participation ($n = 2$) or they refused to complete the primary task of interest ($n = 1$). Our sample size was pre-registered a priori and provides 80% power to reliably detect effects as small as $d = 0.68$ (for between subject t-tests with $\alpha = 0.05$; calculated using the *pwr* package in R; Champely, 2018), which is similar to effect sizes reported in other studies comparing proportional reasoning with discrete vs. continuous stimuli (e.g., for similar trial types, Hurst & Cordes (2018) found $d = 0.68$, Jeong et al., (2007) found an effect size of at least $d = 1.0$, and Boyer et al., (2008) found an effect size of at least $d = 0.6$).

Children participated at a local science museum or in our campus laboratory. In order to streamline the demands on participants, particularly at the museum where children and parents are volunteering their time in an otherwise paid space, we did not collect any additional demographic information from participants. However, we do have self-reported visitor information from the museum where about half of our data was collected, and we expect that our sample would be similar to the broader museum visitorship. Between March 2018 to 2019 (when these data were collected), museum visitors self-identified (more than one option could be

¹ We preregistered a sample of 70 children, but the dynamic nature of data collection at museums resulted in an additional child arriving at the testing-booth and being tested. All 71 children are included in the analyses, but the patterns and interpretation are identical even when the last child is excluded.

Social Evaluations Across Stimulus Formats

selected) as: 68% White, 12% as Hispanic, Latino, or Spanish origin, 8% as Black or African American, 1% as American Indian or Alaska Native, 1% as Middle Eastern or North African, 1% as Native Hawaiian or other Pacific Islander, and <1% as some other race or origins.

Additionally, approximately 65% of adults reported having at least a Bachelor's degree.

Prior to participation, parents or legal guardians provided written informed consent. All children received a small gift (e.g., sticker or small toy) for participating and parents of children who participated in our campus laboratory received \$10 travel compensation. All procedures were approved by the University of Chicago Institutional Review Board (IRB) under protocol "Fairness and Alliances" (IRB15-1237).

Overall design. The central task of interest completed by all children was a social evaluation task adapted from McCrink and colleagues (2010) in which children were asked to make judgements about the "niceness" of two Giver characters after watching the Giver characters share some of their resources with a Receiver character. The resources were represented as a generic blue mass and sharing was depicted by changing the color of the resource to the favorite color of the Receiver character. In this way, we were able to visually represent the total amount of the resource, as well as the proportion of the resources shared. For example, two Giver characters shared some of their blue resources with a Receiver character by changing a portion of their resources red (the favorite color of the third character). See Figures 1 and 2 for visual examples of the stimuli and procedure. Across trials and within subjects we manipulated the absolute and proportional amount of resources that were shared between the two Giver characters. Across conditions and between subjects, we manipulated what the resources looked like by contrasting them on only one dimension – whether they were divided into pieces,

and thus countable, or whether they were continuous, and thus uncountable. This contrast between discrete and continuous resources is the critical comparison in Experiment 1.

Materials and procedure. All children completed a computerized Social Evaluation Task (based on McCrink et al., 2010). Additionally, a subset of children completed two individual difference measures: Spontaneous Matching Task (based on prior unpublished work by Susan Levine) and What's Next Counting Task (Schneider et al., 2019). These tasks were included as exploratory measures to investigate how children's attention to number vs. proportion may depend on their number knowledge or attention to number outside a social context and are included only in the Supplemental Materials and on the OSF project page.

Social evaluation task. The task included 12 trials presented in a randomized order on a computer. On each trial, two characters (the “givers”) were presented on the left side of the screen. Each giver had some resources (presented as a blue rectangle) that they could share with a third character. Givers were both the same animal type (e.g., beavers) on each trial. A third character, shown as a different animal, was presented on the right side of the screen and did not have any resources (the “receiver”; see Figure 1). Different animals were used across the givers and receivers to simplify the verbal information provided, meaning that they could be referred to as their animal name without additional confusion. The same animals were used within the givers in order to prevent children's animal preferences from influencing their judgements about which giver was nicer. The animal characters were randomly paired with a trial (but was the same across children) and were not reused across trials. The only difference across the conditions was whether the blue rectangle of resources was divided into countable smaller units (Discrete) or not (Continuous).

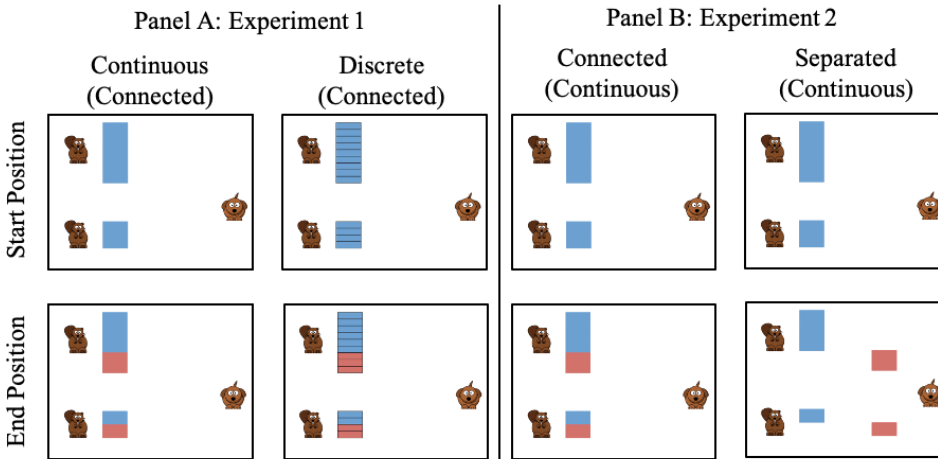


Figure 1: Example stimuli at the start (top row) and end (bottom row) of the video (stills from video procedure in Figure 2) for each condition. Experiment 1 (Panel A) contrasted Continuous (left) and Discrete (right) connected stimuli and Experiment 2 (Panel B) contrasted Connected (left, same as Exp. 1) and Separated (right) continuous stimuli.

On the first trial, children were given information about the set up (the animal labels of cow and monkey are given as examples, but the actual labels referred to the specific animal on that trial): “This cow has this much [point at the top cow and the corresponding blue rectangle] and this cow has this much [point at the bottom cow and the corresponding blue rectangle]. This monkey [point at the right animal] is friends with both cows and his favorite color is red.” The experimenter then advanced the trial to play a video where the receiving animal moved toward the lower blue rectangle, a portion of the rectangle turned red (but remained in the same position), then the receiving animal moved back to their starting position, leaving the red rectangle connected to the blue rectangle. This repeated for the upper rectangle immediately after (see Figure 1 for examples of the start and end position for each condition and Figure 2 for example freeze frames from the videos procedure). During the video the experimenter said: “This cow gives the monkey this much red” for each of the two resources. After the video, the experimenter asked the child to choose who was nicer, pointing to the two “givers” (the characters on the left) and recorded the child’s response by pressing the up or down arrow on the

computer (corresponding to the upper or lower character). We used a generic reference to the resource in order to avoid introducing an additional confound between the discrete and continuous versions of the task. This helped ensure that the only differences between conditions were the carefully manipulated perceptual differences (i.e. none of the language from the experimenter further cued whether the resource was discrete or continuous). Furthermore, we used the color changing as a way to indicate “sharing” in order to keep the resource as a complete whole. That is, we did not want to have the resources be broken up when given to the other character but instead wanted the entire resource (shared and unshared) to stay connected (although, see Experiment 2 where we manipulate this). We opted for this setup in order to keep stimuli similar to those used in other proportional reasoning studies with young children (e.g., Boyer et al., 2008).

On all subsequent trials, after the first introductory trial, children were not given the preamble about the characters and their resources or favorite colors. Instead, the trial began with the video where the child watched the receiving animal move toward each resource and the experimenter said: “This [giver animal, e.g., “cow”] gives the [receiving animal, e.g., “monkey”] this much red” as each resource turned a portion red (but remained in place). If children responded that the animals were the same or that both were nicer, children were prompted to make their best guess and were required to choose one.

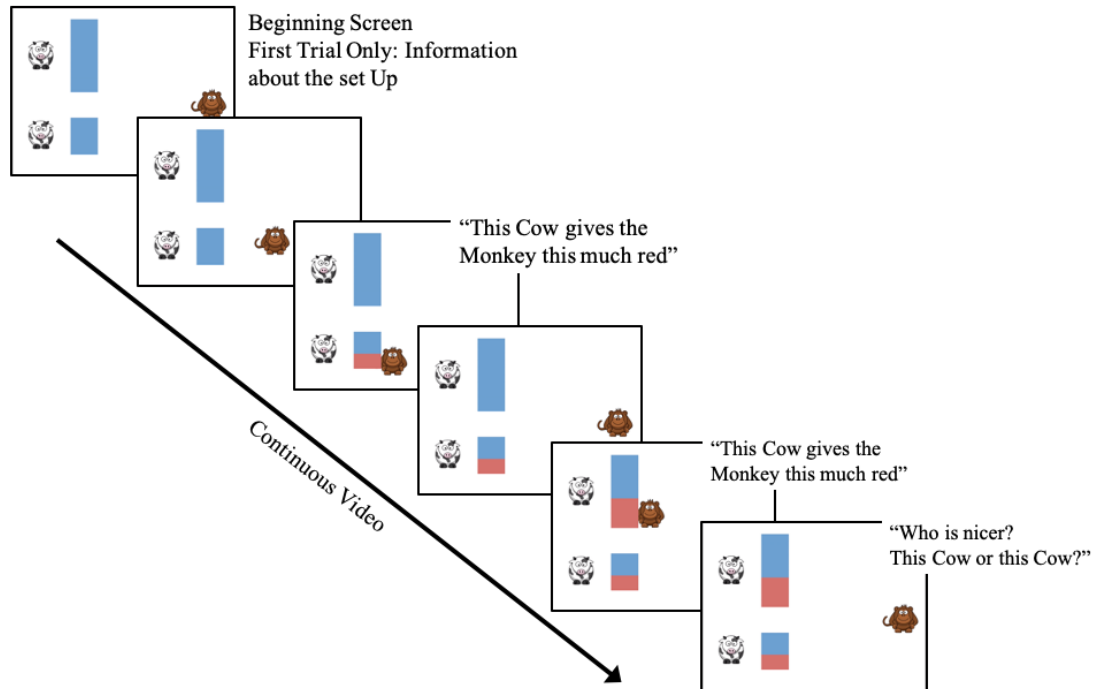


Figure 2: Stills from the video children saw for the Continuous and Connected condition in both Experiments 1 and 2. The Discrete and Separated conditions had the same animal movement but differed in the stimulus format (as shown in Figure 1).

All children completed three different types of trials (four of each type, totaling 12 trials): Proportion Constant, Absolute Constant, and Conflict trials. On the **Proportion Constant** trials, the proportion of the rectangle that turned red was the same across the two characters, but the amount varied (e.g., 2-out-of-4 vs. 3-out-of-6; both are 50% red, but one option is 3 units and the other is 2 units). On half the trials, the upper character shared absolutely more and on the other half of trials, the lower character shared absolutely more. These trials were scored as the proportion of trials (out of four) on which children chose the character who shared absolutely more, as a measure of whether children understood the basic mechanics of the task and attend to absolute amount as a relevant feature when not in conflict with proportion. On the **Absolute Constant** trials, the number or amount of the rectangle that turned red was the same across the two characters, but the proportion varied (e.g., 2-out-of-4 vs. 2-out-of-8; both have 2 units of red,

but the first option is proportionally more [50%] than the second option [25%]). On half the trials, the upper character shared proportionally more and on the other half of trials, the lower character shared proportionally more. These trials were scored as the proportion of trials (out of four) on which children chose the character who shared proportionally more, as a measure of whether children attended to proportion as a relevant feature when not in conflict with number or amount. The critical trials were **Conflict** trials, in which one character shared absolutely more, but proportionally less, and the other character shared proportionally more, but absolutely less (e.g., 2-out-of-4 vs. 3-out-of-9; the first option is numerically less because $2 < 3$, but proportionally more because $50\% > \sim 33\%$). On half the trials, the upper character shared numerically more, but proportionally less than the lower character and on the other half of trials, the upper character shared proportionally more, but numerically less than the lower character. These trials were scored as the proportion of trials (out of four) on which the child chose the character who shared proportionally more, but absolutely less. Thus, a value of one suggests children were consistently choosing based on proportion and a value of zero suggests children were consistently choosing based on absolute amount.

Results and Discussion

All data analyses were performed in R (version 3.5.1) (R Core Team, 2018) using RStudio (R Studio Team, 2016) and the packages *dplyr*, *tidyr*, *stringr*, *readr*, *readxl*, *purrr*, and *ggplot2* from the *tidyverse* (Wickham, 2017), as well as the package *effsize* (Torchiano, 2018).

To address our central question, we pre-registered three between-subject *t*-tests comparing performance across the Discrete (D) and Continuous (C) conditions on each of the three trial types. We expected that children in the Continuous condition would be more likely to attend to proportion than children in the Discrete condition, both on the Absolute Constant trials and on the Conflict trials. We did not predict a difference in performance on the Proportion Constant trials. Although not pre-registered, to provide a general description of performance, we also compare children's performance to chance. To control for the family wise error rates in the primary analyses, we adjusted alpha values in line with Holm's sequential procedure (Holm, 1979; Howell, 2013), and thus report the alpha level used for each for the three between-subject *t*-tests separately. For all other tests, an alpha of 0.05 was used.

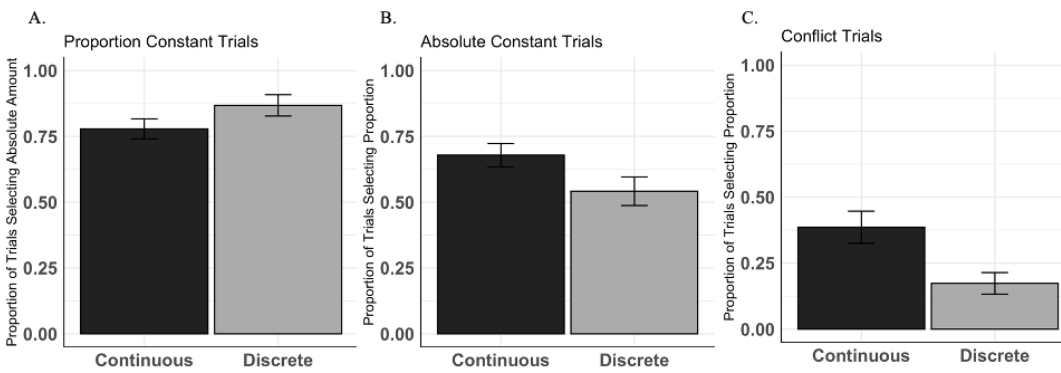


Figure 3: Children's performance in Experiment 1 on each of the three trial types (A: Proportion Constant, B: Absolute Constant, C: Conflict) separated by condition (Continuous, dark grey left bars; Discrete, light grey right bars). Note the dependent variable changes by condition, based on the options that were available. A value of 0.5 would be chance. Error bars represent standard error of the mean.

On **Proportion Constant** trials (Figure 3A), measuring children's use of absolute information when proportion was not available, there was a small but not statistically significant difference between conditions: $M_D = 0.87$, $M_C = 0.78$, $t(69) = 1.61$, $p = 0.11$ (following Holm's sequential procedure, we do not reject the null for test 3/3 because test 2/3 was not significant; Holm, 1979), *Cohen's d* = 0.38. Children performed significantly above chance in both the Discrete condition, $t(35) = 9.1$, $p < 0.001$, 95% CI of mean performance [0.79, 0.95], and the

Continuous condition, $t(34) = 7.32, p < 0.001$, 95% CI of mean performance [0.70, 0.86]. Thus, regardless of whether the shared amount was divided into countable units (Discrete) or was an uncountable area (Continuous), children used absolute information to make social evaluations. This is consistent with prior work using entirely discrete resources (e.g., stickers) suggesting that 4- and 5-year-olds are able to use absolute information in their social evaluations (McCrink et al., 2010) and understood the basic mechanics of the task.

On **Absolute Constant** trials (Figure 3B), measuring children's use of proportion when absolute information was not available, there was a slightly larger, but still not statistically significant difference between conditions: $M_D = 0.54, M_C = 0.68, t(69) = 1.95, p = 0.055$ ($\alpha_{2/3} = 0.025$), *Cohen's d* = 0.46. However, children performed significantly above chance in the Continuous condition, $t(34) = 4.0, p < 0.001$, 95% CI of mean performance [0.59, 0.77], but not the Discrete condition, $t(35) = 0.77, p = 0.45$, 95% CI of mean performance [0.43, 0.65]. This pattern provides some evidence, in line with our hypothesis, that when relevant stimulus information was presented as continuous quantities children were able to use proportional information at an above chance level, whereas children's performance did not differ from chance when this information was presented as discretized, countable units.

On **Conflict** trials (Figure 3C), where we explicitly pit proportion and absolute information against each other, there was a statistically significant difference between conditions, with children in the Continuous condition significantly more likely to select the proportional response than children in the Discrete condition: $M_D = 0.17, M_C = 0.39$, Welch's t-test (because of a significant difference in variances, $p = 0.03$) $t(59.7) = 2.9, p = 0.005$ ($\alpha_{1/3} = 0.016$), *Cohen's d* = 0.69. Further, children in the Discrete condition relied on proportion significantly less than chance, $t(35) = 7.99, p < 0.001$, 95% CI of mean performance [0.09, 0.26],

but children in the Continuous condition while still selecting the absolute amount more than the proportional amount, did not significantly differ from chance, $t(34) = 1.88$, $p = 0.07$, 95% CI of mean performance [0.26, 0.51]. Thus, in line with our hypotheses, children were more likely to use absolute information when the resources were presented as discretized, countable units compared to when they were presented as uncountable continuous areas.

Overall, the pattern of findings with discrete stimuli are in line with those reported by McCrink and colleagues (2010): children did not use proportion in their social evaluations, just as in non-social proportional reasoning tasks involving discrete, countable quantities. However, when the stimuli were continuous and not divided into units, making numerical information not available, children showed a smaller tendency to rely on absolute information over proportional information to make judgements of niceness.

Experiment 2

In Experiment 2, we used the same procedure as in Experiment 1 but modified the stimuli to investigate whether children's social evaluations also depend on the spatial connectedness of the shared and non-shared parts. As in Experiment 1, we hypothesized that when proportional information is made less salient – in this case when the shared and non-shared parts are spatially separated – children would be more likely to judge niceness based on absolute amount shared, compared to when the parts remain spatially connected. This hypothesis is motivated by work in proportional reasoning outside the social context that shows reasoning proportionally about two parts is more difficult than reasoning proportionally about part of a whole (Möhring et al., 2016).

Method

Participants. Seventy children were randomly assigned to one of two conditions:

Connected Continuous condition (CC: $n = 35$; $M_{\text{age}} = 4.9$ years Range = 4.08 to 5.74 years; n_{males}

= 13, $n_{\text{females}} = 22$) and Separated Continuous condition (SC: $n = 35$; $M_{\text{age}} = 4.9$ years Range = 4.10 to 5.84 years; $n_{\text{males}} = 13$, $n_{\text{females}} = 22$). No children were excluded. Recruitment, expected sample demographics, and sample size determination was as described in Experiment 1. All procedures were approved by the University of Chicago IRB under protocol “Relational Math Reasoning” (IRB17-1599).

Materials and Procedure. The overall procedure was identical to Experiment 1 and only differed in the visual aspects of the resources used in the Separated Continuous (SC) condition, which was contrasted with the Connected Continuous (CC) condition, which was identical to the Continuous condition used in Experiment 1. In the Separated Continuous condition, the stimuli were continuous and undivided, but when the receiving character moved to obtain the resource and it turned red, the red part of the resource also moved to the other side of the screen away from the giving character, so that the red and blue parts of the resource were spatially separated on the screen (see Figure 1, Panel B).

Results and Discussion

All data analyses were performed as in Experiment 1 and we again used three between-subject *t*-tests comparing performance across the Separated and Connected conditions on each of the three trial types (proportion constant, absolute constant, and conflict). We predicted that children in the Connected condition would be more likely to choose the proportional response on the Conflict trials, and potentially on the Absolute Constant trials as well, than children in the Separated condition. We did not expect a difference in performance on the Proportion Constant trials. As in Experiment 1, we are using adjusted alpha values in line with Holm’s sequential procedure for the primary analyses. For all other tests, we used an alpha of 0.05.

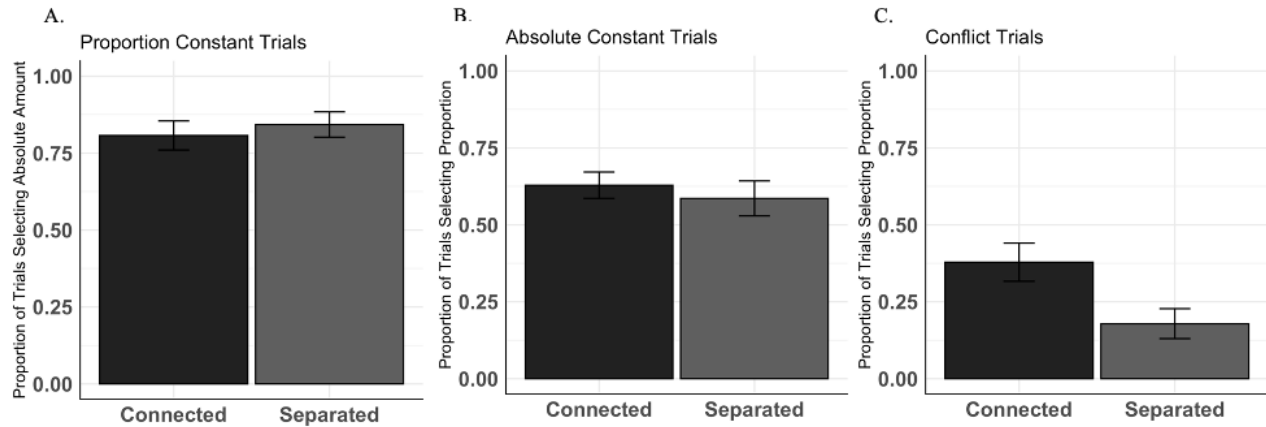


Figure 4: Children's performance in Experiment 2 on each of the three trial types (A: Proportion Constant, B: Absolute Constant, C: Conflict) separated by condition (CC = Connected, darker grey left bars; SC = Separated, lighter grey right bars). Note the dependent variable changes by condition, based on the options that were available. A value of 0.5 would be chance. Error bars represent standard error of the mean.

On **Proportion Constant** trials (Figure 4A) there was not a statistically significant difference between the two conditions: $M_{SC} = 0.84$, $M_{CC} = 0.81$, $t(68) = 0.57$, $p = 0.57$ (following Holm's sequential procedure, we do not reject the null for test 3/3 because test 2/3 is not significant; Holm, 1979), *Cohen's d* = 0.14. Furthermore, children performed significantly above chance on both the Separated condition, $t(34) = 8.3$, $p < 0.001$, 95% CI of mean performance [0.76, 0.93], and the Connected condition, $t(34) = 6.5$, $p < 0.001$, 95% CI of mean performance [0.71, 0.90]. Thus, regardless of whether the shared amount remained connected to the non-shared part or separated from it, children used absolute information to make social evaluations on Proportion Constant trials.

On **Absolute Constant** trials (Figure 4B) there was not a statistically significant difference between conditions: $M_{SC} = 0.59$, $M_{CC} = 0.63$, $t(68) = -0.60$, $p = 0.56$ ($\alpha_{2/3} = 0.025$), *Cohen's d* = 0.14. However, as in Experiment 1, children performed significantly above chance in the Connected condition, $t(34) = 3.0$, $p = 0.005$, 95% CI of mean performance [0.54, 0.72], but did not do so in the Separated condition, $t(34) = 1.5$, $p = 0.14$, 95% CI of mean performance [0.47, 0.70]. Although there was not a significant difference between conditions, this pattern

provides some evidence that children may have a tendency to use proportion when both the shared and not-shared parts remained connected, whereas when the shared and not-shared parts were separated children were inconsistent in their strategies.

On **Conflict** trials (Figure 4C) there was a statistically significant difference between conditions on the proportion of trials in which they selected the proportional response: $M_{SC} = 0.18$, $M_{CC} = 0.38$, $t(68) = 2.5$, $p = 0.013$ ($\alpha_{1/3} = 0.016$), *Cohen's d* = 0.61. Further, children in the Separated condition used absolute amount more than chance (i.e., used proportion less than chance), $t(34) = 6.6$, $p < 0.001$, 95% CI of mean performance [0.08, 0.28], whereas children in the Connected condition used proportion information only slightly less than, and not significantly different from, chance, $t(34) = 2.0$, $p = 0.06$, 95% CI of mean performance [0.26, 0.50]. Thus, in line with our hypotheses, children were more likely to use proportional information when the shared and not-shared parts were spatially connected, rather than separated.

The results of Experiment 2 demonstrate again that, unlike adults (McCrink et al., 2010), young children do not rely on proportional information to make social evaluations. However, the relative weight given to absolute versus proportional information is influenced by the perceptual features of the task (whether the shapes are connected or separated).

Experiment 3

Although our primary interest is in children's use of quantitative information across contexts, in Experiment 3 we compare adults' preferences for absolute versus proportional information across the same visual conditions in order to provide a comparison of what is typical for adults. Based on prior work including adult comparison groups, we expect adults to have an overall tendency to focus on proportional information, even in the discrete and spatially

separated conditions (McCrink et al., 2010). However, it seems important to demonstrate that adults do indeed rely on proportional reasoning in our task, which is somewhat different from those used in past work. Indeed, examining how the levels of absolute vs. proportion preferences seen in young children in Experiments 1 and 2 compare to adults, particularly on the conflict trials, is important for contextualizing the strength of children's tendencies to rely on proportional versus absolute quantitative information. Additionally, we can investigate whether the strength of this pattern varies or remains constant across different perceptual variations, even in adults.

Method

Participants. One-hundred-and-nine adults² ($M_{\text{age}} = 25.5$ years, Range: 18 to 63 years, 76 females, 33 males) are included in the final sample. All participants completed all three unique conditions used in Experiments 1 and 2, but were randomly assigned to which block they received first to allow for a between subject comparison that matched the children: Discrete first ($n = 37$, $M_{\text{age}} = 24.1$ years, Range: 19 to 60 years, 24 females, 13 males), Separated Continuous first ($n = 36$, $M_{\text{age}} = 29.1$ years, Range: 19 to 63 years, 25 females, 11 males), and Connected Continuous first ($n = 36$, $M_{\text{age}} = 23.5$ years, Range: 18 to 63 years, 27 females, 9 males). Sample size was chosen to match the child samples on the between group comparisons ($n = 36$ in each first block), but to have ample power for smaller effects in the within-subject comparison (80% power to detect effects of at least $d = 0.4$ for the main and simple effects across the three conditions within participant; based on simulations from Brysbaert, 2019). Participants were recruited through participant databases that include both students and community members. All adults participated entirely online. As in the prior studies with child samples, we did not collect

² We pre-registered using a sample of 108 participants, but due to issues with randomization and drop out we ended up with one extra participant.

additional demographic information. However, about half of the sample was drawn from a larger pool that self-reported as 39% White, 16 % Black or African American, 15% East Asian, 10% Hispanic, Latinx, or Spanish Origin, 10% South Asian, 2% Middle Eastern or Arab American, < 1 % American Indian or Alaskan Native, < 1% Native Hawaiian or other Pacific Islander, 6% other, and 2% declined to answer. Additionally, approximately 53% reported completing at least a Bachelor's degree. We expect our sample to be similar to this broader pool.

An additional 8 complete datapoints were excluded from the analyses because they were repeat participants (i.e., people who took the study more than once). Adults were compensated with partial course credit or \$5. The entire session took approximately 20 minutes (after completion of the current study, adults completed additional tasks for a separate study that will not be discussed here). All procedures were approved by the University of Chicago IRB under protocol "Relational Math Reasoning" (IRB17-1599).

Materials and Procedure. Adults completed all three unique conditions from the previous studies in three separate blocks: Discrete condition (from Experiment 1), Separated Continuous condition (from Experiment 2), and the Connected Continuous condition (from Experiments 1 and 2). The order of the blocks was randomly assigned to allow for both within-subject comparisons across the whole sample and between-subject comparisons of the first block only. The verbal introduction typically provided to children was included as an instructional text screen prior to the task. We used the Gorilla Experiment Builder (www.gorilla.sc) to create and host our experiment for online data collection (Anwyl-Irvine et al., 2020). The rest of the stimuli and procedure were as in Experiments 1 and 2. To be consistent with the child data reported in Experiments 1 and 2, we only report adults' behavioral choices in the manuscript. However,

adults' reaction times were also analyzed as a secondary dependent variable and the results (reported in Supplemental Materials) showed a very similar pattern to the behavioral responses.

Results and Discussion

The overall pattern is very similar regardless of whether data were analyzed within-subject including all three blocks per participants or if only the first block was analyzed between-subjects (with one exceptions), thus we only report the within-subject analyses in the text (between-subject analyses on the first block of trials are available in Supplemental Materials). To investigate condition differences, we used a one-way repeated measures ANOVA across the three conditions on each trial type separately. To describe the overall performance preferences, we use one-sample t-tests comparing performance to chance. Adults' behavioral choices across all conditions and trial types are presented in Figure 5.

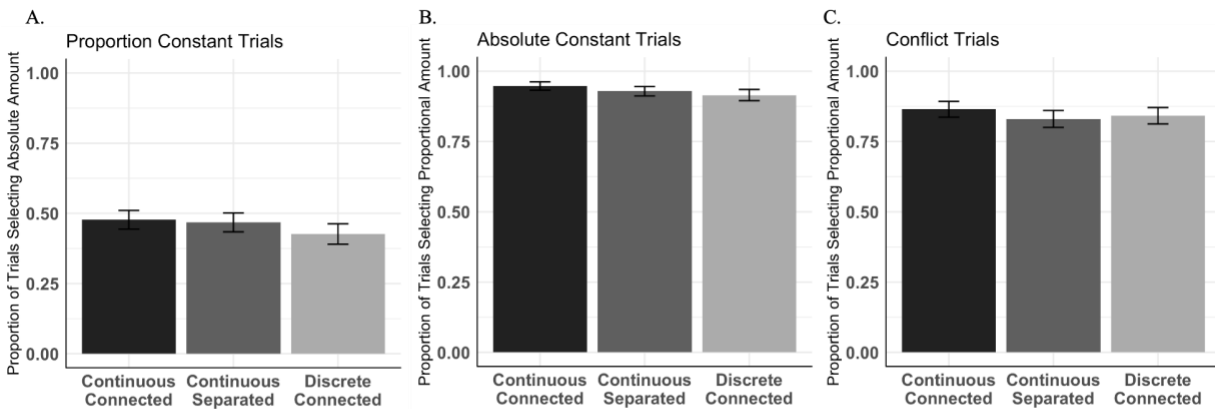


Figure 5: Adults' performance in Experiment 3 on each of the three trial types (A: Proportion Constant, B: Absolute Constant, C: Conflict) separated by condition (C = Connected & Continues from Exp. 1 & 2, left bars; SC = Separated from Exp. 2, middle bars; D = Discrete from Exp. 1, right bars). Note the dependent variable changes by condition, based on the options that were available. A value of 0.5 would be chance. Error bars represent standard error of the mean.

On the **Proportion Constant** trials, adults performed around chance (50%) on both the Connected Continuous condition, $M = 0.48$, $t(108) = -0.69$, $p = 0.49$, 95% CI [0.41, 0.54], and the Separated condition, $M = 0.47$, $t(108) = -0.96$, $p = 0.34$, 95% CI [0.40, 0.53], and significantly, albeit slightly, below chance on the Discrete condition, $M = 0.43$, $t(108) = -2.01$, p

= 0.047, 95% CI [0.35, 0.499]³. This suggests that adults did not reliably use the total amount shared when proportion shared was held constant. Instead, an inspection of the data actually suggests performance was skewed such that many adults reliably choose the character who had *less* of the resource to begin with as “nicer”. Further, there was not a significant main effect of condition, $F(2,216) = 1.23$, $p = 0.23$, $\eta^2_{\text{partial}} = 0.01$, on the proportion of trials participants selected the higher amount.

On the **Absolute Constant** trials, adults overwhelmingly relied on the proportional amount in their evaluations in all three conditions: Connected Continuous, $M = 0.95$, $t(108) = 29.9$, $p < 0.001$, 95% CI [0.92, 0.98], Separated, $M = 0.93$, $t(108) = 25.8$, $p < 0.001$, 95% CI [0.90, 0.96], and Discrete $M = 0.92$, $t(108) = 20.9$, $p < 0.001$, 95% CI [0.88, 0.95]. Further, there was not a significant main effect of condition, $F(2, 216) = 1.58$, Huynh-Feldt corrected $p = 0.21$, $\eta^2_{\text{partial}} = 0.01$, on the proportion of trials on which participants selected the higher proportion.

On the **Conflict** trials, adults again overwhelmingly selected the character who shared proportionally more, over the character who shared absolutely more in all three conditions: Connected Continuous, $M = 0.86$, $t(108) = 12.96$, $p < 0.001$, 95% CI [0.81, 0.92], Separated, $M = 0.83$, $t(108) = 11.0$, $p < 0.001$, 95% CI [0.77, 0.89], and Discrete $M = 0.84$, $t(108) = 11.8$, $p < 0.001$, 95% CI [0.78, 0.90]. Notably, and as predicted, this is the opposite of what we found with young children who selected the character who shared proportionally more at or below chance levels. These results replicate prior work on adults’ choices in a similar paradigm (McCrink et al., 2010). Again, there was not a significant main effect of condition, $F(2, 216) = 1.03$, $p = 0.36$, $\eta^2_{\text{partial}} = 0.009$, on proportion of trials selecting the proportional response.

³ When only data from the first block is analyzed between-subject, participants in the Discrete condition actually performed slightly above chance ($M = 0.58$, $p = 0.09$). Thus, the small effect and discrepancies across data analytic choices suggests that adults’ performance is likely around chance but may be malleable depending on the design of the study and the order in which adults completed the blocks. The full results are reported in Supplemental Materials.

Overall, these results suggest that adults relied on the proportion given (rather than absolute amounts) and unlike children, were *not* impacted by the presentation of resources.

General Discussion

Across three experiments, we investigated 4- and 5-year-olds' and adults' tendency to use the absolute amount versus proportional amount of resources shared to form social evaluations of "givers". We compared children's judgements when the resources were discrete versus continuous and when they were spatially separated versus connected. We found support for our hypothesis that when proportion and absolute information are in conflict, children are more likely to use proportion when the resources are continuous and spatially connected (Experiments 1 and 2), relative to when the resources are discrete and countable (Experiment 1) and when the parts are spatially separated (Experiment 2). These findings suggest that the typical resource distribution displays (e.g., those with cookies and stickers) used in studies examining children's decisions based on resource allocation scenarios may be contributing to 4- and 5-year-old children's tendency to rely on absolute amount shared at the cost of attending to proportion shared. Thus, these findings emphasize the importance of deeply considering how the specific contexts used to measure children's social judgments, and potentially other developmental phenomena more broadly, could be playing a critical role in our conclusions about children's abilities and the developmental processes that underlie them.

Nonetheless, though children did display more proportional reasoning when displays were continuous and connected, 4- and 5-year-old children did not robustly rely on proportional information even with this optimal context. Instead, children relied on absolute amount, which was very different from our adult comparison group, who consistently relied on proportional information when it was available across all visual contexts. Furthermore, adults did not reliably

use the absolute amount shared even when proportional information was held constant. Thus, even in the best-case condition of continuous resources that are spatially connected children showed a behavioral pattern qualitatively distinct from that shown by adults, suggesting that children may have different social preferences than adults (McCrink et al., 2010) and that multiple factors likely impact children's tendency to rely more on absolute amount shared than on proportional amount shared. Importantly, some of these factors are likely related to proportional reasoning limitations more generally, but others may still be related to their analysis of social interactions. For example, one social factor may be the existence of prior collaboration with the recipient (Hamann et al., 2011; Ng et al., 2011). Future work should continue to investigate what factors impact children's social evaluations and how these change over development. For example, when do children become "adult-like" in their responding and what factors – both non-social, such as symbolic fraction knowledge, and social, such as reasoning about equity – impact this development?

Importantly, these findings have implications for our understanding of children's social judgements. In particular, it may be that prior work has underestimated children's ability to socially reason with proportional information when the resources were displayed in a way that did not perceptually support proportional reasoning. Notably, the pattern of findings we obtained leads to the surprising prediction that early in development, social inferences depend on the types of resources being distributed. For example, when someone shares individual cookies (discrete) versus juice (continuous) or when someone shares individual toys (which can be spatially separated) versus a blanket or play-space (which remains connected), children may show systematic differences in whether they think niceness depends on amount versus proportion shared. In contrast to these early inconsistencies, later in development, when children are no

longer as influenced by perceptual features of objects shared, their behavior may show greater consistency across contexts. An important limitation of the current work, however, is that in order to carefully control the perceptual features across contexts we relied on generic and sparse scenarios that are atypical for sharing scenarios. Although the pattern of children's behavior suggests that they understood the basic mechanics of the task despite the sparseness, whether these perceptual features have similar effects in rich sharing scenarios of real-life objects and contexts is an important question for future work.

Additionally, we did not collect demographic information about socioeconomic status (SES) or race/ethnicity in any of the current studies, which limits our ability to consider their role in proportional sharing. It is worth noting that the information we do have about the populations from which these data were collected reveal that they were likely skewed toward being more educated than the general population, which might make one concerned about the generalizability of these data. We expect our key effect, the influence of perceptual manipulation on children's tendency to rely on absolute amount vs. proportional information to be robust to different demographic factors. Indeed, the sparse and abstract nature of our task may have minimized the effects of these individual differences. That is, we used animals (which lack gender or racial/ethnic identities) and abstract resources (i.e., blocks of color, as opposed to valued resources of money, stickers, or candy bars) specifically because they reduce the saliency of these factors in judgments of which giver was nicer. However, we fully acknowledge that demographic factors could impact children's evaluations. The current study did not have specific hypotheses about these demographic factors, nor the statistical power to test such hypotheses. Future work could examine how individual differences in these factors, including experience with resource distribution, race/ethnicity or other cultural differences, socioeconomic

background, and/or more general cognitive and mathematical skills, could impact the developmental trajectory or magnitude of this effect across different social contexts.

Finally, the current findings point to several other important directions for future work. First, whether children's low levels of proportional reasoning are due to difficulties attending to and encoding proportional information based on certain kinds of displays or difference in children's tendency to use proportional strategies is an open question. In the current study, we did include measures of counting ability to investigate whether counting knowledge relates to the preference for numerical vs. proportional information across visual displays. However, the findings were small and inconsistent, making it unclear whether number knowledge plays a role in the tradeoff between absolute amount and proportion. Future work should further investigate all of these features simultaneously (proportional information, numerical information, context specific information such as analysis of social interactions), in order to investigate whether children's attention to these features vary across contexts (e.g., social evaluations vs. probabilities) and if so, whether this variation is due to differences in strategy selection or cognitive difficulties reasoning about certain kinds of information. Second, although not a direct goal of the current study, our findings add to a growing body of work showing the benefits of continuous contexts over discrete contexts for reasoning about proportion (e.g., Boyer et al., 2008; Boyer & Levine, 2015; Hurst & Cordes, 2018; Jeong et al., 2007), which may have implications for how proportional reasoning is taught. Although some have suggested that sharing scenarios are a productive way to teach fractions (e.g., Empson, 1995), it may be that the discreteness of typical sharing scenarios continues to perpetuate children's known "whole number bias" (e.g., Ni & Zhou, 2005). Instead, future work should consider whether sharing scenarios with continuous amounts (e.g., water or whole chocolate bars) could provide both the

direct perceptual access to continuous proportion and the connection to children's intuitions about social sharing.

In summary, the current study provides a powerful demonstration that children may display what look like different social preferences from adults for reasons that are non-social; for example, based on the saliency of different strategies due to the specific nature of the quantities used as resources. By incorporating more diverse sets of resources, in terms of the organization and nature of the quantities used in resource distribution scenarios, we can further our understanding of the factors – cognitive and social – that influence children's reasoning about resource distribution and the developmental trajectory of children's moral evaluations. Importantly, this issue is not only true for social development. More generally, these findings emphasize the need to remain vigilant about how our specific methodological decisions and the contexts we use to study children may impact their behavior, and ultimately our conclusions about child development.

References

- Anwyl-Irvine, A. L., Massonnié, J., Flitton, A., Kirkham, N., & Evershed, J. K. (2020). Gorilla in our midst: An online behavioral experiment builder. *Behavior Research Methods*, 52(1), 388–407. <https://doi.org/10.3758/s13428-019-01237-x>
- Baumard, N., Mascaro, O., & Chevallier, C. (2012). Preschoolers are able to take merit into account when distributing goods. *Developmental Psychology*, 48(2), 492–498. <https://doi.org/10.1037/a0026598>
- Boyer, T. W., Levine, S. C., & Huttenlocher, J. (2008). Development of proportional reasoning: Where young children go wrong. *Developmental Psychology*, 44(5), 1478–1490. <https://doi.org/10.1037/a0013110>
- Chernyak, N., Harris, P. L., & Cordes, S. (2019). Explaining early moral hypocrisy: Numerical cognition promotes equal sharing behavior in preschool-aged children. *Developmental Science*, 22(1), e12695. <https://doi.org/10.1111/desc.12695>
- Chernyak, N., Sandham, B., Harris, P. L., & Cordes, S. (2016). Numerical cognition explains age-related changes in third-party fairness. *Developmental Psychology*, 52(10), 1555–1562. <https://doi.org/10.1037/dev0000196>
- Denison, S., Reed, C., & Xu, F. (2013). The emergence of probabilistic reasoning in very young infants: Evidence from 4.5- and 6-month-olds. *Developmental Psychology*, 49(2), 243–249. <https://doi.org/10.1037/a0028278>
- Denison, S., & Xu, F. (2010). Twelve- to 14-month-old infants can predict single-event probability with large set sizes: Twelve- to 14-month-olds can predict single-event probability. *Developmental Science*, 13(5), 798–803. <https://doi.org/10.1111/j.1467-7687.2009.00943.x>

- Duffy, S., Huttenlocher, J., & Levine, S. (2005). It Is All Relative: How Young Children Encode Extent. *Journal of Cognition and Development*, 6(1), 51–63.
https://doi.org/10.1207/s15327647jcd0601_4
- Dunfield, K. A., & Kuhlmeier, V. A. (2010). Intention-Mediated Selective Helping in Infancy. *Psychological Science*, 21(4), 523–527. <https://doi.org/10.1177/0956797610364119>
- Engelmann, J. M., & Tomasello, M. (2019). Children’s Sense of Fairness as Equal Respect. *Trends in Cognitive Sciences*, 23(6), 454–463. <https://doi.org/10.1016/j.tics.2019.03.001>
- Frydman, O., & Bryant, P. (1988). Sharing and the understanding of number equivalence by young children. *Cognitive Development*, 3(4), 323–339. [https://doi.org/10.1016/0885-2014\(88\)90019-6](https://doi.org/10.1016/0885-2014(88)90019-6)
- Hamann, K., Warneken, F., Greenberg, J. R., & Tomasello, M. (2011). Collaboration encourages equal sharing in children but not in chimpanzees. *Nature*, 476(7360), 328–331.
<https://doi.org/10.1038/nature10278>
- Holm, S. (1979). A Simple Sequentially Rejective Multiple Test Procedure. *Scandinavian Journal of Statistics*, 6(2), 65–70.
- Hook, J. G., & Cook, T. D. (1979). Equity theory and the cognitive ability of children. *Psychological Bulletin*, 86(3), 429.
- Howell, D. C. (2013). *Statistical methods for psychology* (8th ed.). Cengage Learning/Wadsworth.
- Hurst, M. A., & Cordes, S. (2018). Attending to relations: Proportional reasoning in 3- to 6-year-old children. *Developmental Psychology*, 54(3), 428–439.
<https://doi.org/10.1037/dev0000440>

- Hurst, M. A., Shaw, A., Chernyak, N., & Levine, S. (2020, September 4). Giving a Larger Amount or a Larger Proportion: Stimulus Format Impacts Children's Social Evaluations. Retrieved from osf.io/5g34d DOI: 10.17605/OSF.IO/5G34D
- Jara-Ettinger, J., Gibson, E., Kidd, C., & Piantadosi, S. (2016). Native Amazonian children forego egalitarianism in merit-based tasks when they learn to count. *Developmental Science*, 19(6), 1104–1110. <https://doi.org/10.1111/desc.12351>
- Jeong, Y., Levine, S. C., & Huttenlocher, J. (2007). The Development of Proportional Reasoning: Effect of Continuous Versus Discrete Quantities. *Journal of Cognition and Development*, 8(2), 237–256. <https://doi.org/10.1080/15248370701202471>
- Kanngiesser, P., & Warneken, F. (2012). Young Children Consider Merit when Sharing Resources with Others. *PLoS ONE*, 7(8), e43979. <https://doi.org/10.1371/journal.pone.0043979>
- Kenward, B., & Dahl, M. (2011). Preschoolers distribute scarce resources according to the moral valence of recipients' previous actions. *Developmental Psychology*, 47(4), 1054–1064. <https://doi.org/10.1037/a0023869>
- Lakusta, L., & Carey, S. (2015). Twelve-Month-Old Infants' Encoding of Goal and Source Paths in Agentive and Non-Agentive Motion Events. *Language Learning and Development*, 11(2), 152–175. <https://doi.org/10.1080/15475441.2014.896168>
- McCrink, K., Bloom, P., & Santos, L. R. (2010). Children's and adults' judgments of equitable resource distributions: Judgments of equitable resource distributions. *Developmental Science*, 13(1), 37–45. <https://doi.org/10.1111/j.1467-7687.2009.00859.x>
- McCrink, K., & Wynn, K. (2007). Ratio Abstraction by 6-Month-Old Infants. *Psychological Science*, 18(8), 740–745. <https://doi.org/10.1111/j.1467-9280.2007.01969.x>

- Möhring, W., Newcombe, N. S., Levine, S. C., & Frick, A. (2016). Spatial proportional reasoning is associated with formal knowledge about fractions. *Journal of Cognition and Development, 17*(1), 67–84.
- Ng, R., Heyman, G. D., & Barner, D. (2011). Collaboration promotes proportional reasoning about resource distribution in young children. *Developmental Psychology, 47*(5), 1230–1238. <https://doi.org/10.1037/a0024923>
- Posid, T., Fazio, A., & Cordes, S. (2015). Being Sticker Rich: Numerical Context Influences Children’s Sharing Behavior. *PLOS ONE, 10*(11), e0138928. <https://doi.org/10.1371/journal.pone.0138928>
- R Core Team. (2018). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. <https://www.R-project.org/>
- R Studio Team. (2016). *RStudio: Integrated Development for R*. RStudio Inc. <http://www.rstudio.com/>
- Schneider, R., Sullivan, J., Marušič, F., Žaucer, R., Biswas, P., Mišmaš, P., Plesničar, V., & Barner, D. (2019). Do children use language structure to discover the recursive rules of counting? *Cognitive Psychology, in press*. <https://psyarxiv.com/cf9nm/>
- Shaw, A. (2013). Beyond “to Share or Not to Share”: The Impartiality Account of Fairness. *Current Directions in Psychological Science, 22*(5), 413–417. <https://doi.org/10.1177/0963721413484467>
- Squire, S., & Bryant, P. (2002). The Influence of Sharing on Children’s Initial Concept of Division. *Journal of Experimental Child Psychology, 81*(1), 1–43. <https://doi.org/10.1006/jecp.2001.2640>

Torchiano, M. (2018). *effsize: Efficient Effect Size Computation*. <https://CRAN.R-project.org/package=effsize>

Warneken, F., & Tomasello, M. (2013). The emergence of contingent reciprocity in young children. *Journal of Experimental Child Psychology*, *116*(2), 338–350.
<https://doi.org/10.1016/j.jecp.2013.06.002>