Cognitive Development 68 (2023) 101390

Contents lists available at ScienceDirect

Cognitive Development

journal homepage: www.elsevier.com/locate/cogdev

Winning or losing: Children's proportional reasoning across motivational contexts

Karina Hamamouche [a,*], Sara Cordes [b]

[a] Butler University, United States
[b] Boston College, United States

ARTICLE INFO

Keywords:
proportional reasoning
framing
numerical bias
whole number bias

ABSTRACT

Children tend to prioritize whole number information over relational information in proportional reasoning tasks, such that they judge a spinner with 4/10 red pieces as *more* likely to land on red than a spinner with 2/3 red pieces, because 4 > 2 (e.g., Hurst & Cordes, 2018a; Jeong et al., 2007). This whole number bias is hypothesized to be a driven by fluency in verbal counting in early childhood, which is thought to promote attention to whole number information. In this study, we explored (1) the relation between verbal counting abilities and whole number biases and (2) whether distinct framing contexts – either encouraging children to maximize the number of stickers won, or minimizing the number of stickers lost - differentially impact children's proportional reasoning. Three- to nine-year olds (N = 210, M_{age} = 5.7 years) chose which of two spinners they preferred to spin. Children in the Gain condition learned that if the spinner landed on red, they would win a sticker and if it landed on blue, nothing would happen; children in the Loss condition learned that if the spinner landed on red, nothing would happen, but if it landed on blue, they would lose a sticker. Counter to prior work, performance of both older (6–9 year olds) and younger (3–5 year olds) children revealed whole number biases. Notably, whole number biases were not related to counting abilities. Importantly, we find framing the task in a Loss scenario lessened whole number biases, suggesting that task framing can alter children's attention to whole number information in a proportional reasoning context.

Proportional reasoning, or the ability to understand multiplicative part-whole relationships between quantities, is fundamental to our ability to reason in the world around us. This skill not only allows us to succeed in math and science classes (Booth & Newton, 2012; DeWolf et al., 2015; Resnick et al., 2016; Sadler & Tai, 2007; Siegler et al., 2012; Hurst & Cordes, 2018a), but also helps us perform everyday activities like cooking dinner (Boyer et al., 2008; Boyer & Levine, 2015; Lamon, 1993). Given the importance of proportional reasoning in our everyday lives, it is pertinent to investigate how this ability develops and importantly, how real-world constraints may impact our ability to effectively engage in proportional reasoning. In the present study, we investigate two factors that may influence children's early proportional reasoning abilities: (1) mastery of the verbal counting procedure in the preschool years and (2) task framing. In particular, we explore whether the acquisition of verbal counting and whether the task framing – focusing on trying to maximize wins versus avoid losses – may impact children's performance on a proportional reasoning task.

* Correspondence to: Department of Psychology, Butler University, 4600 Sunset Avenue, Indianapolis, IN 46208, United States.
E-mail address: khamamou@butler.edu (K. Hamamouche).

https://doi.org/10.1016/j.cogdev.2023.101390
Received 21 June 2022; Received in revised form 14 September 2023; Accepted 20 October 2023
Available online 4 November 2023

1. Proportional reasoning

Although significant work has revealed that both children and adults struggle to learn symbolic proportion (e.g., fractions and decimals; Boulet, 1998; DeWolf et al., 2014; De Wolf & Vosniadou, 2015; Hurst & Cordes, 2018b; Mazzocco & Devlin, 2008), a growing body of literature reveals children also struggle with proportional reasoning in the context of nonsymbolic displays (e.g., pie charts). In particular, though children are capable of engaging in proportional reasoning as early as infancy (Denison & Xu, 2014; McCrink & Wynn, 2007) and can do so in the context of continuous (i.e., non-discrete) displays, children encounter significant difficulties thinking relationally in the presence of whole number information (Jeong et al., 2007; see also Boyer et al., 2008; Braithwaite & Siegler, 2018; Hurst & Cordes, 2018a).

As one demonstration of this "whole number bias" (Ni & Zhou, 2005), Jeong et al. (2007) presented children with game spinners divided into blue and red sections. Children learned if the spinner landed on the red, they would *win* stickers, and if it landed on blue, they would *lose* stickers (a combined gain/loss scenario). After learning the contingencies of the spinner game, children were then shown pairs of spinners and were asked to judge which of the two spinners would help them win more stickers. That is, their task was to pick the spinner with the greater *proportion* of red. Importantly, when whole number information was either not available (the spinners only had one red section and one blue section, resulting in no countable sections) or was consistent with proportion (the spinner with the greater number of red pieces also had the greater proportion of red), children succeeded in selecting the spinner with the greater proportion of red. In other words, they were capable of engaging in pure proportional reasoning when whole number information was irrelevant. However, on trials in which whole number information was present but misleading (i.e., the spinner with the greater number of red pieces actually had a smaller proportion of overall red; e.g., 2/3 vs 4/9), children frequently selected the spinner with the greater absolute number of red pieces, ignoring proportional information. Thus, children were biased by the whole number information in the displays and selected the spinner with the greater *number* of red pieces, not the greater overall proportion of red (Jeong et al., 2007; see also Boyer et al., 2008; Braithwaite & Siegler, 2018; Hurst & Cordes, 2018a).

Several studies have replicated these findings, showing evidence of whole number biases in children ages 6 and up (e.g., Boyer et al., 2008). However, only one prior study has explored whether similar biases held in younger children (4-5 year olds), revealing the whole number bias did not emerge in younger children (Hurst & Cordes, 2018a). Given the emphasis on counting in early childhood, it was hypothesized that the whole number bias may emerge as a product of experience with the counting procedure, such that children who are proficient counters may be more attuned to count the more salient winning pieces, relying more on whole number strategies. Focusing on the more salient numerator (the number of winning pieces) rather than the relationship between the winning and losing pieces on the spinner may lead children to count the red pieces, a strategy that would lead to an incorrect response on misleading trials. Given that 4-5 year olds may not yet be proficient counters, they would not be prone to counting, and thus not demonstrate a whole number bias. While this hypothesis has been proposed, it has yet to be tested and so more data are needed to verify that the presence of the whole number bias emerges with age. In the current study, we explore the relation between the presence of whole number biases in proportional reasoning and counting proficiency, to determine whether the whole number bias is driven by attainment of counting proficiency in the preschool years.

Notably, although this spinner task has been used in several studies (e.g., Abreu-Mendoza et al., 2020; Hurst & Cordes, 2018a; Hurst et al., 2022; Jeong et al., 2007), children were always faced with a situation in which they would **win** resources when the spinner landed on red *and* **lose** resources when the spinner landed on blue. It is unknown how these two facets of the reward process may have each individually contributed to children's performance and thus the presence of whole number biases. That is, were children primarily motivated by the prospect of winning stickers, and thus had their attention drawn to the red pieces? Or alternatively, did the fear of possibly losing stickers guide their focus? Given prior research suggesting that the motivational framing of a task can impact attention to relevant information in both children and adults (e.g., Bookbinder & Brainerd, 2017; Kensinger et al., 2007; Ngo et al., 2019), we considered the possibility that motivational framing may similarly impact children's attention to whole number information in the context of a proportional reasoning task. In particular, we explored whether framing the spinner task in a way that highlights either the winning of stickers ***or*** on the losing of stickers may shift children's attention away from the number of red pieces, allowing for a greater focus on the relationship between the pieces of the spinner. If so, motivational framing has the potential to impact the magnitude of whole number biases found in proportional reasoning contexts.

It is conceivable that motivational factors, brought on by task framing, may have a strong influence on children's proportional reasoning performance. Several studies have demonstrated the malleability of children's attention to proportion. This work has demonstrated that children's performance on proportional reasoning tasks is impacted by the type of problems presented (i.e., the presence of continuous and discrete entities; the presence of consistent or misleading information) and the order of presentation of problem types (Boyer et al., 2008; Hurst & Cordes, 2018a; Jeong et al., 2007). For example, children who are initially prompted to use proportional strategies by first completing a block of continuous trials (in which discrete whole number information is not available) outperform children who have not had this prior experience (Boyer & Levine, 2015; Hurst & Cordes, 2018a). Relatedly, research has revealed that children's attention to proportion is modified through subtle changes in language. For example, Hurst and Cordes (2019) found that children who were presented with categorical labels for equivalent fractions (i.e., using the same term to label equivalent fractions 3/4 and 6/8) performed better on a proportional reasoning task than children who heard traditional fraction labels or others that emphasized the part-whole information. Other work suggests that children's gesturing styles may be related to proportional reasoning performance (Hurst et al., 2022). More recently, evidence suggests that competition with others can also contribute to gender differences in whole number biases when engaged in proportional reasoning (Fish et al., 2023). Together, these studies suggest that children's attention to proportional information (compared to whole-number information) may be quite easily shifted. In the present study, we capitalize on the malleability of children's proportional reasoning skills by investigating whether motivational framing might also impact children's tendency to focus on whole number information during a proportional reasoning task.

2. Motivational framing

Several studies show that task framing – focusing on gains or losses – can be a powerful influence on adult's performance in a variety of domains, from decision making to perceptual learning (e.g., Kahneman & Tversky, 1979; Tversky & Kahneman, 1981). Numerous research studies using adult participants demonstrate an asymmetrical effect of negative versus positive information. Several studies reveal that negative information is remembered more easily than positive information (e.g., Kensinger et al., 2007; Ngo et al., 2019). For example, adults have greater memories for images of negative items compared to positive ones (Bookbinder & Brainerd, 2017; Kensinger et al., 2007) and adults remember more negative words compared to neutral ones, suggesting that adults' memory performance is enhanced in a negative context (see Kensinger & Corkin, 2003). In the same vein, people tend to have more vivid memories and remember more details from negative, compared to positive events (for a review see: Kensinger, 2007). Moreover, adult decision-making studies suggest that losses loom larger than gains (Kahneman & Tversky, 1979; Tversky & Kahneman, 1981), such that motivations may be enhanced when tasks are framed as avoiding a loss.

Fewer studies, however, have explored the effects of framing in children. Work by Levin and colleagues has found that children engage in more risk-taking behaviors when trying to avoid losses compared to obtaining gains (Levin & Hart, 2003; Levin et al., 2007), suggesting that children are attuned to framing. Recent work with younger participants has found a similar result – children's mnemonic discrimination, which is usually relatively poor, was enhanced when presented in a Loss frame, compared to a gain one (Ngo et al., 2019). In this study, children played a game in which they observed a bird eating different foods. Sometimes the food made the bird healthier (i.e., Gain condition), whereas other times the food made the bird sicker (i.e., Loss condition). After learning which foods made the bird healthier or sicker, children completed a forced choice task in which they were asked to choose which food items the bird had previously eaten. Overall memory performance was better for younger children (4-5 year olds) when the task was placed in the gain/loss framing compared to a no framing condition, suggesting that gain/loss framing can increase children's performance during challenging tasks. More importantly, children (4-8 year olds) and adults were more likely to remember the items that made the bird sicker, compared to the items that made the bird healthier, indicating that memory performance was enhanced in the Loss framing context. While people tend to remember negative information over positive or neutral information (e.g., Kensinger et al., 2007), this study also hints at the possibility that loss framing may change the salience of stimuli more so than gain framing, even for children. Yet, it should be noted that other work has suggested that traditional framing effects do not emerge until later childhood (Reyna & Ellis, 1994). Thus, more work is needed to explore the effects of framing in younger samples. Since past work on proportional reasoning has revealed children's attention to whole number information in the spinner task to be quiet malleable when children are able to both gain *and* lose (simultaneously focusing on both frames), exploring the effects of framing on proportional reasoning seemed like a logical next step.

Why would task framing impact whole number biases? According to Regulatory Focus Theory (Higgins, 1998), people's basic motivational tendencies are to approach pleasure and avoid pain. Higgins (1998) argues that people approach tasks with either a growth (i.e., promotion focus) or a security focus (i.e., prevention focus). People who are concerned with security tend to engage in more careful, analytical thinking, compared to those who are motivated by growth concerns. Substantial research has shown that adults with a prevention focus tend to outperform peers with a promotion focus on a variety of tasks, perhaps due to the focus on accuracy over speed (see Förster et al., 2003; Miele et al., 2009; Rosenzweig & Miele, 2016). For example, college students with a prevention focus outperformed their peers with a promotion focus on reading comprehension tests when the text was ambiguous (Miele et al., 2009, Study 2), on college midterms and finals (Rosenzweig & Miele, 2016, Study 3), and on sections of the SAT (Rosenzweig & Miele, 2016, Studies 1 & 2; Sternberg et al., 2008). One's regulatory focus can also impact seemingly simple tasks. For example, another study found that students with a promotion focus perform less accurately, but more quickly, on a connect-the-dots drawing task (Förster et al., 2003). Fewer studies have explored how children respond to a prevention focus mindset. In one study, children were induced into a promotion focus (describing situations where motivation helps achieve goals) or prevention focus (describing situations where motivation helps avoid failure) and then were given 5 tokens that they could spend in a shop or put into the bank. The research found that inducing a prevention focus in 9-11 year olds resulted in a preference for immediate spending (compared to saving; Trzcińska et al., 2021), suggesting that children may be susceptible to this kind of framing. In the present study, we reasoned that children in the Gain condition, who are aiming to win stickers, may be more inclined to approach the spinner task with a promotion focus, which would lead to a greater focus on the number of pieces that would result in greater gains (i.e., a whole number focus on red pieces). On the other hand, children in the Loss condition may approach the task with a prevention focus, which would lead to greater distributed attention to the relationship between red and blue pieces in the spinners. Given that individuals with a prevention focus tend to think more analytically, we would expect proportional reasoning – the skill necessary to succeed in this task – to be enhanced in the Loss condition.

2.1. The current study

The current study explores the emergence of whole number biases in two age groups: younger children (3-5 year olds) and older children (6-9 year olds), allowing for an exploration of the prevalence of whole number biases across early to middle childhood. First, we aimed to replicate prior work exploring proportional reasoning in preschoolers, revealing evidence of proportional reasoning abilities in this young group, but in the absence of whole number biases. Then, in light of theories linking the presence of whole number biases and verbal counting ability (Hurst & Cordes, 2018a), we explored the relation between proportional reasoning abilities – in particular, the presence of whole number biases in proportional reasoning tasks – and verbal counting proficiency in this youngest age group. To do so, we explored whether there was a relation between the presence of whole number biases in children's proportional judgments and their performance on a counting assessment, the Give-N task. If, as hypothesized, mastery of the count procedure promotes the salience of whole number information leading to the emergence of whole number biases, then we should find a relation between whole number biases in children's proportional judgments and their Give-N performance.

Moreover, given the malleability of children's proportional reasoning abilities and the powerful effect of framing (e.g., Ngo et al., 2019), we explored whether gain or loss framing impacts children's performance during a proportional reasoning task. Children completed the spinner proportional reasoning task (as in Jeong et al., 2007) in either a Gain frame or a Loss frame. Children in the Gain condition learned that if the spinner landed on red, they would *win* a sticker and if it landed on blue, nothing would happen. Children in the Loss condition learned that if the spinner landed on red, nothing would happen, but if it landed on blue, they would *lose* one of the stickers given to them at the start of the task. Note, while these differential instructions should lead to the same responses – selecting the spinner that is most likely to land on (and thus has a greater proportion of) red - the instructions differ in whether the child's goals were to maximize their sticker gains, or to minimize their sticker losses. Children were presented with both continuous trials (in which the spinners are composed of only one red section and one blue section, making whole number information not available) and discrete trials (in which the spinner is broken into multiple red and blue pieces, making whole number information salient).

Given that prior work has shown that attention to number in proportional reasoning tasks is fairly malleable (e.g., Boyer et al., 2008; Boyer & Levine, 2015; Hurst & Cordes, 2018a, Hurst & Cordes, 2019), we hypothesized that children in the Loss condition would demonstrate fewer whole number biases. Because past work demonstrates that loss frames increase the saliency of stimuli (Ngo et al., 2019), we would expect placing the proportional reasoning task in a loss frame would increase children's attention to proportional information (by reducing the child's focus on the "winning" pieces), thus decreasing whole number biases. In particular, increased motivation and/or the induction of a prevention-focused mindset in the Loss condition may lead to a greater attention to the relationship between blue and red pieces – a focus on the proportion of red. If so, we would expect children in the Loss condition to perform better overall on the task while also demonstrating less of a whole number bias on discrete trials.

Alternatively, prior work suggesting that losses loom larger than gains (e.g., Kahneman & Tversky, 1979; Tversky & Kahneman, 1981) may point to children in the Loss condition having a heightened awareness to numerical information. Given that children highly value stickers and thus may be motivated to avoid losing them, they may want to rely on learned strategies that have proven successful for them in the past, such as verbal counting. Evidence in support of this finds that children use well-learned strategies like counting on their fingers when performing difficult addition problems (Siegler, 1987). Since whole number information is well-practiced, but proportional information in this context is quite novel for children in this age group, children may prefer the learned strategy of counting the number of red pieces, resulting in a greater whole number bias. In this case, number may be even more salient to them in the Loss condition, and as such, children may demonstrate both worse performance overall and greater whole number biases in the Loss condition.

We had three research questions. First, do whole number biases truly emerge over the course of early childhood, and if so, are these biases related to counting proficiency? Second, does motivational framing differentially impact proportional reasoning in general (as measured by performance on the continuous trials)? And last, does framing differentially impact children's attention to number in a proportional reasoning task (as measured by performance on discrete trials, where number is a salient feature)?

3. Methods

3.1. Participants

Three- to nine- year olds (N = 210, Age Range: 3.15 years – 9.92 years, $M_{age} = 5.7$ years, 117 females, 91 males, 2 unreported) from the greater Boston area were recruited to participate in this study. Children participated in the lab, or at various museums, schools, and after school programs. Ten additional children participated in the study, but were not included for the following reasons: program/experimenter error ($n = 2$), being uninterested in the task ($n = 1$), confused by instructions ($n = 2$), English not the primary language ($n = 4$), or out of age range ($n = 1$).

Given the possibility of age-related changes in proportional reasoning performance (see Hurst & Cordes, 2018a), we divided our sample into a younger age group (3-5 year olds, who were posited to not demonstrate a whole number bias) and an older age group (6-9 year olds). A priori calculations in G*Power (Faul et al., 2009) indicated a total sample size of 164 would be sufficient to detect a small to medium effect size (f =.15) requiring 0.9 power on the central analyses exploring whether framing and/or age group impacted the presence of a whole number bias. After data from 160 participants was collected, it was determined that we had an unequal distribution of children across the younger and older age groups, which compromised our ability to explore questions regarding the relation between counting proficiency and whole number biases. Thus, we collected additional data from the youngest age group in order to equate the size of the samples of older and younger children in our study. The final younger age sample provided us with sufficient

Table 1
Demographic Information for each Age Group.

Age Group	N	Mean Age (SD)	Gain Condition	Loss Condition
Younger Children	105	4.12 years (.74)	54	51
Older Children	105	7.28 years (1.03)	56	49

power (0.9) to detect a small to medium effect size (f =.15) in correlational analyses exploring the relation between counting proficiency and whole number biases. Table 1 provides demographic information for each age group separately.

3.2. Stimuli

Stimuli were modeled after Hurst and Cordes (2018a). The two cardboard spinners (one Discrete (i.e., broken up into pieces): Fig. 1 left, and one Continuous: Fig. 1 right) used for familiarization were identical to that of previous work and measured 15.6 cm in diameter.

On each trial of the computerized task, children saw two spinners that were a similar circular shape, but could not actually be spun. Identical to Hurst and Cordes (2018a), on each trial, the two spinners varied in proportion and physical size (small = 6.1 cm diameter, medium = 8.8 cm diameter, and large = 11.4 cm diameter) so that children could not use the total amount of red on the screen as a cue for responding. For example, children may compare a medium-sized spinner that had 2/6 red pieces to a small-sized spinner that had 4/8 red pieces. Like Hurst and Cordes (2018a), in each block of trials, there were four small-medium comparisons, two small-large comparisons, and two large-medium comparisons. The correct response appeared on the left and right side of the screen eight times (4 times/Block). A list of the comparisons is located in Table A1 in Appendix A. The proportional reasoning task had acceptable reliability (α =.775).

3.3. Procedure

Children were randomly assigned to either a Gain or Loss Condition. In order to familiarize children to the task, children in both conditions were first given three stickers and shown a physical discrete spinner made out of cardboard (Fig. 1, left). Then, the experimenter described how the spinner worked. In the *Gain* condition ($n = 110$), children were told if the spinner landed on red, they would win a sticker, but if the spinner landed on blue nothing would happen. In the *Loss* condition ($n = 100$), children were told if the spinner landed on blue, they would lose a sticker, but if the spinner landed on red nothing would happen (see Appendix B for the full script). To ensure children had learned the rules, the experimenter completed two practice trials in which they spun the spinner twice and asked children to identify the outcome. The experimenter corrected children if they did not accurately indicate the outcome, and gave (or took away) children's stickers based on the outcome of each spin and the child's condition.

After familiarization, children participated in a computerized proportional reasoning task on a 13-inch Mac laptop. During this task, two spinners were presented side by side and the child was asked which spinner they would use to get more stickers. Children pointed to the spinner they chose and the experimenter noted their response by pressing the designated keys on the keyboard. Because the spinners on the computer did not actually spin, children did not win or lose stickers during the computerized task (comparable to prior studies; e.g., Hurst & Cordes, 2018a). During the computerized comparison task, children completed two blocks (Discrete and Continuous, in that order). The Discrete Block involved eight trials in which the spinners were divided into equally-sized pieces that were either red or blue (e.g., 2 red pieces and 4 blue pieces; see Fig. 2). Furthermore, half of the Discrete trials were "counting consistent" (i.e., the spinner with the greater number of red pieces also had the greater proportion of red) and the other half were "counting misleading" (i.e., the spinner with the greater number of red pieces actually had the smaller proportion of red – and thus would be an incorrect choice; See Fig. 2). Counting consistent and misleading trials were randomly intermixed.

Following the Discrete block, children were then familiarized to the Continuous spinner (see Fig. 1, right) using the same procedure as that for the Discrete block. Children then participated in the Continuous Block that consisted of eight trials in which the spinners had only one red portion and only one blue section (i.e., the colors were not broken into discrete countable pieces, See Fig. 3). Given work suggesting that prior experience with continuous trials dampens the whole number bias by prompting children to use proportional, instead of numerical, strategies (Boyer & Levine, 2015; Hurst & Cordes, 2018a), we chose to always present Discrete trials first in order to maximize the likelihood of a whole number bias in our sample (and thus allow us to explore how framing impacts the whole number bias). This block of trials was included to ensure that participants were able to engage in proportional reasoning when numerical cues were unavailable. Following the proportional reasoning task, children and their parents were debriefed and children took home the stickers they received during familiarization as a prize.

After completing the proportional reasoning task, 3-4-year olds (n = 62)[1] completed the Give-N task (e.g., Le Corre & Carey, 2007; Wynn, 1990) to assess their number knowledge and counting proficiency. During this task, children were asked to place a certain number of small toy ducks into a "pond" (blue basket) across several trials. The researcher began by asking the child to place one duck in the pond, and once children responded, the researcher asked "Is that *one* duck?". If the child responded correctly, the researcher than asked the child to place 3 ducks in the pond on the next trial, and continued to increase the number of ducks requested by one on every trial (asking for 4, 5, and then 6 ducks) whenever the child responded correctly. If the child responded incorrectly on any trial, then the researcher asked the child to place one fewer duck in the pond on the next trial (e.g., if the child is unable to place 3 ducks in the pond correctly, then on the next trial, the researcher asked the child to place 2 ducks). This titration procedure continued until the child responded incorrectly on two trials of the same set size, or until the child was able to correctly place 6 ducks in the pond twice.

[1] Seven additional 4-year olds did not have useable Give-N data due to experimenter error ($n = 6$) or due to time constraints ($n = 1$). Eight 5 year olds also completed the Give-N task; however, since we intended to focus on 3 and 4 year olds' counting abilities, since they were more likely to be in the process of learning to count, the data from the eight 5-year olds has not been included on the analyses of counting proficiency. Results remain consistent if the data from these 5-year olds is included in the analysis.

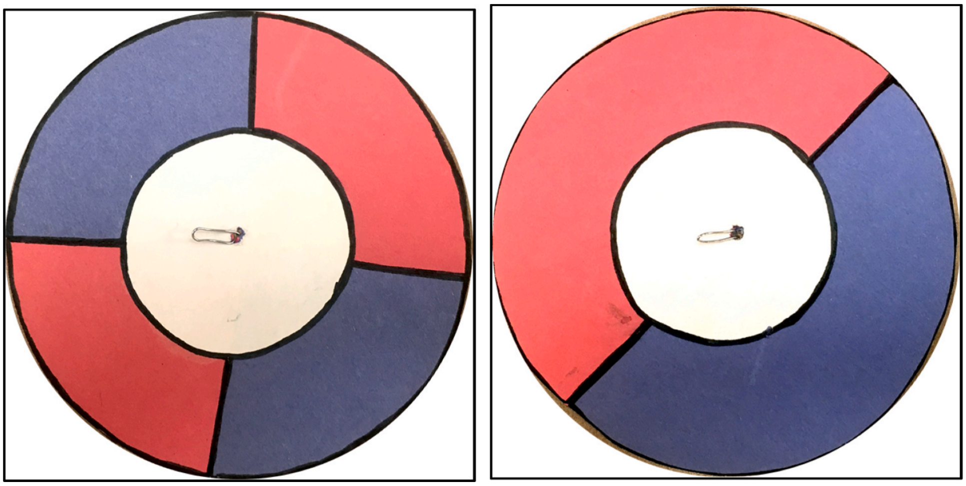

Fig. 1. Discrete (on left) and Continuous (on right) spinners used for familiarization.

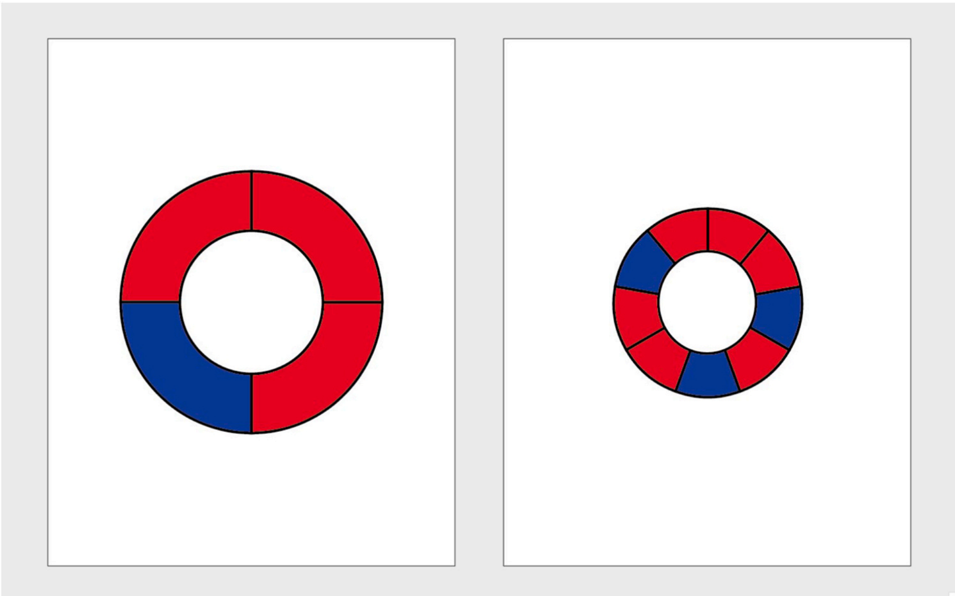

Fig. 2. Example of a counting misleading trial from the Discrete Block of the computerized proportional reasoning task. Whereas the spinner on the left would be more likely to land on red given a greater proportion of red ($3/4 > 6/9$), children more often indicate the spinner on the right is more likely to land on red because it has a greater absolute number of red pieces ($6 > 3$).

3.4. Dependent variables and data coding

Proportion correct in judging the spinner with the greater proportion of red was calculated separately for each block (Continuous versus Discrete) and within the discrete trials, for each trial type (Consistent versus Misleading) separately. For the Give-N task, children who answered correctly up to 5 or 6 were considered to be proficient counters (as Cardinal Principal Knowers, (CP-knowers)).

3.5. Data analysis

We calculated both frequentist statistics and Bayesian analyses in JASP (Version 0.16, JASP team, 2021) using default priors. For each analysis, we reported either BF_{01}, which compares the likelihood of the data under the null hypothesis to the alternative hypothesis, or BF_{10}, which compares the likelihood of the data under the alternative hypothesis to the null hypothesis. We report the Bayes Factor that is greater than one. The Bayes factors can be interpreted as follows: BF = 1 indicates no evidence, BF = 1-3 represents anecdotal evidence, BF = 3-10 represents substantial evidence, BF = 10-30 represents significant evidence, BF = 30-100 represents

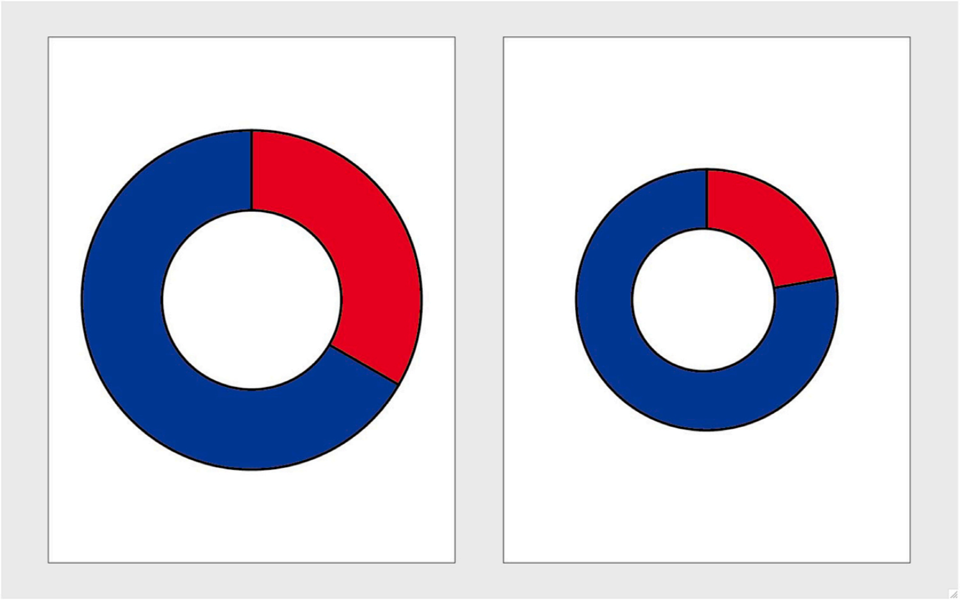

Fig. 3. A sample trial during the Continuous Block of the computerized proportional reasoning task.

very strong evidence, and BF > 100 represents decisive evidence (Wagenmakers et al., 2011). Thus, a BF_{01} of 12 would indicate that the data are 12 times more likely under the null model compared to the alternative, representing significant evidence. For the repeated measures ANOVAs, we indicate which model best fit the data.

4. Results

Children in both age groups performed significantly above chance (0.5) on the Continuous Trials (Younger Children: M =.57, SE =.02, t(104) = 3.52, p <.001, d =.34, BF_{10} = 32.70; Older Children: M =.84, SE =.02, t(104) = 15.64, p <.001, d = 1.53, BF_{10} = 7.51e+25) and the Discrete Trials (Younger Children: M =.56, SE =.02, t(104) = 2.83, p =.006, d =.28, BF_{10} = 4.61; Older Children: M =.73, SE =.02, t(104) = 10.20, p <.001, d =.995, BF_{10} = 2.36e+14).

4.1. Does framing impact pure proportional reasoning in the absence of whole number information?

First, we analyzed performance on the Continuous trials to determine whether the different framing conditions impacted attention to proportion on trials in which number could not interfere with performance. If (as predicted) the Loss framing increased motivation to avoid losing stickers, we would expect better performance on the Continuous trials in the Loss condition compared to the Gain condition. We conducted a univariate ANOVA with Condition (Gain, Loss) and Age Group (Older, Younger) as fixed factors on performance on the Continuous trials only. The analysis revealed a main effect of Age Group, F(1, 206) = 79.87, p <.001, η_p^2 =.28, and no

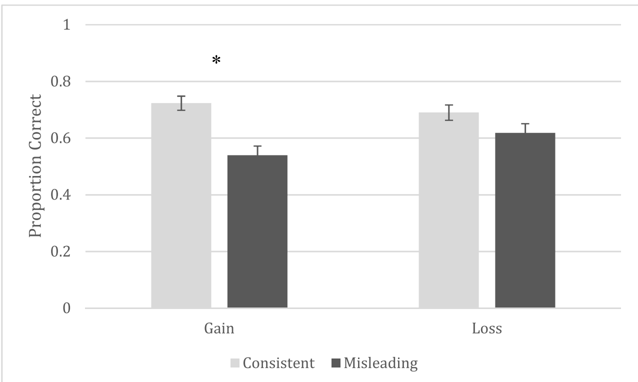

Fig. 4. Whole number biases (as demonstrated by better performance on discrete consistent compared to discrete misleading trials) were significantly greater in the Gain Condition than in the Loss condition.

other main effects or interactions (*p's* > .53). Not surprisingly, older children (M = .84, SE = .02) outperformed their younger counterparts (M = .57, SE = .02) in this pure proportional reasoning task. Framing did not appear to have any impact on performance on Continuous trials, such that children in the Gain (M = .70, SE = .03) and Loss (M = .71, SE = .03) conditions performed comparably, (t(208) = .39, p = .70, d = .05, BF_{01} = 6.19), with Bayesian analyses indicating substantial support in favor of the null model (i.e., no effect of Condition). The Bayesian ANOVA suggested that the model including Age Group best fit the data.

4.2. Does framing alter whole number biases?

To determine whether children's attention to proportion in the face of whole number information was impacted by gain or loss framing, we next performed analyses on performance on the Discrete trials exclusively. We conducted a repeated measures ANOVA exploring the impact of the within-subjects variable of Trial Type (Consistent, Misleading) and the between-subjects variables of Age Group (Younger, Older) and Condition (Gain, Loss) on performance in the Discrete Block of trials. Results revealed a main effect of Trial Type, $F(1, 206) = 23.31$, $p < .001$, $\eta_p^2 = .10$, such that performance was better on the Consistent (M = .71, SE = .02) compared to the Misleading trials (M = .58, SE = .02), consistent with a reliance upon whole number information in the display – a whole number bias (see Fig. 4). There was also a main effect of Age Group, $F(1, 206) = 33.30$, $p < .001$, $\eta_p^2 = .14$, such that older children (M = .73, SE = .02) outperformed younger children (M = .56, SE = .02). Lastly, there was a significant Condition x Trial Type interaction, $F(1, 206) = 4.24$, $p = .041$, $\eta_p^2 = .02$ and a marginal Age Group x Trial Type interaction, $F(1, 206) = 3.77$, $p = .053$, $\eta_p^2 = .02$. The Bayesian repeated measures ANOVA suggested that the model including Trial Type and Age Group best fit the data.

To follow-up on the significant Condition x Trial Type interaction, we conducted additional paired samples t-tests comparing performance on the misleading versus consistent trials in the Gain and Loss conditions separately. In the Gain condition, participants performed significantly better on the consistent trials (M = .72, SE = .03) compared to the misleading trials (M = .54, SE = .03, $t(109)$ = 4.93, $p < .001$, d = .47, BF_{10} = 4826.03), consistent with a whole number bias. In the Loss condition, participants performed comparably on the consistent (M = .69, SE = .03) and misleading trials (M = .62, SE = .03, $t(99)$ = 1.90, p = .060, d = .19, BF_{01} = 1.61; see Fig. 4). The Bayesian analyses thus show decisive support for a whole number bias in the Gain condition, but anecdotal evidence for the null hypothesis in the Loss condition. Consistent with the claim that the Loss condition led to less numerical interference on the discrete misleading trials, additional analyses revealed children in the Gain condition did not exceed chance levels of performance (.5) on the discrete misleading trials ($t(109)$ = 1.18, p > .23, d = .11, BF_{01} = 4.80), whereas children in the Loss condition performed above chance on these trials ($t(99)$ = 3.54, $p < .001$, d = .35, BF_{10} = 34.36).

Although the Age Group x Trial Type interaction was only marginal, given that our research question was to explore the development of whole number biases, we then compared performance on the consistent and misleading trials in each age group separately. The analysis revealed that both age groups performed better on the consistent compared to the misleading trials, showing evidence of a whole number bias (Younger Children: $M_{Consistent}$ = .60, $SE_{Consistent}$ = .02, $M_{Misleading}$ = .52, $SE_{Misleading}$ = .03, $t(104)$ = 2.12, p = .037, d = .21, BF_{01} = 1.09; Older Children: $M_{Consistent}$ = .82, $SE_{Consistent}$ = .02, $M_{Misleading}$ = .64, $SE_{Misleading}$ = .04, $t(104)$ = 4.77, $p < .001$, d = .47, BF_{10} = 2456.63; see Fig. 5). Replicating prior research, we do find a consistent whole number bias (better performance on consistent trials relative to misleading trials) in older children. Counter to prior research (Hurst & Cordes, 2019), the younger age group also performed significantly better on consistent trials compared to misleading trials – suggesting a reliance upon whole number information. However, the marginal interaction revealed a slightly smaller whole number bias in the younger children compared to the older children ($t(208)$ = 1.96, p = .051, d = .27, BF_{01} = 1.11).

4.3. Are whole number biases related to counting proficiency?

Finally, we explored whether children's whole number biases were related to their counting proficiency, as demonstrated on the Give-N task. Initial analyses revealed no significant correlations between children's knower-levels on the Give-N task and their performance on the discrete misleading trials (p > .9) or between knower-level and the difference in performance on discrete consistent

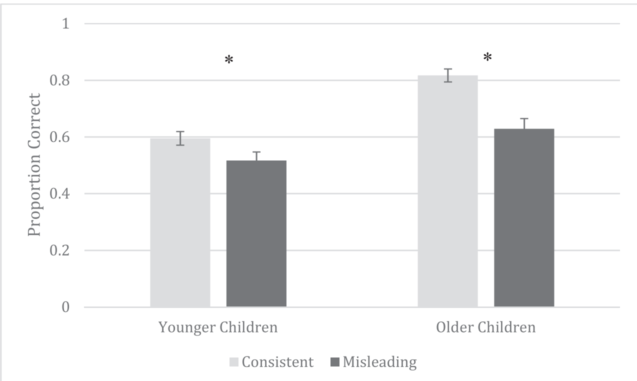

Fig. 5. Performance was significantly better on Consistent compared to Misleading trials for both age groups.

and discrete misleading trials (a measure of whole number bias; $p > .6$). Notably, despite including younger children than Hurst and Cordes (2019), the majority of our 3-4 year olds (49/62) were either 5- or 6- knowers (CP-knowers), demonstrating proficiency in counting. If a bias to attend to whole number information is driven by proficiency with the count routine, then children classified as CP-knowers would be expected to demonstrate a whole number bias in the spinner task. A paired samples t-test revealed that the subset of 3 and 4-year olds who were classified as proficient counters (CP-knowers) did *not* perform significantly better on discrete consistent trials compared to discrete misleading trials, $t(48) = 1.26$, $p > .21$, d =.18, $BF_{01} = 3.05$, indicating no whole number bias in this sample of proficient counters. Thus, the Bayesian analyses confirm that the data are 3.05 times more likely under the null hypothesis, providing anecdotal evidence in support of the conclusion that becoming a proficient counter alone does not explain the development of whole number biases in childhood.

5. Discussion

Despite the importance of proportional reasoning, children and adults alike struggle on these tasks. In particular, previous research has shown that older children have a whole number bias when performing proportional reasoning tasks, in which they prioritize discrete numerical information over proportional information (Boyer & Levine, 2015; Boyer et al., 2008; Braithwaite & Siegler, 2018; Jeong et al., 2007; Hurst & Cordes, 2018a). Given that children's performance on proportional reasoning tasks is susceptible to numerous factors (e.g., Hurst & Cordes, 2018a), we were interested in whether framing a proportional reasoning task in terms of gains or losses may increase children's performance through means of promoting either a prevention or promotion focus. Moreover, we aimed to investigate whether prior findings of a developmental trend in the prevalence of whole number biases would replicate in a new sample of children, and whether counting proficiency was related to the emergence of whole number biases in this younger sample.

5.1. The emergence of whole number biases across development

First, we explored children's proportional reasoning skills as a whole across early to middle childhood. Mimicking past research, our results revealed age related changes in proportional reasoning performance, such that older children outperformed younger children (Hurst & Cordes, 2018a; Fish et al., 2023; see also O'Grady & Xu, 2019). Despite age-related differences, results indicated that both age groups performed above chance on the Continuous block, suggesting that children of this age are capable of reasoning proportionally. Thus, while older children and adults may struggle with proportional reasoning, the basic ability to reason proportionally is present in early childhood.

Moreover, past literature on proportional reasoning has shown that a whole number bias likely emerges around age 6 (see Boyer et al., 2008; Hurst & Cordes, 2018a; Jeong et al., 2007). Counter to prior work, however, our results indicate that both younger (3-5 year olds) and older (6-9 year olds) children performed significantly better on the consistent compared to the misleading trials, exhibiting a whole number bias. There are many potential reasons why our data do not align with previous research. First, the majority of studies using the spinner task have focused on children 6 years and up (see Abreu-Mendoza et al., 2020; Boyer et al., 2008; Boyer & Levine, 2015; Jeong et al., 2007) and only one study thus far has included children under the age of 5 (see Hurst & Cordes, 2018a). Further studies including younger children are needed for understanding whether a whole number bias is present in younger children. Additionally, prior work demonstrated that the presence of a whole number bias was impacted by the order of trials presented, such that children who saw discrete trials first were more likely to show a whole number bias (Hurst & Cordes, 2018a). Given this finding, in the present study, we intentionally presented our participants with the discrete trials first to enhance the likelihood of a whole number bias. While Hurst and Cordes (2018a) did not find younger children to be susceptible to order effects, it is possible that our choice to present the discrete trials first contributed to the presence of a whole number bias in the younger age group in our study. Future research is needed for better understanding the effects of experiences on the development of whole number biases in young children. Lastly, it is important to note that although the analyses confirmed a whole number bias was present in performance of both age groups, the younger children did not perform above chance on the misleading trials. Moreover, the marginal Age group x Trial type interaction and Bayesian analyses indicated a marginally stronger whole number bias for older compared to younger children. Thus, it remains possible that the presence of a whole number bias is stronger in older compared to younger children. Our results add to the current literature demonstrating notable changes in proportional reasoning and attentional biases over development (e.g., Boyer et al., 2008; Hurst & Cordes, 2018a; Jeong et al., 2007). Future work should continue to explore the emergence of the whole number biases in the preschool years to determine exactly how early these biases emerge and whether their emergence is related to counting abilities.

Although we found evidence of a whole number bias in our younger age group, many reasons have been proposed as to why younger children previously have not shown a whole number bias in prior work (see Hurst & Cordes, 2018a). One possibility is that this bias appears once children become proficient counters. As children gain experience with counting, numerical information may become more salient to children, making children more likely to spontaneously focus on or attend to whole number information (see Hannula & Lehtinen, 2005; Hannula et al., 2007). To directly address this theory, in the present study, we administered a test of counting proficiency (Give-N) in addition to the proportional reasoning task to the youngest participants in order to determine whether counting abilities were related to the presence of a whole number bias. Notably, the majority of children given the counting assessment (approximately 80%) were identified as proficient counters (Cardinal-Principal Knowers in the Give-N task; Wynn, 1990). However, we found no evidence of a whole number bias in these proficient counters. Moreover, additional analyses revealed no correlation between a child's knower level and their performance on the disrcrete trials of the proportional reasoning task. Thus, our data suggest it is unlikely that counting proficiency alone determines the presence of a whole number bias.

An alternative explanation, however, is that experience with formal schooling in our sample may provide a greater emphasis on whole number information, making this topic somewhat overlearned in young school-aged children. While we did not gather information about the schooling of children in our sample, it is notable that most of our preschool participants were recruited from local preschools where whole number information may already be emphasized. Future research is necessary for investigating whether formal education corresponds with the emergence of the whole number bias. However, it should be noted that there is some evidence of whole number biases in adults of cultures without formal educational systems (Alonso-Diaz et al., 2019), suggesting extensive experience with whole number information either in or out of the classroom may drive these biases. In fact, some evidence suggests that even preverbal infants are particularly tuned to number, even moreso than other continuous quantities (e.g., Brannon et al., 2004; Cordes & Brannon, 2009; Libertus et al., 2013), suggesting the possibility that whole number biases may be present very early in development due to innate biases. Regardless, given the important implications of the whole number bias for proportional reasoning, future research should explore whether whole number biases are present even earlier in development or if introducing proportional reasoning earlier in schooling may mitigate the emergence of whole number biases.

5.2. The effect of framing

In addition to replicating previous research on whole number biases, we were also interested in whether framing the task in terms of gains or losses would impact children's proportional reasoning performance. Because research suggests that we are better at remembering negative information (e.g., Kensinger et al., 2007) and loss framing has been shown to increase motivation (e.g., Ngo et al., 2019) and induce a prevention focus (see Higgins, 1998), we were particularly interested in how children would perform in the Loss condition. While few studies have tested the effects of framing in children, we predicted that the Loss condition would either 1) increase performance by inducing a prevention focus, or 2) cause children to use overlearned counting strategies leading to worse performance on the proportional reasoning task. Overall, our results indicated that those in the Gain condition showed the traditional whole number bias. Children assigned to the Loss condition, however, performed only marginally better on the consistent compared to the misleading trials. Most notably, whereas children in the Gain condition did not perform better than chance on trials in which whole number conflicted with proportional reasoning, children in the Loss condition performed significantly better than chance on these discrete misleading trials. This finding was unique to the discrete trials, as children in the Gain and Loss conditions performed comparably on the continuous trials. Thus, the framing did not impact proportional reasoning overall; it specifically impacted the presence of a whole number bias in the Loss condition. This finding is in line with our first prediction, suggesting that the Loss framing likely induced a prevention focus leading to increased attention to proportional information and a reduced whole number bias.

This finding aligns with past literature showing that adults with a prevention focus outperform adults with a promotion focus (e.g., Förster et al., 2003; Miele et al., 2009; Rosenzweig & Miele, 2016). In particular, adults with a prevention focus tend to approach tasks more analytically. To approach this task more analytically, children should have focused on the *relationship* between the number of red and blue pieces, instead of the absolute number of winning red pieces. If children in the Loss condition did this, they would have been less likely to rely upon discrete numerical information on the misleading trials, revealing less of a whole number bias. These findings also align with the dynamic strategy choice account (Alibali & Sidney, 2015). This account argues that people can implicitly implement a variety of strategies when comparing magnitudes of fractions, including intuitive strategies (i.e., more automatic and retrieval based – such as focusing on the entire spinner to determine relative amount) and analytical strategies (i.e., more effortful – including overlearned strategies such as counting in this case). Importantly, our findings suggest that those in the Loss condition, who did not show a whole number bias, seem to be using more intuititive or automatic strategies, rather than more effortful, analytical ones.

Relatedly, work shows that children who are better at inhibition perform better on the discrete trials of proportional reasoning tasks (Abreu-Mendoza et al., 2020). The loss framing may have increased inhibition by encouraging children to approach the task more analytically. While we predicted that the loss framing may increase motivation, shift attention, and/or promote inhibition, which would lead to better performance, we did not directly measure motivation or strategy use in our sample. Future work investigating how motivated children are during the task and/or the strategies children invoke may be useful for exploring this possibility.

Not only do our results demonstrate the effect of framing on proportional reasoning, this study also adds to current literature showing that young children are susceptible to gain-loss framing. While some work suggests children as young as 4 and 5 are impacted by the way in which a task is framed (Levin & Hart, 2003; Ngo et al., 2019; Schlottmann & Tring, 2005), other studies have suggested that framing does not affect performance in younger children (see Reyna & Ellis, 1994). Our study indicates that even our youngest participants were affected by the framing of the task. That is, to simply perform at above chance levels, children had to understand the condition-specific instructions which involved understanding the framing of the task. If children in the Loss condition did not understand that they would *lose* stickers when they landed on blue, they would not have performed above chance on the task. Similarly, if children in the Gain condition did not understand that landing on red would *win* them stickers, they would not have been successful on the task. Children in both conditions performed above chance on the continuous trials, thus indicating that children were aware of the framing and that our manipulation was effective.

Additionally, much of the work on framing in adults has dealt with emotionally laden situations. For example, many studies have used tasks that involve winning/losing money (see Mikels & Reed, 2009; Smith & Levin, 1996 Study 1) or medical decision making, which is oftentimes emotional (see Almashat et al., 2008; Cormier O'Connor et al., 1985; Malloy et al., 1992; Marteau, 1989; Moxey et al., 2003; Smith & Levin, 1996 Study 2). Whether our manipulation – potentially winning or losing stickers – similarly evoked emotional reactions in our sample is unknown. Future work should explore whether winning/losing stickers evokes similar emotions in children to winning/losing money in adults. Moreover, this work could explore whether children are more susceptible to the effects of framing in emotionally-laden situations. Lastly, it is important to note that the gain-loss framing used in the present study is not identical to the gain-loss framing used in research with adults. In particular, the two conditions in the present study did not hold the same expected values during our familiarization trials. Notably, children in both conditions started with 3 stickers; however, those in the Gain condition were given the opportunity to win stickers, while those in the Loss condition lost stickers, making the expected number of stickers at the end of the familiarization trials different between the two conditions. It should be noted that the test trials did not involve winning or losing any actual stickers – just selecting the spinner they would prefer to spin – making it unlikely that the differences in the familiarization trials impacted our results. However, future work should be careful to ensure that all trials in the gain and loss conditions have similar expected values.

In conclusion, we replicate previous evidence of a whole number bias during proportional reasoning tasks in 6-9-year-old children (Hurst & Cordes, 2018a). Younger children (3-5 year olds) also showed evidence of a similar, yet weaker bias. Importantly, the proficient counters in our sample did not show a whole number bias, suggesting this bias may emerge from another aspect of development; potentially children's increasing experience with formal schooling that makes number a salient cue during proportional reasoning tasks (see also Hurst & Cordes, 2018a). Finally, we found evidence that framing a task in terms of losses weakened the presence of a whole number bias, extending past work demonstrating that framing impacts children's performance on complex math tasks. Given that this is the first study of its kind to investigate how framing may impact proportional reasoning, we believe that the use of gain or loss framing to motivate children's success on challenging math tasks remains a relevant topic of investigation.

Data availability

The data that support the findings of this study are available through the Open Science Framework: https://osf.io/8cg4m/?view_only=f3598d9111584187a1e9cb035980c808.

Acknowledgements

This study was supported by NSF Award 1920725 to S.C. The authors would like to thank Carolyn Patterson and Alyson Wong for their assistance with data collection.

Appendix A. Description of trials

Table A1
Proportion comparisons for the computer task.

Discrete Trials		
Left Stimulus	**Right Stimulus**	**Trial Type**
5/10	4/5	Misleading
3/4	6/9	Misleading
2/4	3/9	Misleading
4/10	2/3	Misleading
4/8	2/6	Consistent
6/8	2/3	Consistent
4/8	8/10	Consistent
2/5	6/9	Consistent
Continuous Trials		
Left Stimulus	**Right Stimulus**	
5/10	4/5	
5/7	8/9	
4/9	1/5	
1/3	2/9	
3/6	5/8	
2/6	5/8	
3/5	4/9	
2/3	3/9	

Appendix B. Protocol script

Gain Condition

"Today we are going to play a game with this spinner! I'm going to give you some stickers, we'll put them here." [Researcher gives child 3 stickers]. "Now, I'm going to spin this spinner and if it lands on red, you win a sticker, but if it lands on blue nothing happens." [Researcher spins the spinner]. "Ok, it landed here. What does that mean?" [Reseacher allows child to respond, corrects them if they are incorrect, and completes the action of giving a sticker to the child if it landed on red, or doing nothing if it landed on blue. This practice trial occurs twice. After practice trials are complete, the researcher moves the stickers to the side for the child to take home later].

"Now we're going to see more spinners. Your job is to pick the spinner that will get you more stickers. Remember, if the spinner lands on red, you win a sticker. If the spinner lands on blue, nothing happens."

Loss Condition

"Today we are going to play a game with this spinner! I'm going to give you some stickers, we'll put them here." [Researcher gives child 3 stickers]. "Now, I'm going to spin this spinner and if it lands on blue, you lose a sticker, but if it lands on red nothing happens." [Researcher spins the spinner]. "Ok, it landed here. What does that mean?" [Reseacher allows child to respond, corrects them if they are incorrect, and completes the action of taking a sticker away from the child if it landed on blue, or doing nothing if it landed on red. This practice trial occurs twice. After practice trials are complete, the researcher moves the stickers to the side for the child to take home later].

"Now we're going to see more spinners. Your job is to pick the spinner that will get you more stickers. Remember, if the spinner lands on blue, you lose a sticker. If the spinner lands on red, nothing happens."

References

Abreu-Mendoza, R. A., Coulanges, L., Ali, K., Powell, A. B., & Rosenberg-Lee, M. (2020). Children's discrete proportional reasoning is related to inhibitory control and enhanced by priming continuous representations. *Journal of Experimental Child Psychology, 199*, Article 104931.

Alibali, M. W., & Sidney, P. G. (2015). Variability in the natural number bias: who, when, how, and why. *Learning and Instruction, 37*, 56–61.

Almashat, S., Ayotte, B., Edelstein, B., & Margrett, J. (2008). Framing effect debiasing in medical decision making. *Patient education and counseling, 71*(1), 102–107.

Bookbinder, S. H., & Brainerd, C. J. (2017). Emotionally negative pictures enhance gist memory. *Emotion, 17*(1), 102.

Booth, J. L., & Newton, K. J. (2012). Fractions: Could they really be the gatekeeper's doorman? *Contemporary Educational Psychology, 37*(4), 247–253.

Boutlet, G. (1998). Didactical implications of children's difficulties in learning the fraction concept. *Focus on Learning Problems in Mathematics, 20*(4), 19–34.

Boyer, T., & Levine, S. (2015). Prompting children to reason proportionally: Processing discrete units as continuous amounts. *Developmental Psychology, 51*(5), 615–620.

Boyer, T., Levine, S., & Huttenlocher, J. (2008). Development of proportional reasoning: Where young children go wrong. *Developmental Psychology, 44*(5), 1478–1490.

Braithwaite, D. W., & Siegler, R. S. (2018). Developmental changes in the whole number bias. *Developmental Science, 21*(2), Article e12541.

Brannon, E. M., Abbott, S., & Lutz, D. J. (2004). Number bias for the discrimination of large visual sets in infancy. *Cognition, 93*, B59–B68.

Cordes, S., & Brannon, E. M. (2009). The relative salience of discrete and continuous quantities in young infants. *Developmental Science, 12*(3), 453–463.

Cormier O'Connor, A. M., Boyd, N. F., Tritchler, D. L., Kriukov, Y., Sutherland, H., & Till, J. E. (1985). Eliciting preferences for alternative cancer drug treatments: The influence of framing, medium, and rater variables. *Medical Decision Making, 5*(4), 453–463.

De Wolf, M., & Vosniadou, S. (2015). The representation of fraction magnitude and the whole number bias reconsidered. *Learning and Instruction, 37*, 39–49.

Denison, S., & Xu, F. (2014). The origins of probabilistic inference in human infants. *Cognition, 130*(3), 335–347.

DeWolf, M., Bassok, M., & Holyoak, K. J. (2015). From rational numbers to algebra: Separable contributions of decimal magnitude and relational understanding of fractions. *Journal of experimental child psychology, 133*, 72–84.

DeWolf, M., Grounds, M. A., Bassok, M., & Holyoak, K. J. (2014). Magnitude comparison with different types of rational numbers. *Journal of Experimental Psychology: Human Perception and Performance, 40*(1), 71.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G* Power 3.1: tests for correlation and regression analyses. *Behavior Research Methods, 41*(4), 1149–1160.

Fish, L. R., Hildebrand, L., Chernyak, N., & Cordes, S. (2023). Who's the winner? Children's math learning in competitive and collaborative scenarios. *Child Development*.

Förster, J., Higgins, E. T., & Bianco, A. T. (2003). Speed/accuracy decisions in task performance: built-in trade-offs or separate strategic concerns? *Organizational Behavior and Human Decision Processes, 90*, 148–164.

Hannula, M. M., & Lehtinen, E. (2005). Spontaneous focusing on numerosity and mathematical skills of young children. *Learning and Instruction, 15*, 237–256.

Hannula, M. M., Räsänen, P., & Lehtinen, E. (2007). Development of counting skills: Role of spontaneous focusing on numerosity and subitizing-based enumeration. *Mathematical Thinking and Learning, 9*(1), 51–57.

Higgins, E. T. (1998). Promotion and prevention: regulatory focus as a motivational principle. In *In Advances in experimental social psychology* (Vol. 30, pp. 1–46). Academic Press.

Hurst, M. A., & Cordes, S. (2018a). Attending to relations: Proportional reasoning in 3-to 6- year-old children. *Developmental psychology, 54*(3), 428.

Hurst, M. A., & Cordes, S. (2018b). Children's understanding of fraction and decimal symbols and the notation-specific relation to pre-algebra ability. *Journal of Experimental Child Psychology, 168*, 32–48.

Hurst, M. A., & Cordes, S. (2019). Talking about proportion: Fraction labels impact numerical interference in non-symbolic proportional reasoning. *Developmental Science, 22*(4), Article e12790.

Hurst, M. A., Wong, A., Gordon, R., Alam, A., & Cordes, S. (2022). Children's gesture use provides insight into proportional reasoning strategies. *Journal of Experimental Child Psychology, 214*, Article 105277.

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.

Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica, 47*(2), 263–291.

Kensinger, E. A. (2007). Negative emotion enhances memory accuracy: Behavioral and neuroimaging evidence. *Current Directions in Psychological Science, 16*(4), 213–218.

Kensinger, E. A., & Corkin, S. (2003). Memory enhancement for emotional words: Are emotional words more vividly remembered than neutral words? *Memory & cognition, 31*(8), 1169–1180.

Kensinger, E. A., Garoff-Eaton, R. J., & Schacter, D. L. (2007). Effects of emotion on memory specificity in young and older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 62*, 209–215. https://doi.org/10.1093/geronb/62.4.P208

Lamon, S. J. (1993). Ratio and proportion: Connecting content and children's thinking. *Journal for research in mathematics education*, 41–61.

Le Corre, M., & Carey, S. (2007). One, two, three, four, nothing more: An investigation of the conceptual sources of the verbal counting principles. *Cognition, 105*(2), 395–438.

Levin, I. P., & Hart, S. S. (2003). Risk preferences in young children: Early evidence of individual differences in reaction to potential gains and losses. *Journal of Behavioral Decision Making, 16*(5), 397–413.

Levin, I. P., Hart, S. S., Weller, J. A., & Harshman, L. A. (2007). Stability of choices in a risky decision-making task: a 3-year longitudinal study with children and adults. *Journal of Behavioral Decision Making, 20*(3), 241–252.

Libertus, M. E., Starr, A., & Brannon, E. M. (2013). Number trumps area for 7-month old infants. *Developmental Psychology, 50*, 1.

Malloy, T. R., Wigton, R. S., Meeske, J., & Tape, T. G. (1992). The influence of treatment descriptions on advance medical directive decisions. *Journal of the American Geriatrics Society, 40*(12), 1255–1260.
Marteau, T. M. (1989). Framing of information: Its influence upon decisions of doctors and patients. *British Journal of Social Psychology, 28*(1), 89–94.
Mazzocco, M. M., & Devlin, K. T. (2008). Parts and 'holes': Gaps in rational number sense among children with vs. without mathematical learning disabilities. *Developmental Science, 11*(5), 681–691.
McCrink, K., & Wynn, K. (2007). Ratio abstraction by 6-month-old infants. *Psychological science, 18*(8), 740–745.
Miele, D. B., Molden, D. C., & Gardner, W. L. (2009). Motivated comprehension regulation: Vigilant versus eager metacognitive control. *Memory & Cognition, 37*(6), 779–795.
Mikels, J. A., & Reed, A. E. (2009). Monetary losses do not loom large in later life: Age differences in the framing effect. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 64*(4), 457–460.
Moxey, A., O'Connell, D., McGettigan, P., & Henry, D. (2003). Describing treatment effects to patients: How they are expressed makes a difference. *Journal of General Internal Medicine, 18*(11), 948–959.
Ngo, C. T., Newcombe, N. S., & Olson, I. R. (2019). Gain-loss framing enhances mnemonic discrimination in preschoolers. *Child development, 90*(5), 1569–1578.
Ni, Y., & Zhou, Y. D. (2005). Teaching and learning fraction and rational numbers: The origins and implications of whole number bias. *Educational Psychologist, 40*(1), 27–52.
O'Grady, S., & Xu, F. (2019). The development of nonsymbolic probability judgments in children. *Child development*.
Resnick, I., Jordan, N. C., Hansen, N., Rajan, V., Rodrigues, J., Siegler, R. S., & Fuchs, L. S. (2016). Developmental growth trajectories in understanding of fraction magnitude from fourth through sixth grade. *Developmental Psychology, 52*(5), 746.
Reyna, V. F., & Ellis, S. C. (1994). Fuzzy-trace theory and framing effects in children's risky decision making. *Psychological Science, 5*(5), 275–279.
Rosenzweig, E. Q., & Miele, D. B. (2016). Do you have an opportunity or an obligation to score well? The influence of regulatory focus on academic test performance. *Learning and Individual Differences, 45*, 114–127.
S. Alonso-Diaz J.F. Cantlon S.T. Piantadosi Intrinsic whole number bias in an indigenous populaton Proceedings of the 41st Annual Meeting of the Cognitive Science Society. Montreal, QC, Canada: Cognitive Science Society 2019.
Sadler, P. M., & Tai, R. H. (2007). Advanced placement exam scores as a predictor of performance in introductory college biology, chemistry and physics courses. *Science Educator, 16*(2), 1–19.
Schlottmann, A., & Tring, J. (2005). How children reason about gains and losses: Framing effects in judgement and choice. *Swiss Journal of Psychology, 64*(3), 153–171.
Siegler, R. S. (1987). The perils of averaging data over strategies: An example from children's addition. *Journal of Experimental Psychology: General, 116*(3), 250.
Siegler, R. S., Duncan, G. J., Davis-Kean, P. E., Duckworth, K., Claessens, A., Engel, M., & Chen, M. (2012). Early predictors of high school mathematics achievement. *Psychological science, 23*(7), 691–697.
Smith, S. M., & Levin, I. P. (1996). Need for cognition and choice framing effects. *Journal of Behavioral Decision Making, 9*(4), 283–290.
Sternberg, R. J., Grigorenko, E. L., & Zhang, L. (2008). Styles of learning and thinking matter in instruction and assessment. *Perspectives on Psychological Science, 3*, 486–506.
Trzcińska, A., Sekścińska, K., & Maison, D. (2021). The role of self-control and regulatory foci in money-saving behaviours among children. *Current Psychology, 40*, 344–354.
Tversky & Kahneman. (1981). The framing of decisions and the psychology of choice. *Science, 211*, 452–458.
Wagenmakers, E.-J., Wetzels, R., Borsboom, D., & van der Maas, H. L. J. (2011). Why psychologists must change the way they analyze their data: The case of psi: Comment on Bem (2011). *Journal of Personality and Social Psychology, 100*(3), 426–432. https://doi.org/10.1037/a0022790
Wynn, K. (1990). Children's understanding of counting. *Cognition, 36*(2), 155–193.