Boundary Conditions for the Positive Skew Bias

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Abstract

Gambles that involve a large but unlikely gain coupled with a small but likely loss – like purchasing a lottery ticket or insurance – are positively-skewed. Positively-skewed gambles are preferred by people. Here we attempt to better understand when people are more drawn towards positively-skewed outcomes. For instance, animal research suggests that there may be a greater preference for more strongly-skewed options. Here we explore if this trend extends to humans. In two online studies (Study 1: $n = 209$; Study 2: $n = 210$), healthy participants between the ages of 22 and 85 made choices between a positively-skewed gamble and either a certain outcome (Study 1) or a symmetric gamble (Study 2). After making their choices, participants were queried about their decision-making strategy, affective status, cognitive abilities, and real-world financial decision making. Logistic regression analyses revealed that people were more likely to accept moderately- and strongly-skewed gambles over equivalent certain outcomes (Study1), but they less likely to accept moderately- and strongly-skewed gambles over equivalent symmetric gambles (Study 2). Exploratory analyses revealed that participants who were more likely to accept skewed gambles endorsed an affective strategy (Study 1) and reported experiencing higher arousal (Study 2). Participants in both studies with stronger cognitive abilities were less likely to accept skewed gambles. Collectively, these results suggest greater preference for more strongly positively-skewed gambles is (1) limited to potential gains and (2) more common when choosing between a skewed option and a certain outcome.

Keywords: decision making, risk taking, skew, strategy

Word count: 5349

Boundary Conditions for the Positive Skew Bias

Real-world decisions often involve uncertainty. Choosing a romantic partner, undergoing minor surgery, or investing in the stock market all involve a degree of risk, or uncertainty about the probability of a specific outcome. When economists, psychologists, and neuroscientists study risky decision making, they often focus on the mean (or expected value) and variance (or risk) associated with specific outcomes (Knutson & Huettel, 2015), while little attention given to the skewness, or asymmetry in the distribution of potential outcomes. However, skewed risks are common in real life and recently researchers have begun to examine the influence of skew on risky decision making (Åstebro, Mata, & Santos-Pinto, 2015; Burke & Tobler, 2011; Spiliopoulos & Hertwig, 2015; Symmonds, Wright, Bach, & Dolan, 2011; Wright, Symmonds, & Dolan, 2013; Wu, Bossaerts, & Knutson, 2011).

Skewed risks are scenarios where a large but unlikely outcome is coupled with a small but more likely outcome. Positively-skewed gambles thus involve a large but unlikely gain coupled with a small but likely loss - like purchasing auto insurance. While there is a small chance you will need insurance to pay for a costly repair, it is more likely you will lose your premium. Negatively-skewed gambles, on the other hand, involve a large but unlikely loss coupled with a small but likely gain - like undergoing a minor medical procedure. While there is a small chance something could go wrong, leading to disability or death, most likely the patient will see a small improvement in health. Researchers have discovered that people tend to prefer positively-skewed gambles and display positive arousal when considering positively-skewed gambles (Wu et al., 2011). This tendency to prefer positively-skewed gambles seems to become more exacerbated with age (Seaman, Green, Shu, & Samanez-Larkin, 2018; Seaman, Leong, Wu, Knutson, & Samanez-Larkin, 2017).

There are a number of limitations of the current research on skewed risk taking. For instance, the research in older adults has been restricted to the three specific stimuli used in our prior studies (Seaman et al., 2018, 2017). This is problematic because only one level of skewness ($= 1.25$) has been tested. Research in non-human primates suggests that there

may be a greater preference for more strongly-skewed options (Strait & Hayden, 2013). Is this also true for humans? How skewed does a gamble need to be in order to be preferred?

The studies reported here examine how the positive-skew bias generalizes beyond the specific circumstances investigated. Specifically, we examine how various levels of skewness in risky gambles and types of offers made influence the positive-skew bias (as measured by differential acceptance rates). This will allow us to determine the conditions under which individuals are drawn to positively-skewed gambles. In Study 1, participants chose between a certain outcome and a skewed gamble. Participants in Study 2 chose between a symmetric and a skewed gamble. We predict that the positive-skew bias will increase with greater skewness in both certain (Study 1) and uncertain (Study 2) conditions. Further, we wanted to examine how the age-related positive-skew bias observed in our previous studies (Seaman et al., 2018, 2017) is impacted by these different levels of skewness. We predict that the positive-skew bias will increase with age and that this bias will become more pronounced with higher degrees of skewness. Our exploratory goals were to better understand the how strategies and abilities influence skewed decision making and how this lab-based measure of skewed decision making relates to real-world decision making. Within each study, we examined how the positive-skew bias related to: (1) self-reported decision strategies, (2) affective state, (3) numeracy and graph literacy, and (4) real-world investment and fraud decisions.

Experiment 1: Certain Outcome vs Risky Gambles

Methods

Participants

Two hundred nine ($M_{age} = 53.64$, $SD_{age} = 17.16$, Range = 22 - 85) participants were recruited for an online study using Qualtrics Panels; survey files are available on the Open Science Framework (OSF; <https://osf.io/d56b2/>). Screening questions were used to exclude people with a history of psychiatric/neurological illness or prior head injury. Age and gender

quotas were used to ensure the sample included equal numbers of men and women in each age decade. After completing a brief demographic survey, participants viewed instructions for the Skewed Gambling Task and completed three practice questions. Then the participants completed the brief skewed Gambling Task described below. After completing the task, participants were asked a series of questions about the strategies implemented during the task. Then they completed a series of questionnaires about bad investments, fraud, their affective state, and their cognitive abilities. The Duke University Institutional Review Board approved all experimental procedures.

Skewed Gambling Task

During the skewed gambling task, participants chose between a certain outcome (Figure 1a) and a skewed gamble (Figure 1b). Gambles did not play out and the participants received no feedback about their choices. Choices were hypothetical; the task was not incentive compatible in that participants were not paid according to their choices.

Skewed gambles varied systematically in the degree of skewness on each trial, spanning from maximum uncertainty (50/50 gamble) to certainty (100% win) in 5% increments (variance = 500, skewness = 0 to ± 46169). Thus, the stimulus set included 9 positively-skewed gambles for 5 expected values ($-5, -0.5, 0, 0.5, 5$) for a total of 45 distinct gambles. These stimulus values were preregistered with a detailed stimulus spreadsheet on OSF (<https://osf.io/vwhxb>).

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114 Post-Task Strategy Questionnaire

115 We designed a series of post-task questions to probe the self-reported decision
 116 strategies that participants used while making their decisions. The following statements used
 117 a 5-point Likert scale ranging from 1: "Strongly Disagree" to 5: "Strongly Agree". The first
 118 two statements were taken from an existing study (Figner, Mackinlay, Wilkening, & Weber,
 119 2009) to assess the overall strategy used by participants. Next, we asked four questions that
 120 were designed to examine what kind of information participants believed influenced their
 121 behavior, specifically valence (potential win or loss) or information type (monetary amount
 122 or probability).

Strategy	Item
affect-based	"I solved the task on a gut level."
deliberative-based	"I tried to solve the task mathematically."
win amount	"I tried to solve the task by focusing on how much money I could win."
loss amount	"I tried to solve the task by focusing on how much money I could lose."
win probability	"I tried to solve the task by focusing on how likely it was that I would win."
loss probability	"I tried to solve the task by focusing on how likely it was that I would win."

Modifications to Preregistration

In addition to the 45 positively-skewed gambles described above, the preregistration also included 45 negatively-skewed gambles, for a total of 90 trials overall. Pilot testing revealed that with 90 trials, many participants were responding randomly and dropping out of the study. Thus, we decided reduce the length of the the survey by eliminating the negatively-skewed gambles and having participants respond to the 9 levels of skewness for only one of the five expected values. Effectively, this changed the expected value manipulation from a *within-subjects* to a *between-subjects* manipulation. We also added two catch trials, or trials where one of the options was substantially better than the other option. These catch trials were used as additional screeners; participants who answered either question incorrectly were eliminated from the sample. We also removed the Future Time Perspectives and Emotional Regulation Questionnaires from the study to reduce the number of items in the study.

Data analysis

We used R (Version 3.6.1; R Core Team, 2019) for all our analyses; data and code are available on OSF (<https://osf.io/d56b2/>). Multilevel binary logistic regressions were carried out using the lme4 package in r. The following models were used to examine the effect of skewness (varied within-subjects; three degrees of skewness (weak, moderate, strong)

compared to symmetric gambles), valence (varied within-subjects; gain and loss compared to neutral), magnitude (varied between-subjects; expected values of \$0.5 and \$5 compared to \$0), the interaction between valence and magnitude (varied between-subjects; gain-\$0.5, gain-\$5, loss-\$0.5, and loss-\$5 compared to \$0), and age (varied between-subjects as a continuous variable) on gamble acceptance:

Baseline Model.

$$ACCEPT = b_{0j} + b_{1j}(skewness) + e_{ij}$$

$$b_{0j} = \beta_{00} + u_{0j}$$

Model 1.

$$ACCEPT = b_{0j} + b_{1j}(skewness) + b_{2j}(valence) + b_{3j}(skewness * valence) + e_{ij}$$

$$b_{0j} = \beta_{00} + u_{0j}$$

Model 2.

$$ACCEPT = b_{0j} + b_{1j}(skewness) + b_{2j}(magnitude) + b_{3j}(skewness * magnitude) + e_{ij}$$

$$b_{0j} = \beta_{00} + u_{0j}$$

Model 3.

$$ACCEPT = b_{0j} + b_{1j}(skewness) + b_{2j}(valence * magnitude) + b_{3j}(skewness * valence * magnitude) + e_{ij}$$

$$b_{0j} = \beta_{00} + u_{0j}$$

Model 4.

$$ACCEPT = b_{0j} + b_{1j}(skewness) + b_{2j}(valence * magnitude) + b_{3j}(skewness * valence * magnitude) + b_{4j}(age) + e_{ij}$$

$$b_{0j} = \beta_{00} + u_{0j}$$

Next, we examined individual differences and how these impacted acceptance of skewed gambles. To do this, we calculated an individual difference measure of the positive skew bias by adding up the number of times the participant accepted a skewed gamble. This measure varied for 0 (no bias) to 9 (strong bias). We then tested whether our measures of strategy, emotional state, cognitive ability, or real-world decision making related to positive-skew bias.

Results

Skewed Gamble Acceptance

As predicted, there was a main effect of degree of skew (Figure 2; Baseline Model, Table 1), with an increased acceptance of moderately- and strongly-skewed gambles over symmetric gambles (moderately-skewed: $t(208) = -2.95$, $p = 0.004$; strongly-skewed: $t(208) = -4.19$, $p < .001$). We next tested if valence moderated this effect by adding valence and its interactions to the baseline model (Model 1, Table 1). Adding these predictors significantly improved model fit, $\chi^2(8, N = 209) = 29.23$, $p < .001$. In particular, people were not more

likely to accept moderately- and strongly-skewed gambles if those gambles were in the loss domain (moderately-skewed: $t(81) = -0.82$, $p = 0.413$, strongly-skewed: $t(81) = -0.89$, $p = 0.377$). We also tested if magnitude moderated the the degree of skew by adding magnitude and its interactions to the baseline model (Model 2, Table 1). Adding these predictors also significantly improved model fit, $\chi^2(8, N = 209) = 24.60$, $p = 0.002$. People were not more likely to accept moderately- and strongly-skewed gambles if these gambles were for large magnitudes (expected value = \$5; (moderately-skewed: $t(82) = 1.03$, $p = 0.305$, strongly-skewed: $t(82) = -0.39$, $p = 0.698$).

Becausse valence and magnitude were not completely orthogonal in this design, we created a factor that included both magnitude and valence (magval) and added this to the baseline model (Model 3, Table 1). Adding this interaction factor significantly improve model fit, $\chi^2(16, N = 209) = 54.66$, $p < .001$. In contrast to the prevailing trend of people accepting skewed gambles over symmetric gambles, people were not more likely to accept skewed gambles when they were for large losses (expected value = -\$5; Model 3, Table 2; moderately-skewed: $t(37) = 1.31$, $p = 0.198$, strongly-skewed: $t(37) = 1.90$, $p = 0.065$). Also, compared to conditions that showed an increased acceptance of gambles with increased skewness (expected value = -\$0.50, \$0, or +\$0.50), in the expected value = +\$5 condition people were not more likely to accept moderatly-skewed gambles than symmetric gambles ($t(44) = 0.26$, $p = 0.793$), and there was a nonsignificant trend towards being more likely to accept strongly-skewed gambles than symmetric gambles ($t(44) = -1.91$, $p = 0.063$). Thus, consistent with our first hypothesis, there was a pattern of increased acceptance of gambles with greater skewness in all but the large loss condition.

Finally, we tested whether or not there was a difference in gamble acceptance aross the adult lifespan. In Model 4 we added age a predictor to the model. Contrary to our second prediction, adding age did not improve model fit, $\chi^2(1, N = 209) = 0.01$, $p = 0.928$. Because age was not a significant predictor, we do not examine age effects in our exploratory

analyses below.

Self Reported Strategy

More participants endorsed an affective strategy than a deliberative strategy, $t(208) = 2.39$, $p = 0.02$ and these decision strategies were related to positive-skew acceptance. People who said they used an affective strategy were more like to accept gambles ($r = 0.17$, $p = 0.012$ while there was no relationship between a deliberative strategy and gamble acceptance.

More participants also agreed with statements focused on wins than on losses, $F(1, 831) = 28.95$, $p < .001$. People who focused on losing were more likely to reject skewed gambles. This was true for focusing both on the monetary loss ($r = -0.40$, $p < .001$) or and the likelihood of loss ($r = -0.34$, $p < .001$). Further, people who focused on how much money they could win were more likely to accept gambles ($r = 0.35$, $p < .001$). All of these relationships remained the same size and direction when controlling for the expected value condition participants were in (See supplementary materials). Collectively, these results suggest that affective strategies and focusing on winning increase the positive-skew bias while focusing on possible losses decreases the positive-skew bias.

Affective status

We asked participants to rate how often they experience various emotions using the “actual affect” subscale from the Affect Valuation Index (Tsai, Knutson, & Fung, 2006). The scale asks respondents to rate how much they actually feel a number of states on average, ranging from 1 = never to 5 = all the time. During data analysis, we discovered that six items were missing from our survey. Three of these items measured positive affect, two of these items measured negative space affect, and one of these items measured low arousal - positive affect. We were still able to calculate a score for low arousal - positive affect from the three other words related to that dimension. However, we did not have enough data to estimate positive and negative affect because of these missing values.

We did find differences in the emotions that participants reported experiencing. Participants were most likely to experience low arousal - positive emotions (e.g. calm, relaxed, or peaceful; $m = 3.46$) and least likely to experience high arousal - negative emotions (e.g. fearful, hostile, or nervous; $m = 1.84$). However, there was no relationship between experienced emotions and gamble acceptance. This suggests that current emotional state does not impact the positive-skew bias.

Cognitive abilities

We assessed participants on two cognitive abilities that could possibly influence their decision-making abilities: numerical ability and graph literacy. We estimated numeracy using the Expanded (15-item) Numeracy Scale (Peters, Dieckmann, Dixon, Hibbard, & Mertz, 2007) and graph literacy using the 10-item Subjective Graph Literacy Scale (Garcia-Retamero, Cokely, Ghazal, & Joeris, 2016). Numeracy scores ranged from 0 to 14 with a mean score of 9 and graph literacy scores ranged from 10 to 58 with a mean score of 33. For both of these measures we saw that greater cognitive ability was associated with decreased acceptance of skewed gambles (Numeracy: $r = -0.20$, $p = 0.003$; Graph literacy: $r = -0.20$, $p = 0.004$). Both of these relationships remained the same size and direction when controlling for the expected value condition participants were in (See supplementary materials). This suggests that people with greater cognitive ability were displayed less of a positive-skew bias.

Real-World Decision Making

We asked participants a series of questions about their experience with monetary investments and fraud. While almost half of participants said they have lost money on investments ($N = 98/209$), only a small proportion of them attributed that loss to fraud ($N = 7$). While participants were ambivalent about their ability to detect a fraudulent investment, they were confident in their ability to avoid making a fraudulent investment and to resist high-pressure sales tactics (See supplementary materials).

Some of these real-world decisions were related to acceptance of positively-skewed gambles. While there was no relationship between losing money through risky investments or fraud and the positive-skew bias, there was a relationship between people's *confidence* and the positive-skew bias. People who were more confident in their ability to resist high-pressure sales tactics were less likely to accept positively-skewed gambles ($r = -0.16, = 0.024$). This relationship remained the same size and direction when controlling for the expected value condition of participants (See supplementary materials). This suggests that a lack of confidence may play a role in the positive-skew bias.

Interim Discussion

Consistent with our predictions, we found an increase in gamble acceptance as the degree of skewness increased, which suggests a preference for strongly-skewed and moderately-skewed gambles over weakly-skewed and symmetric gambles. We did not, however, find an age-related increase in preference for positively-skewed gambles. This is not only contrary to our hypotheses, but is also inconsistent with prior studies of age differences in acceptance of skewed gambles, and thus merits further exploration. Our exploratory analyses revealed several interesting associations with acceptance of skewed gambles. Those who made decisions based on their gut feelings, focused on how much money they could possibly win, and who were less confident in their ability to avoid fraudulent investments were more likely to accept skewed gambles. Those who had higher numeracy or graph literacy were less likely accept skewed gambles. Collectively, these exploratory analyses suggest that affective mechanisms may fuel skewed gamble acceptance while cognitive mechanisms may fuel skewed gamble avoidance.

One problem with our exploratory outcome measure in this study, positive-skew bias, is that the extreme ends of this measure cannot be disentangled from risk-aversion and risk-seeking. In other words, if someone never chose a gamble (positive-skew bias = 0), it could be because they are avoiding positively-skewed gambles or it could be because they are

generally risk-averse. Likewise, if someone always chose a gamble (positive-skew bias = 9), it could be because they like positively-skewed gambles or it could be because they are generally risk-seeking. To avoid this confound, in Study 2 we forced participants to make a choice between two gambles, a symmetric gamble and an equivalent skewed gamble.

Experiment 2: Symmetric Risky Gambles vs Skewed Risky Gambles

Methods

Participants

As in Study 1, 210 participants ($M_{age} = 54.53$, $SD_{age} = 16.95$, Range = 25 - 85) were recruited using Qualtrics Panels. Qualtrics files are available on OSF (<https://osf.io/d56b2/>). The exact same screening questions and questionnaires were used for this study. The study only differed in skewed gambling task design, as described below.

Skewed Gambling Task

During this version of the skewed gambling task, participants chose between a symmetric gamble (Figure 1c) and a skewed gamble (Figure 1b). As in Study 1, skewed gambles varied systematically in the degree of skewness on each trial, spanning from maximum uncertainty (50/50 gamble) to certainty (100% win) in 5% increments (variance = 500, skewness = 0 to ± 46169). Thus, the stimulus set included 9 positively-skewed gambles for 5 expected values (-5, -0.5, 0, 0.5, 5) for a total of 45 distinct gambles. These stimulus values were preregistered with a detailed stimulus spreadsheet on OSF (<https://osf.io/vwhxb>).

As in Study 1, gambles did not play out, participants received no feedback about their choices, and choices were hypothetical. The same modifications were made to the design in this study; each participant only answered 9 questions where all gambles had the same expected value. The also completed two catch trials.

Results

Skewed Gamble Acceptance

There was a main effect of degree of skew (Fig 5, Baseline Model, Table 2), but it was in the opposite direction of predictions and Study 1. There was a *decrease* in acceptance of moderately- and strongly-skewed gambles compared to weakly-skewed gambles (moderately-skewed: $t(209) = 2.12$, $p = 0.035$, strongly-skewed: $t(209) = 2.15$, $p = 0.033$). We next tested if this relationship was modified by valence by adding valence and its interactions to the baseline model (Model 1, Table 2). Adding these predictors significantly improved model fit, $\chi^2(6, N = 210) = 23.41$, $p = 0.001$. In particular, people were less likely to accept strongly skewed gambles for a loss ($t(83) = 3.58$, $p = 0.001$). We also tested if magnitude moderated the effect of degree of skew by adding magnitude and its interactions to the baseline model (Model 2, Table 2). Unlike the first study, adding these predictors did not significantly improve model fit, $\chi^2(6, N = 210) = 10.07$, $p = 0.122$.

As in Study 1, valence and magnitude were not completely orthogonal in this design. We again created a factor that included both magnitude and valence (magval) and added this to the baseline model (Model 3, Table 2). Adding this factor significantly improved model fit,

$\chi^2(6, N = 210) = 14.88, p = 0.021$. People accepted strongly-skewed gambles less than weakly-skewed gambles but only for modest losses (expected value = \$0.50, $t(41) = 2.88, p = 0.006$). Collectively, these results do not support our hypothesis; they actually show that the opposite pattern. Here we found that gamble acceptance decreases with increasing degrees of skewness, and this trend seems to be primarily driven by gambles in the loss domain.

Finally, we tested whether or not there was a difference in gamble acceptance across the adult lifespan. In Model 4 we added age as a predictor to the model. Contrary to our second prediction, adding age did not improve model fit, $\chi^2(1, N = 210) = 1.48, p = 0.224$. Because age was not a significant predictor, we do not examine age effects in our exploratory analyses below.

Self-Reported Strategy

Contrary to Study 1, more participants in this study endorsed a deliberative strategy than an affective strategy, $t(209) = -3.90, p < .001$ and neither strategy related to skewed gamble acceptance ($r_s > 0.12$). In terms of information, people were more focused on wins instead of losses (Valence: $F(1, 831) = 4.50, p < .001$) and more focused on how much they could win/lose than the likelihood of a win/loss (Information Type: $(F(1, 831) = 5.78, p < .001)$. Critically, those who focused more on how much they could potentially win were more likely to accept skewed gambles ($r = 0.27, p < .001$), and this effect survived when controlling for expected value condition. Those who focused more on the likelihood of losing were less likely to accept skewed gambles ($r = -0.14, p = 0.050$) but this effect did not survive when controlling for expected value condition. Taken together, these results suggest that a focus on possible winnings may increase the positive-skew bias.

Affective Status

Again, we asked participants to rate how often they experience various emotions. As in Study 1, participants in this study were most likely to experience low arousal - positive

emotions ($M = 3.47$, $SD = 0.71$) and least likely to experience high arousal - negative emotions ($m = 2.31$ $SD = 0.70$). Unlike Study 1, some of these experienced emotions were related to skewed decision making. In particular, people who endorsed high arousal (e.g. aroused, surprised, or astonished; $r = 0.13$, $p = 0.051$ and high arousal - positive (e.g. enthusiastic, excited, strong, or elated; $r = 0.17$, $p = 0.013$) words were more likely to accept skewed gambles. This suggests that high arousal may contribute to positive-skew bias.

Cognitive Abilities

We also assessed participants on numeracy and graph literacy, two cognitive abilities that could possibly influence their decision-making abilities. Numeracy scores ranged from 0 to 14 with a mean score of 9 while graph literacy scores ranged from 10 to 58 with a mean score of 36. As in Study 1, higher numeracy scores predicted less acceptance of skewed gambles ($r = -0.14$, $p = 0.035$), however, this result did not survive when controlling for the participant's expected value condition. Further, graph literacy not predictive of skewed gamble acceptance ($r = -0.11$, $p = 0.109$). Collectively, these results provide limited support for the idea that people with greater cognitive ability displayed less of a positive-skew bias.

Real-World Decision Making

We also asked participants a series of questions about their experience with monetary investments and fraud. While almost eighty percent of participants said they have lost money on investments ($N = 166/210$), only a small proportion of them attributed that loss to fraud ($N = 31$). As in Study 1, while participants were ambivalent about their ability to detect a fraudulent investment, they were confident in their ability to avoid making a fraudulent investment and to resist high-pressure sales tactics (See supplementary materials). Unlike Study 1, none of these real-world decisions were related to acceptance of positively-skewed gambles.

Intermin Discussion

Contrary to our predictions and the results of Study 1, here we found that gamble acceptance decreases with increasing degrees of skewness. Notably, this trend seems to be a framing effect, driven by gambles in the loss domain. Despite this overall difference in skewed gamble acceptance, some individual differences were consistent with those examined in Study 1. For instance, again, we did not find an age-related increase in preference for positively-skewed gambles. We saw that people who focused more on potential monetary wins were more likely to accept positively-skewed gambles. We also observed a new relationship in this study: individuals experiencing high arousal displayed a greater positive-skew bias. We also did not observe a relationship between either cognitive abilities or real world decision making and positive-skew bias.

General Discussion

This series of studies examined the positive-skew bias. While the results supported our hypothesis that the positive-skew bias will increase with increasing skewness under certain conditions (Study 1), our results did not support this hypothesis under uncertain (Study 2) conditions. Our hypothesis was based on a study by Strait and Hayden (2013), which showed that monkeys demonstrated a preference for strong positively-skewed gambles. However, in Strait and Hayden (2013), monkeys were only making decisions about possible gains. Here we asked people to make decisions in both the gain and loss domain and in Study 2 we see some evidence of a reflection or sign effect, where choices are different for gains and losses (Fagley, 1993). The pattern of decreasing gamble acceptance for more strongly-skewed gambles only occurred in the loss domain (expected value = -\$5.00 or \$0.50). Under neutral (expected value = \$0) and gain (expected value = \$0.50 and \$5.00) conditions, this pattern is not present and in the highest gain condition (expected value = \$5.00) we see a pattern similar to that of Study 1 where the most strongly-skewed gambles are preferred. This sign effect was not predicted, and should be further explored in future

studies using a within-subject design.

Many dual process models decision making suggest that risk taking is a result of competition between a more reactive affective system and a more controlled deliberative system (Figner et al., 2009). Prior studies of skewed gambling in young adults have shown greater affective response to positively-skewed gambles (Wu et al., 2011), suggesting that affective processes may lead to a preference for positively-skew gambles. We found support for this perspective in Study 1, where participants were more likely to endorse an affective (compared to deliberative) strategy and individuals using an affective strategy were more likely to accept positively-skewed gambles. However, neither of these trends were present in Study 2; in fact, participants in Study 2 were more likely to endorse a deliberative (compared to affective) strategy. It is possible that the samples for each study differed in terms of their preferred strategy, or it is possible that the type of questions encountered in each study influenced the type of strategy pursued by participants. Perhaps individuals were more likely to rely on their gut (affective) in the certain vs. risky condition because the cognitive costs were relatively low while individuals were more likely to rely on deliberation when facing two risky gambles. While affective strategies were not predictive of positive skew bias in Study 2, the actual affect experienced by participants was predictive. Individuals who were experiencing high arousal or high arousal-positive emotions were more likely to accept positively-skewed gambles. Collectively, across both studies, affective strategies and experiences were associated with a bias towards positively-skewed gambles.

Across both studies, participants who were more likely to focus on the monetary amount of possible wins were more likely to accept skewed gambles. Here, because we equated the options on expected value, the potential winnings for skewed gambles were always larger than the alternative option. Research has also shown that greater visual attention to specific decision features can increase the likelihood that that option is chosen (Krajchich, Armel, & Rangel, 2010; Krajchich & Rangel, 2011). By focusing more on the

monetary gains, it is possible that participants overweighted the possible gains and that led them to accept more positively-skewed gambles. Research has also shown that focusing on potential wins increases risk taking (Nygren, 1998). In Study 1, the skewed gamble was also the only risky option, so it is possible that focusing on possible wins caused participants to choose the skewed gamble more often. Future studies could examine visual attention during decision making to determine if participants' subjective reports align with objective measures of visual attention.

Participants across both studies with stronger cognitive abilities were more likely to *avoid* skewed gambles, although this effect was much smaller in Study 2. This is largely consistent with research showing that less numerate individuals are more susceptible to framing effects (Peters & Levin, 2008), take more disadvantageous risks (Jasper, Bhattacharya, Levin, Jones, & Bossard, 2013), and use simple strategies and affect when making decisions (Pachur & Galesic, 2013). Here, it is possible that individuals with stronger numeracy skills were more likely to engage in a deliberative strategy and avoid skewed gambles, while individuals with weaker numeracy skills were more likely to engage in an affective strategy and accept skewed gambles. Interventions aimed at improving risk communication using icon arrays instead of pie charts (as was done here) could improve risk comprehension (Galesic, Garcia-Retamero, & Gigerenzer, 2009) and potentially mitigate the positive-skew bias in low numeracy individuals.

One surprising result was that we did not see any age differences in acceptance of skewed gambles. This is surprising because it was in direct contrast to prior studies that have found a relationship (Seaman et al., 2018, 2017). Even limiting our sample to those who answered a similar question (Study 1, expected value = \$0, $N = 41$), we see no effects of age (although it should be noted this subsample skews older than the whole study sample; the mean age was 57 years old and the majority were over the age of 60). There are several possible reasons we did not see an effect here. First, this study differs from our prior studies

in several notable ways. For instance, in our previous studies we used a limited set of conditions (expected value = \$0, skewness = 1.25). Here we varied both expected value and skewness. It is possible that age differences only appear under very specific conditions of expected value = \$0 or moderately-skewed. Second, in our previous studies, individuals also considered negatively-skewed gambles, and the age effects were strongest for the contrast between negatively-skewed gambles and positively-skewed gambles (Seaman et al., 2017). Finally, it is possible that the age-related positive-skew bias we observed in our prior studies were a statistical abnormality. Further studies are needed to determine the existence of this phenomenon and how robust it is to different gamble characteristics and conditions.

While all these individual differences are intriguing, follow-up studies designed to directly test these effects are needed to clarify the role of age, strategy, and cognitive ability in the preference for positively-skewed gambles. There are also several other limitations of this study. First, the expected value of the gamble varied between subjects; this means that differences we saw between valence (wins or losses) and magnitude (\$5.00 or \$0.50) may be due to individual differences in those samples instead of based on the conditions. Similarly, the foil to skewed gambles (either an equivalent certain option or a symmetric risky gamble) varied between studies, so the difference in positively-skewed gamble acceptance we observe between studies could also be due to sample characteristics. Future studies should vary these features within subjects to get a complete understanding of how gamble features (like expected value) or decision context (like foil) influence the acceptance of positively-skewed gambles.

Although the positive skew bias seems to be grow stronger with increasing skewness, this seems to be limited to choices about possible gains and is more prevalent when choosing between a certain outcome and a skewed outcome. Exploratory analyses display a general pattern of affective mechanisms increasing the positive skew bias and cognitive mechanisms decreasing the positive skew bias, but follow-up studies are needed. A better understanding

468 of these underlying mechanisms can inform the development of specific interventions to
469 reduce the positive-skew bias in everyday decision making.

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Table 2

	Baseline		Model 1		Model 2		Model 3		Model 4	
<i>Predictors</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>
(Intercept)	1.60 (0.94 – 2.70)	0.081	1.93 (0.56 – 6.64)	0.298	1.93 (0.56 – 6.67)	0.297	1.94 (0.56 – 6.71)	0.297	1.93 (0.55 – 6.71)	0.302
deg_skew [Weak]	0.95 (0.62 – 1.45)	0.809	1.22 (0.45 – 3.34)	0.698	1.22 (0.45 – 3.34)	0.698	1.22 (0.45 – 3.35)	0.698	1.22 (0.45 – 3.35)	0.698
deg_skew [Moderate]	2.23 (1.45 – 3.43)	<0.001	5.18 (1.77 – 15.13)	0.003	5.19 (1.77 – 15.17)	0.003	5.20 (1.77 – 15.22)	0.003	5.19 (1.77 – 15.21)	0.003
deg_skew [Strong]	3.87 (2.49 – 6.00)	<0.001	7.56 (2.51 – 22.80)	<0.001	7.58 (2.51 – 22.88)	<0.001	7.60 (2.52 – 22.95)	<0.001	7.60 (2.52 – 22.95)	<0.001
valence [gain]			0.29 (0.06 – 1.30)	0.105						
valence [loss]			2.29 (0.50 – 10.44)	0.285						
deg_skew [Weak] * valence [gain]			0.88 (0.25 – 3.03)	0.835						
deg_skew [Moderate] * valence [gain]			0.51 (0.14 – 1.85)	0.303						
deg_skew [Strong] * valence [gain]			1.00 (0.26 – 3.77)	0.998						

<i>Predictors</i>	Baseline		Model 1		Model 2		Model 3		Model 4	
	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>
deg_skew [Weak] * valence [loss]			0.61 (0.18 – 2.09)	0.429						
deg_skew [Moderate] * valence [loss]			0.26 (0.07 – 0.96)	0.044						
deg_skew [Strong] * valence [loss]			0.20 (0.05 – 0.75)	0.017						
magnitude [0.5]					0.54 (0.12 – 2.40)	0.417				
magnitude [5]					1.31 (0.29 – 6.02)	0.727				
deg_skew [Weak] *magnitude [0.5]					1.56 (0.46 – 5.28)	0.477				
deg_skew [Moderate] * magnitude [0.5]					0.86 (0.24 – 3.10)	0.818				
deg_skew [Strong] * magnitude [0.5]					1.14 (0.31 – 4.28)	0.841				
deg_skew [Weak] *magnitude [5]					0.31 (0.09 – 1.07)	0.064				

<i>Predictors</i>	Baseline		Model 1		Model 2		Model 3		Model 4	
	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>
deg_skew [Moderate] * magnitude [5]					0.14 (0.04 – 0.50)	0.003				
deg_skew [Strong] * magnitude [5]					0.16 (0.04 – 0.60)	0.007				
magval [loss.5]							5.33 (0.84 – 33.90)	0.076	5.37 (0.84 – 34.36)	0.076
magval [loss.0.5]							1.22 (0.22 – 6.84)	0.821	1.23 (0.22 – 6.91)	0.816
magval [gain.0.5]							0.23 (0.04 – 1.30)	0.097	0.23 (0.04 – 1.31)	0.098
magval [gain.5]							0.39 (0.07 – 2.28)	0.299	0.40 (0.07 – 2.31)	0.304
deg_skew [Weak] * magval [loss.5]							0.18 (0.04 – 0.82)	0.027	0.18 (0.04 – 0.82)	0.027
deg_skew [Moderate] * magval [loss.5]							0.10 (0.02 – 0.48)	0.004	0.10 (0.02 – 0.48)	0.004
deg_skew [Strong] * magval [loss.5]							0.04 (0.01 – 0.22)	<0.001	0.04 (0.01 – 0.22)	<0.001

	Baseline		Model 1		Model 2		Model 3		Model 4	
<i>Predictors</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>
deg_skew [Weak] * magval [loss.0.5]							1.61 (0.40 – 6.56)	0.503	1.61 (0.40 – 6.56)	0.503
deg_skew [Moderate] * magval [loss.0.5]							0.56 (0.13 – 2.41)	0.438	0.56 (0.13 – 2.41)	0.438
deg_skew [Strong] * magval [loss.0.5]							0.74 (0.16 – 3.30)	0.690	0.74 (0.16 – 3.30)	0.690
deg_skew [Weak] * magval [gain.0.5]							1.55 (0.37 – 6.45)	0.544	1.55 (0.37 – 6.45)	0.544
deg_skew [Moderate] * magval [gain.0.5]							1.36 (0.31 – 6.05)	0.683	1.37 (0.31 – 6.05)	0.682
deg_skew [Strong] * magval [gain.0.5]							1.85 (0.40 – 8.54)	0.433	1.85 (0.40 – 8.55)	0.432
deg_skew [Weak] * magval [gain.5]							0.45 (0.11 – 1.97)	0.292	0.45 (0.10 – 1.97)	0.292
deg_skew [Moderate] * magval [gain.5]							0.17 (0.04 – 0.75)	0.020	0.17 (0.04 – 0.75)	0.020

	Baseline		Model 1		Model 2		Model 3		Model 4	
<i>Predictors</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>
deg_skew [Strong] * magval [gain.5]							0.51 (0.11 – 2.37)	0.391	0.51 (0.11 – 2.37)	0.391
Age									1.02 (0.68 – 1.54)	0.928
Random Effects										
σ_2	3.29		3.29		3.29		3.29		3.29	
τ_{00}	7.24 _{ID}		7.22 _{ID}		7.28 _{ID}		7.34 _{ID}		7.34 _{ID}	
ICC	0.69		0.69		0.69		0.69		0.69	
N	209 _{ID}		209 _{ID}		209 _{ID}		209 _{ID}		209 _{ID}	
Observations	2090		2090		2090		2090		2090	
Marginal R ₂ / Conditional R ₂	0.032 / 0.698		0.079 / 0.712		0.060 / 0.707		0.096 / 0.720		0.096 / 0.720	

Table 3

<i>Predictors</i>	Baseline		Model 1		Model 2		Model 3		Model 4	
	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>
(Intercept)	14.21 (8.00 – 25.27)	<0.001	5.55 (1.82 – 16.90)	0.003	5.52 (1.82 – 16.77)	0.003	5.63 (1.82 – 17.37)	0.003	5.89 (1.90 – 18.27)	0.002
deg_skew [Moderate]	0.67 (0.47 – 0.96)	0.029	0.68 (0.31 – 1.47)	0.324	0.68 (0.31 – 1.47)	0.324	0.67 (0.31 – 1.47)	0.323	0.68 (0.31 – 1.47)	0.324
deg_skew [Strong]	0.59 (0.41 – 0.85)	0.004	0.85 (0.39 – 1.86)	0.691	0.85 (0.39 – 1.86)	0.691	0.85 (0.39 – 1.86)	0.690	0.85 (0.39 – 1.86)	0.691
valence [gain]			3.48 (0.88 – 13.70)	0.075						
valence [loss]			3.20 (0.82 – 12.47)	0.094						
deg_skew [Moderate] * valence [gain]			1.19 (0.45 – 3.14)	0.729						
deg_skew [Strong] * valence [gain]			1.48 (0.55 – 3.96)	0.435						
deg_skew [Moderate] * valence [loss]			0.82 (0.31 – 2.15)	0.680						
deg_skew [Strong] * valence [loss]			0.30 (0.11 – 0.78)	0.014						

	Baseline		Model 1		Model 2		Model 3		Model 4	
<i>Predictors</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>
magnitude [0.5]					3.78 (0.95 – 14.98)	0.058				
magnitude [5]					3.01 (0.78 – 11.57)	0.109				
deg_skew [Moderate] * magnitude [0.5]					0.91 (0.34 – 2.44)	0.844				
deg_skew [Strong] * magnitude [0.5]					0.38 (0.14 – 1.04)	0.059				
deg_skew [Moderate] * magnitude [5]					1.05 (0.41 – 2.71)	0.916				
deg_skew [Strong] * magnitude [5]					0.93 (0.36 – 2.41)	0.882				
magval [loss.5]							2.31 (0.49 – 11.01)	0.293	2.30 (0.48 – 10.96)	0.296
magval [loss.0.5]							5.10 (0.98 – 26.52)	0.053	4.55 (0.87 – 23.89)	0.073
magval [gain.0.5]							3.09 (0.61 – 15.59)	0.172	3.21 (0.64 – 16.25)	0.158
magval [gain.5]							4.16 (0.84 – 20.67)	0.082	3.79 (0.76 – 18.93)	0.104

	Baseline		Model 1		Model 2		Model 3		Model 4	
<i>Predictors</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>
deg_skew [Moderate] * magval [loss.5]							1.19 (0.40 – 3.51)	0.751	1.19 (0.40 – 3.50)	0.754
deg_skew [Strong] * magval [loss.5]							0.41 (0.14 – 1.19)	0.099	0.41 (0.14 – 1.18)	0.098
deg_skew [Moderate] * magval [loss.0.5]							0.47 (0.14 – 1.58)	0.224	0.47 (0.14 – 1.57)	0.221
deg_skew [Strong] * magval [loss.0.5]							0.19 (0.05 – 0.63)	0.007	0.18 (0.05 – 0.62)	0.007
deg_skew [Moderate] * magval [gain.0.5]							1.63 (0.51 – 5.22)	0.409	1.63 (0.51 – 5.21)	0.410
deg_skew [Strong] * magval [gain.0.5]							0.74 (0.23 – 2.34)	0.606	0.74 (0.23 – 2.33)	0.603
deg_skew [Moderate] *magval [gain.5]							0.91 (0.30 – 2.77)	0.868	0.91 (0.30 – 2.76)	0.866
deg_skew [Strong] * magval [gain.5]							3.32 (0.99 – 11.13)	0.052	3.32 (0.99 – 11.11)	0.052
Age									1.34 (0.83 – 2.15)	0.227
Random Effects										
σ^2	3.29		3.29		3.29		3.29		3.29	
τ_{00}	8.08 _{ID}		8.12 _{ID}		8.06 _{ID}		8.33 _{ID}		8.34 _{ID}	

	Baseline		Model 1		Model 2		Model 3		Model 4	
<i>Predictors</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>	<i>Odds Ratios</i>	<i>p</i>
ICC	0.71		0.71		0.71		0.72		0.72	
N	210 _{ID}		210 _{ID}		210 _{ID}		210 _{ID}		210 _{ID}	
Observations	1890		1890		1890		1890		1890	
Marginal R ₂ / Conditional R ₂	0.004 / 0.712		0.037 / 0.722		0.023 / 0.717		0.050 / 0.731		0.056 / 0.733	