Predicting Risk Attitudes from the Precision of Mental Magnitude Representation

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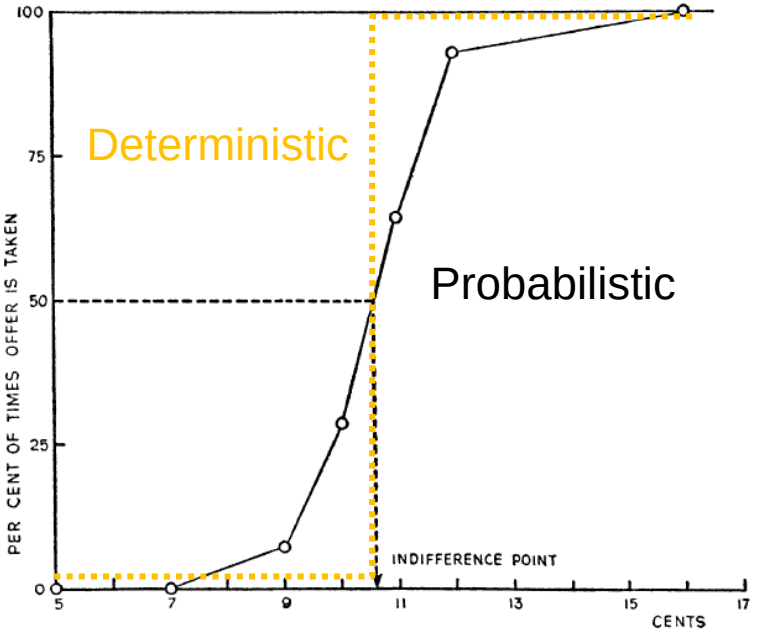
Economic choice involves magnitudes

Economic models of choice…

- …are usually **deterministic** (EUM, argmax models)
- …are usually **not mechanistic** (prescriptive or descriptive)

Problems:

- Cannot account for probabilistic nature of choice (Mosteller and Nogee, 1951; Hey and Orme, 1994)
- Inconsistent prescriptions over sufficiently small bets (Rabin, 2000; Cox et al., 2013)



Mosteller and Nogee (1951)

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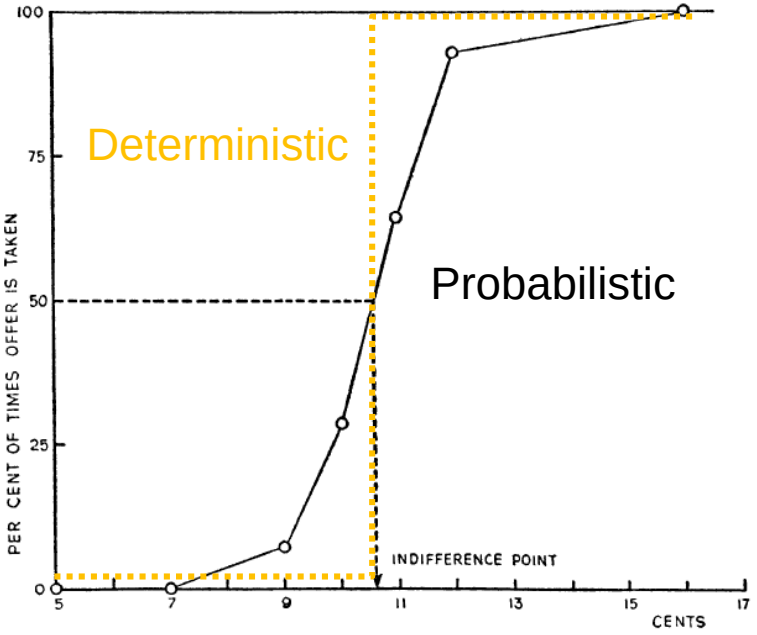
Fundamentally different perspective?

Mechanistic choice model:

People pick the larger expected payoff, subject to capacity constraints

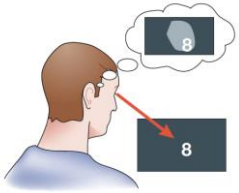
- Noise in magnitude processing

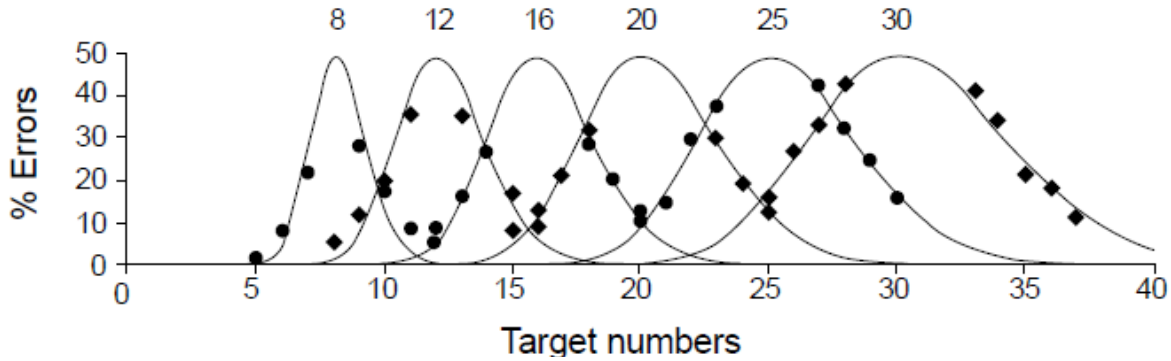


Mosteller and Nogee (1951)

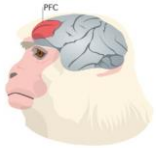
Noisy Logarithmic Encoding of Magnitudes

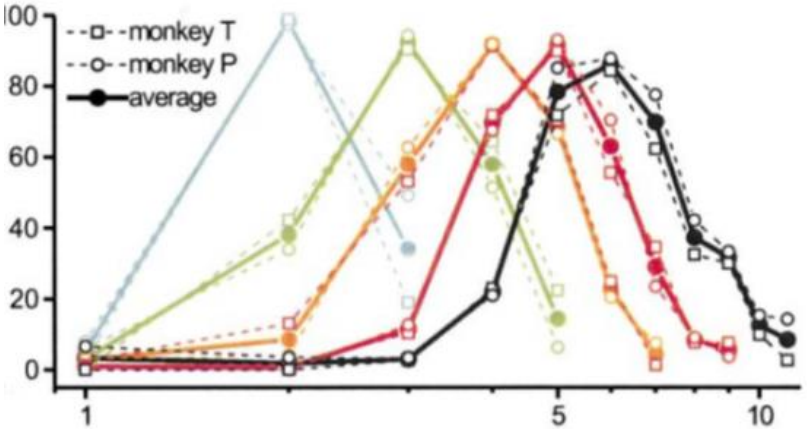
Humans





Monkeys

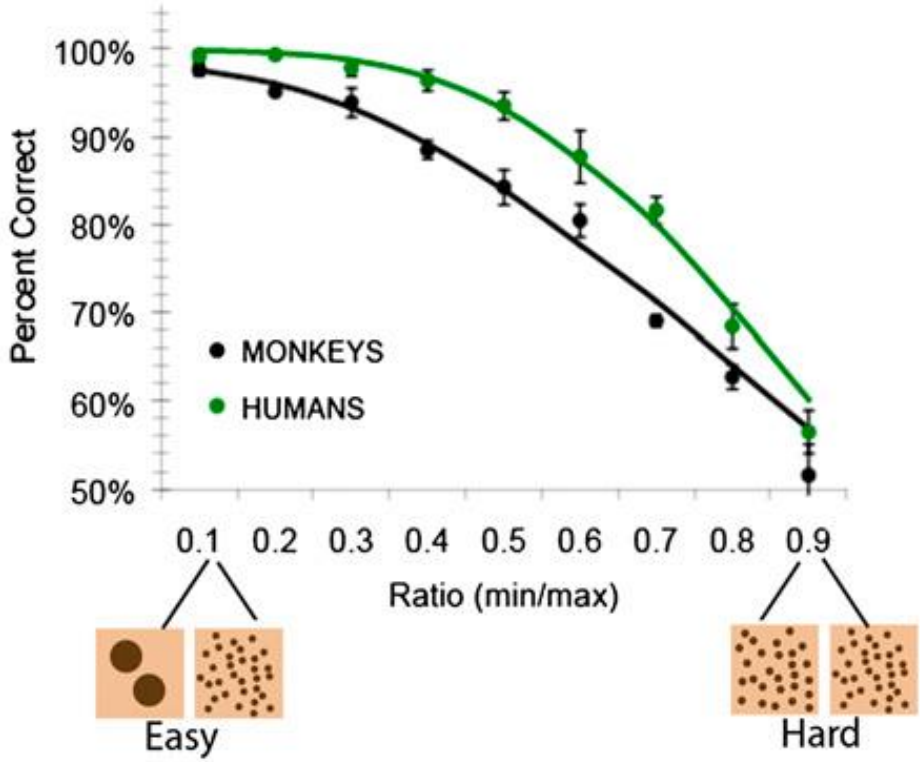




Nieder, 2016, *Nat. Rev. Neuro.;* Nieder and Miller, 2003, *Neuron*; Dehaene, 2002, *Trends in Cog. Sci.*; Dehaene et al., 1998, *TINS*

Noisy Logarithmic Encoding of Magnitudes

Weber's Law



Nieder, 2016, *Nat. Rev. Neuro.;* Nieder and Miller, 2003, *Neuron*; Dehaene, 2002, *Trends in Cog. Sci.*; Dehaene et al., 1998, *TINS*

A Model of Noisy Encoding in Risky Choice

Khaw, Li, and Woodford (KLW, 2018) proposed that risky choice behavior is determined by the noise in mental number representations.

Bias

$$\mathbf{Pr}(\boldsymbol{r}) = \boldsymbol{\Phi}\left(\frac{\log(r/s) - \beta^{-1}\log(p^{-1})}{\sqrt{2}v}\right)$$

Noise

KLW accounts for several aspects of choice not captured by EUM:

- **Probabilistic choice.**
- **Apparent risk aversion in small bets.**

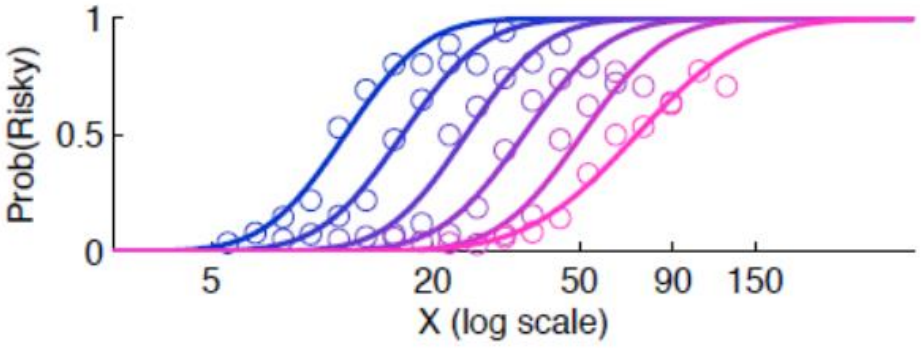
- Both emerge from noisiness of mental magnitude representations

A Model of Noisy Encoding in Risky Choice

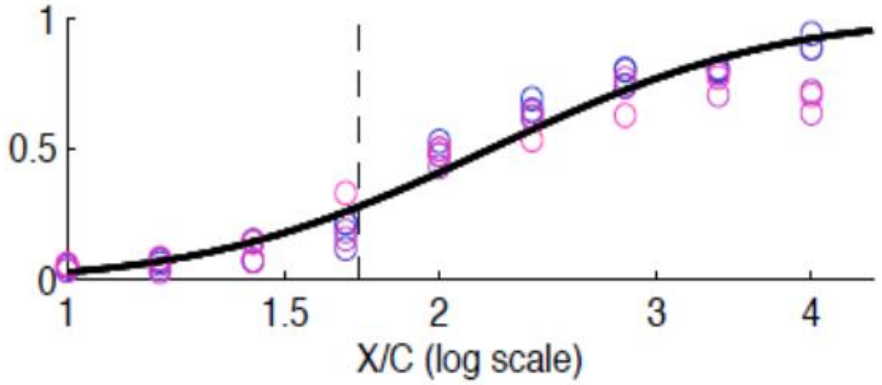
KLW accounts for **Weber's Law**:

- **Logarithmic Encoding.** Psychometric or choice curves have the same slope when magnitude is scaled logarithmically
- **Scale Invariance.** A single choice curve fits all magnitude levels, across the ratio of the choice options

Logarithmic Encoding



Scale Invariance



Substantiating the KLW Model

If KLW model really captures characteristics of magnitude representations, then:

- Individuals should employ similar magnitude representations for both basic psychophysical tasks and risky choice
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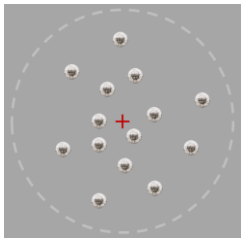
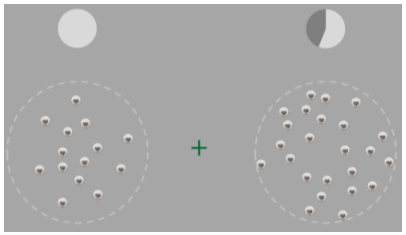
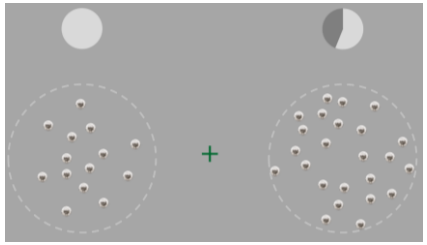
- The degree of noise should correlate across presentation formats
- It should be possible to predict risk attitudes based on the noisiness of magnitude representations employed in basic psychophysical tasks

Different tasks



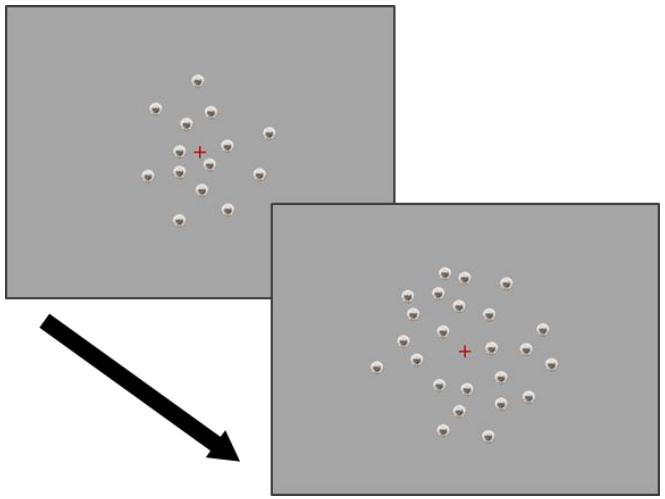


Same task,
different presentation formats

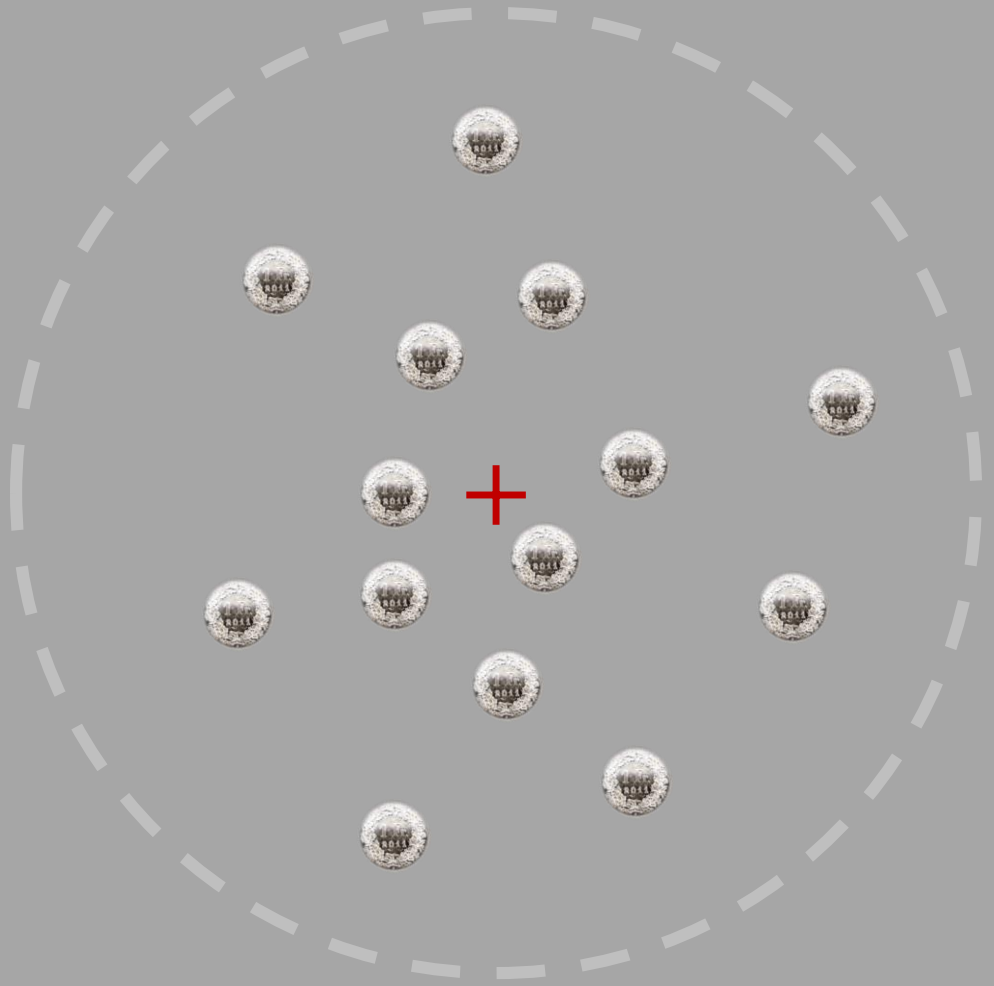


Can we predict people's risk attitudes based on how precisely they encode magnitudes?

Estimating the precision of magnitude representation



Magnitude Comparison



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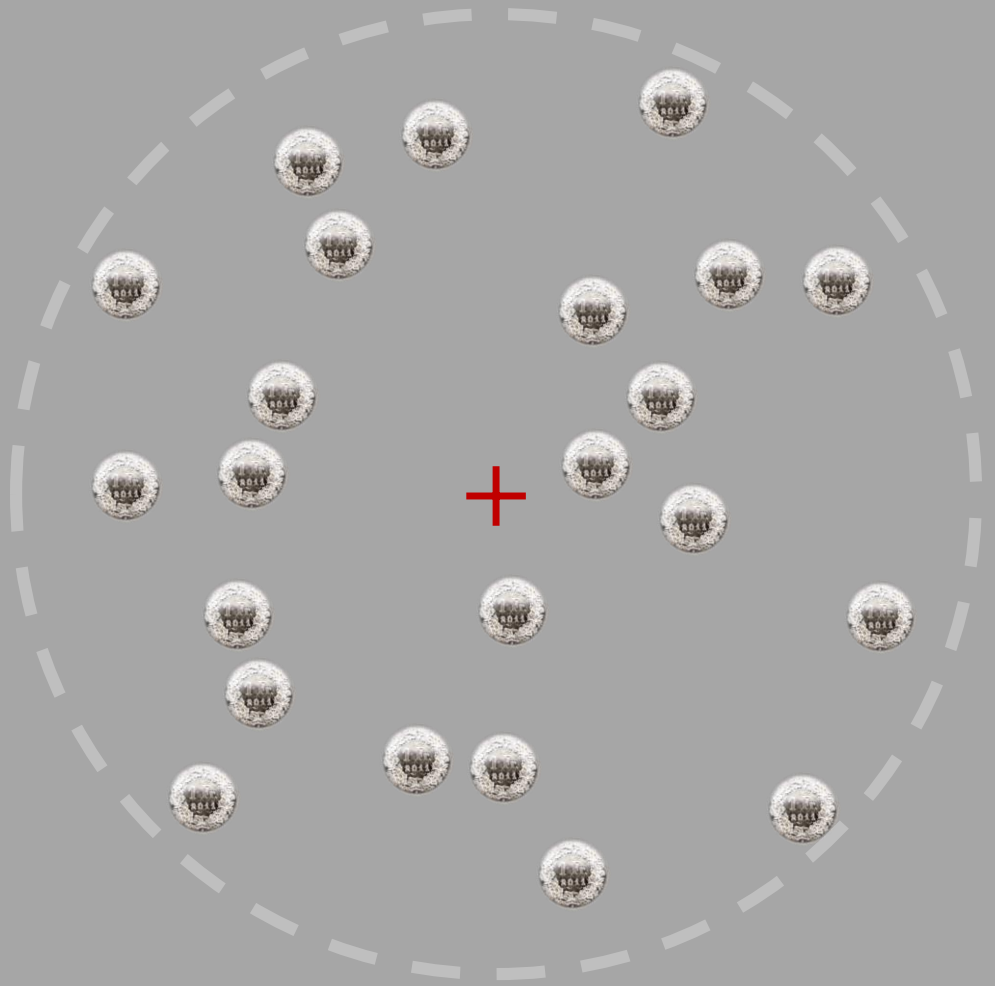

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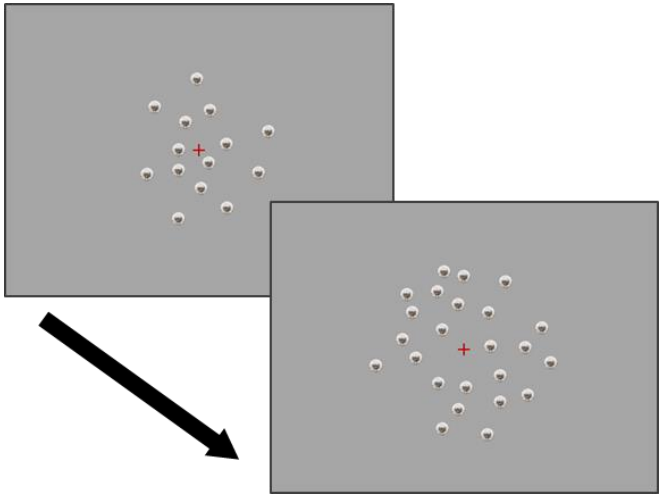
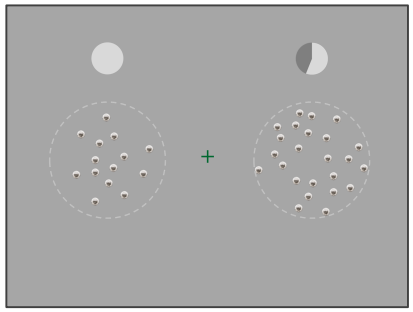
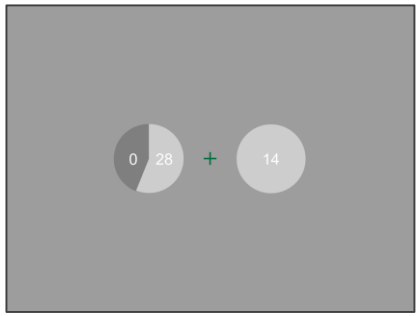


Using the fitted model to predict risk attitudes in separate risky gambles

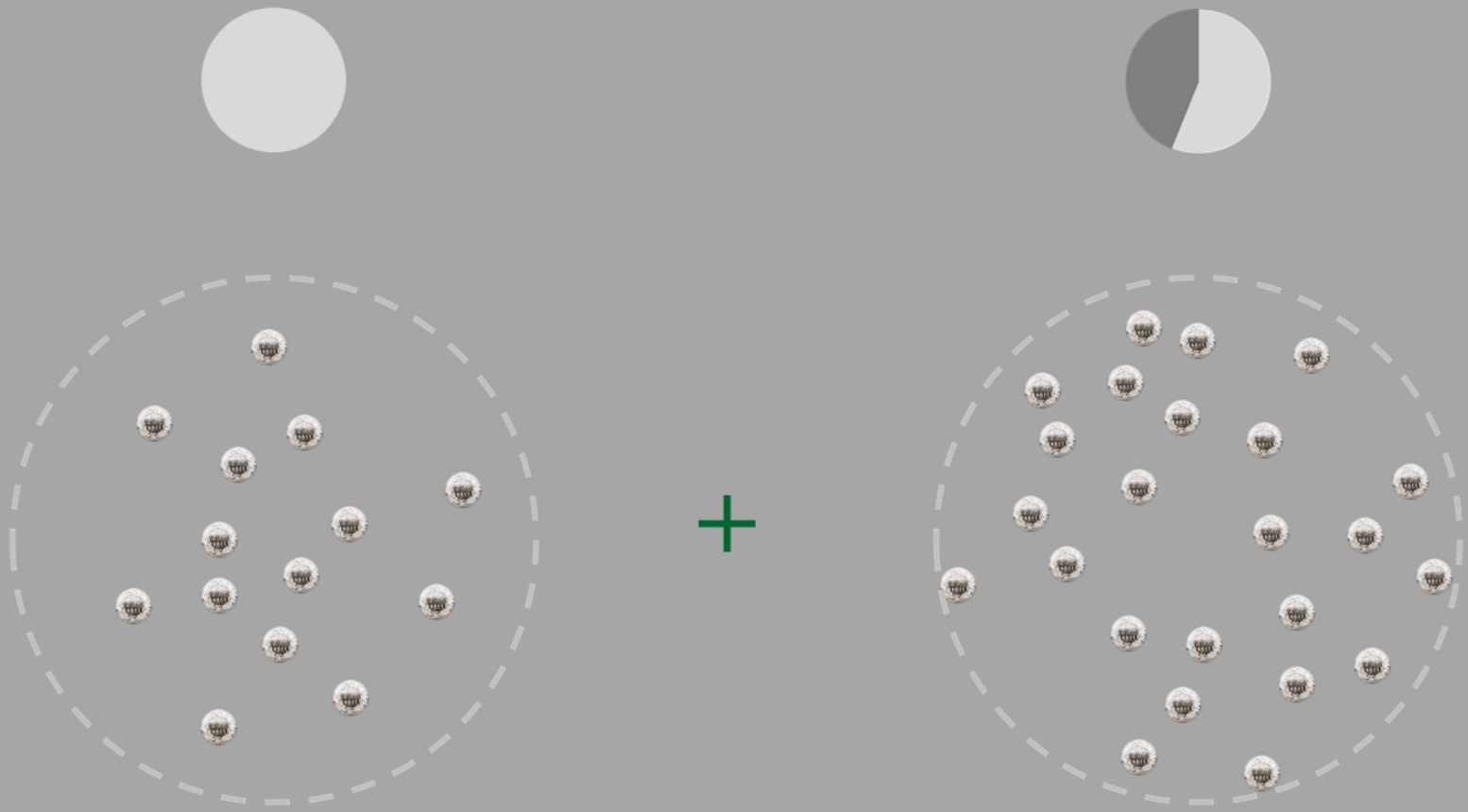
Payoffs as Coins



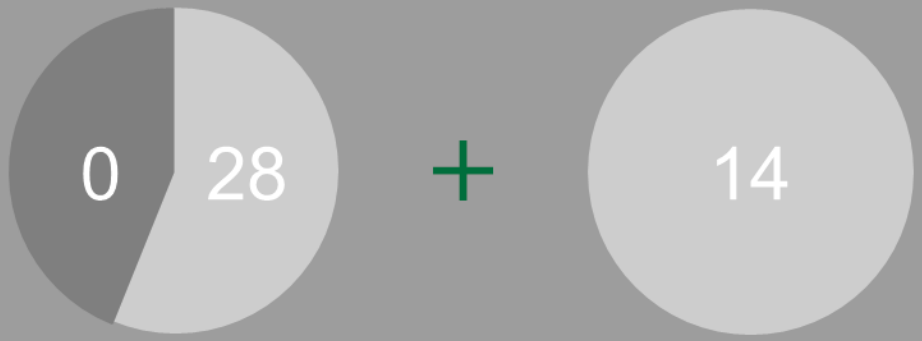
Payoffs as Numbers



Payoffs as Coins



Payoffs as Numbers



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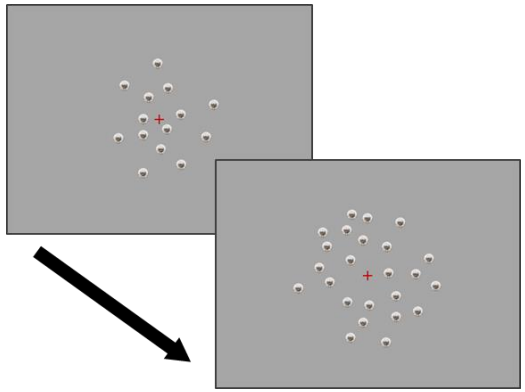
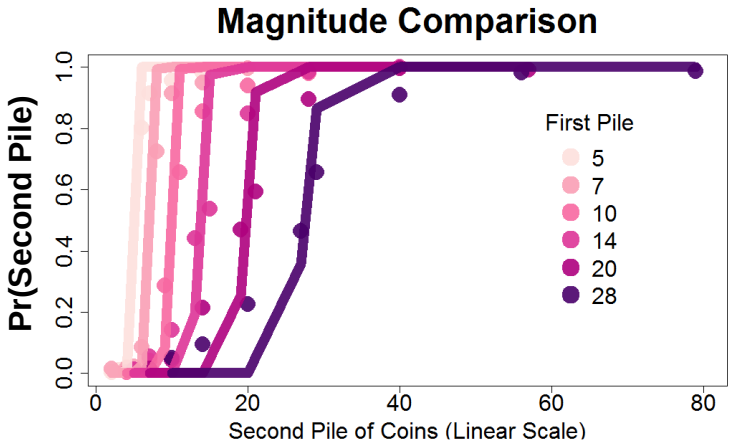
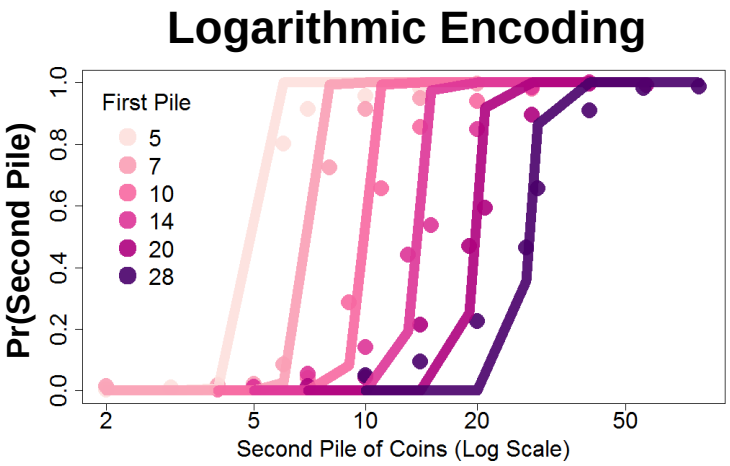
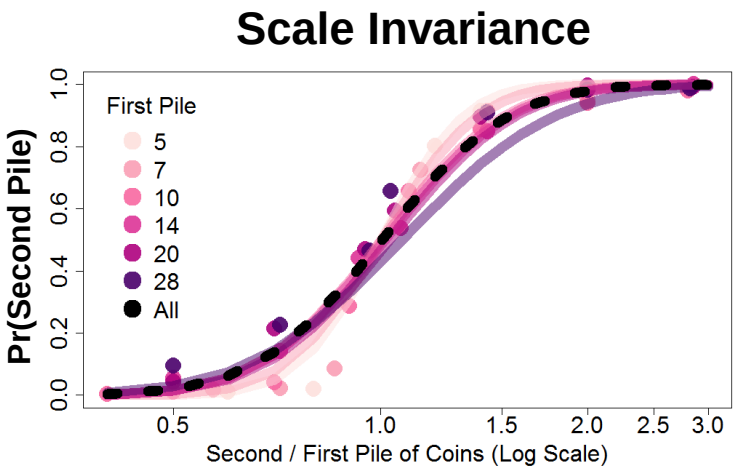
1) Do we see logarithmic scale invariance in magnitude comparison?

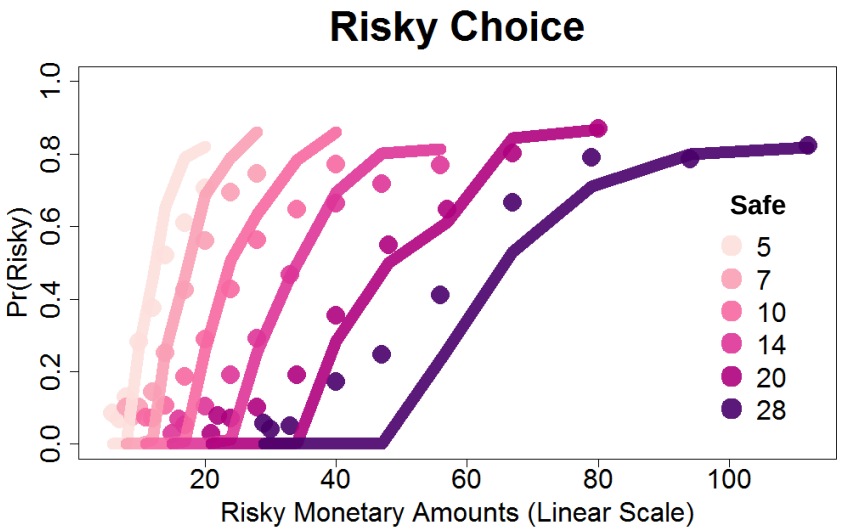


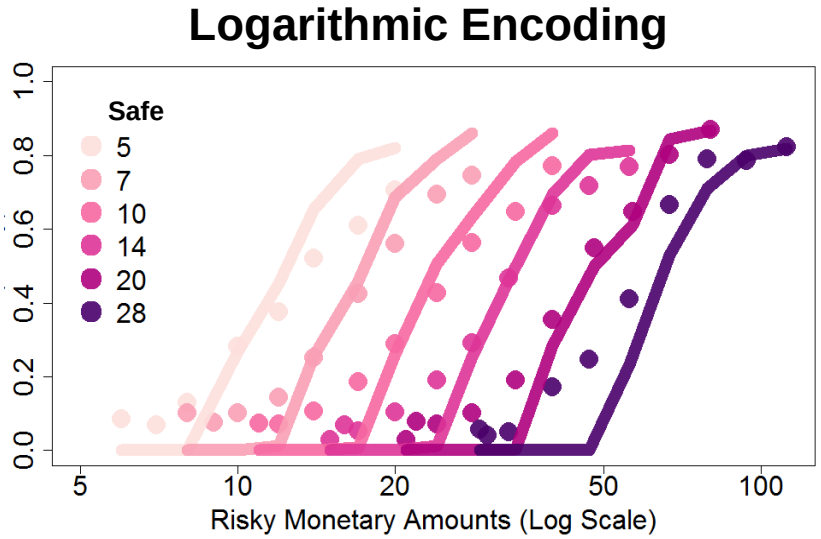


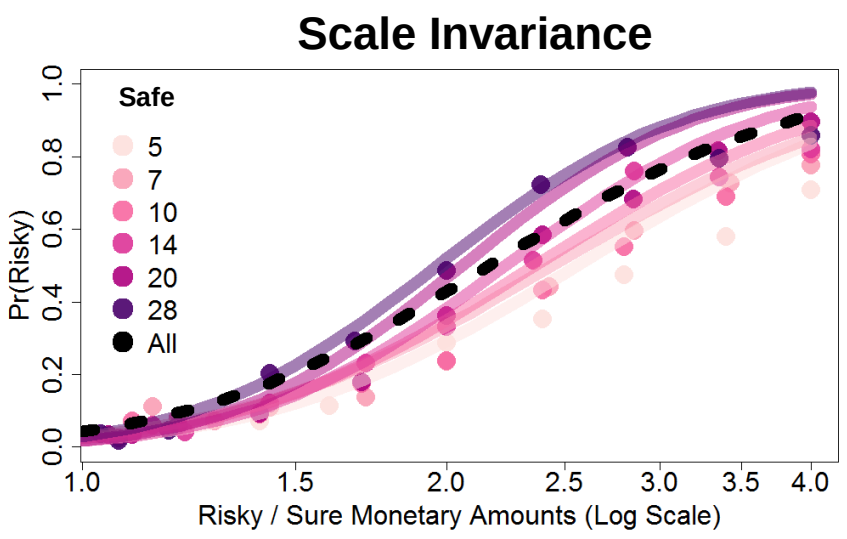




2) Do we see logarithmic scale invariance in risky choice?



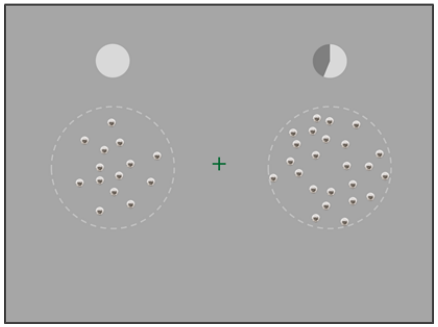




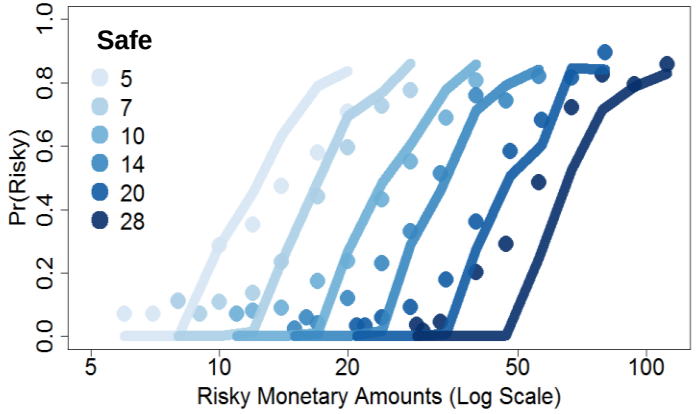
3) Are similar magnitude representations used for risky choices presented as numbers or coins?

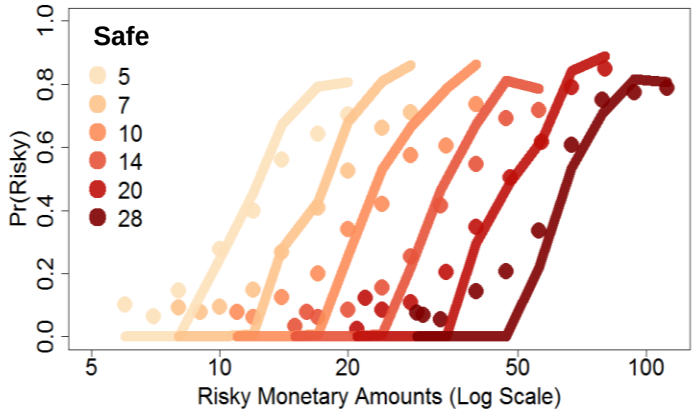
Payoffs as Numbers

Payoffs as Coins

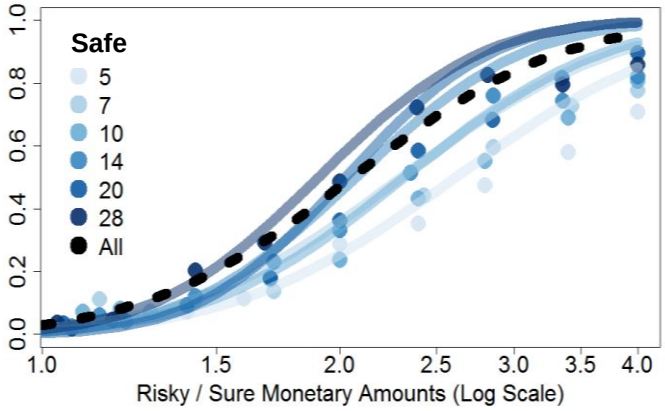


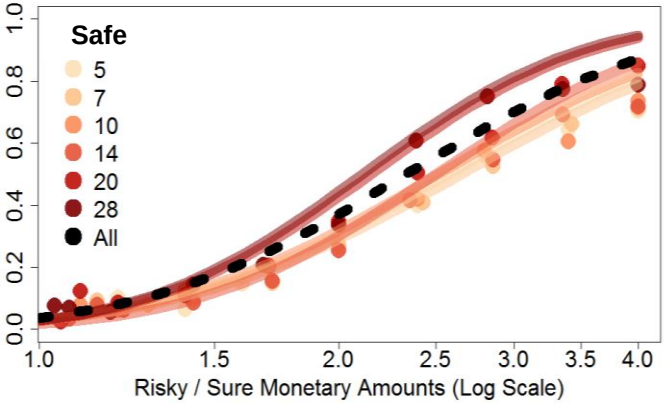
Logarithmic Encoding





Scale Invariance





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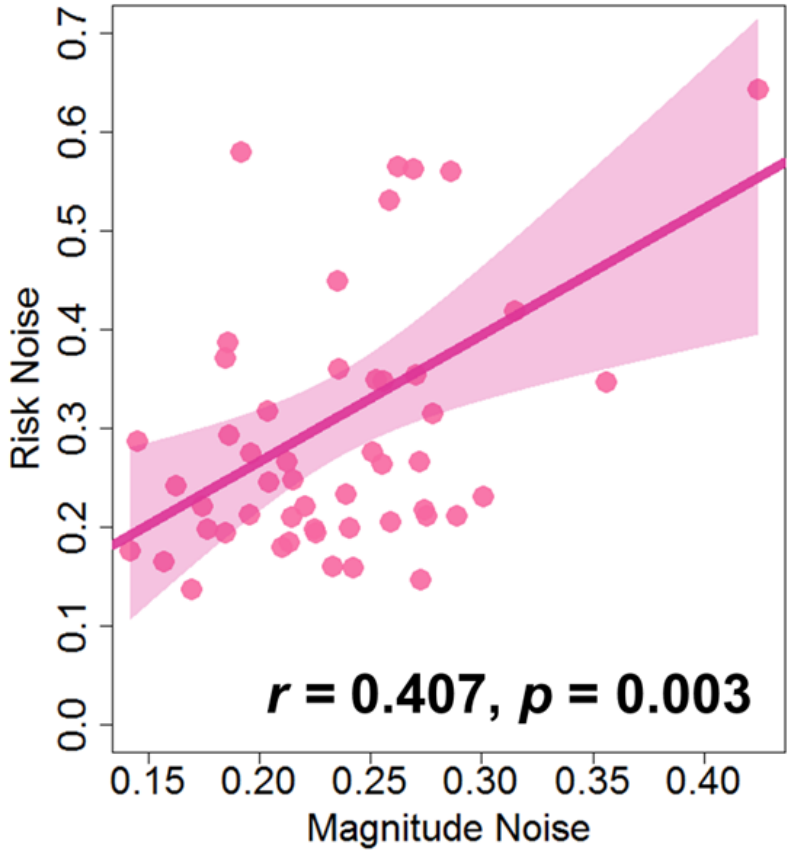
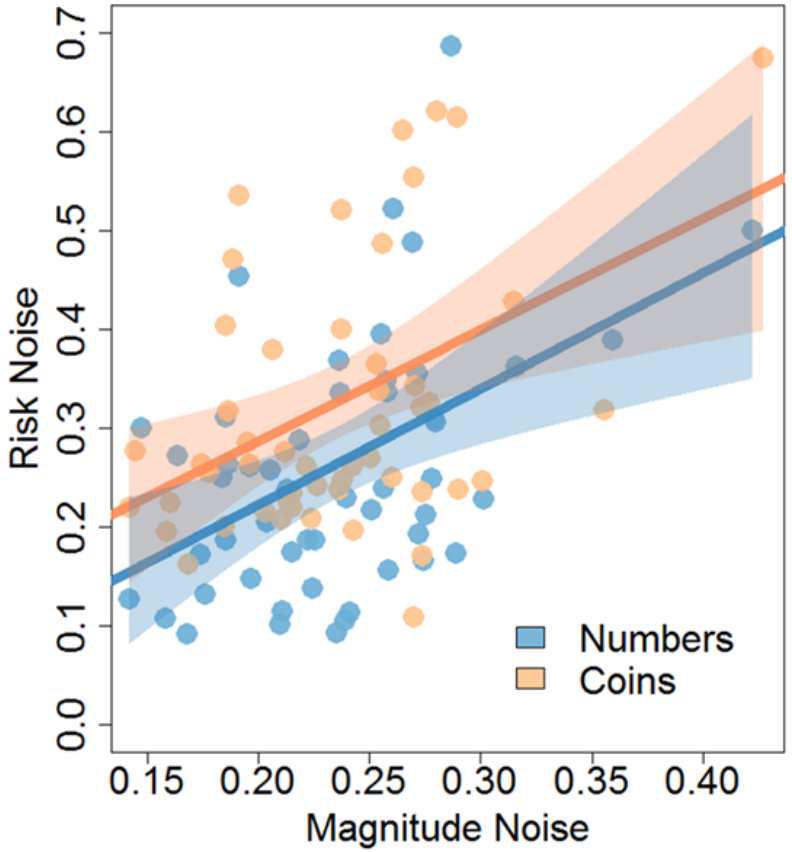
- The degree of noise should correlate across presentation formats
- It should be possible to predict risk attitudes based on the noisiness of magnitude representation employed in basic psychophysical tasks

4) Do people employ similar magnitude representations for risky choice and magnitude comparison?





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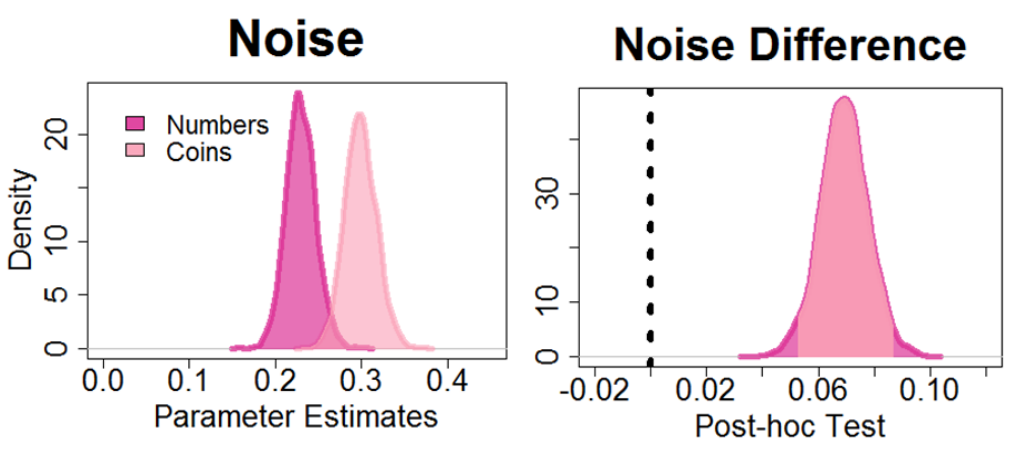
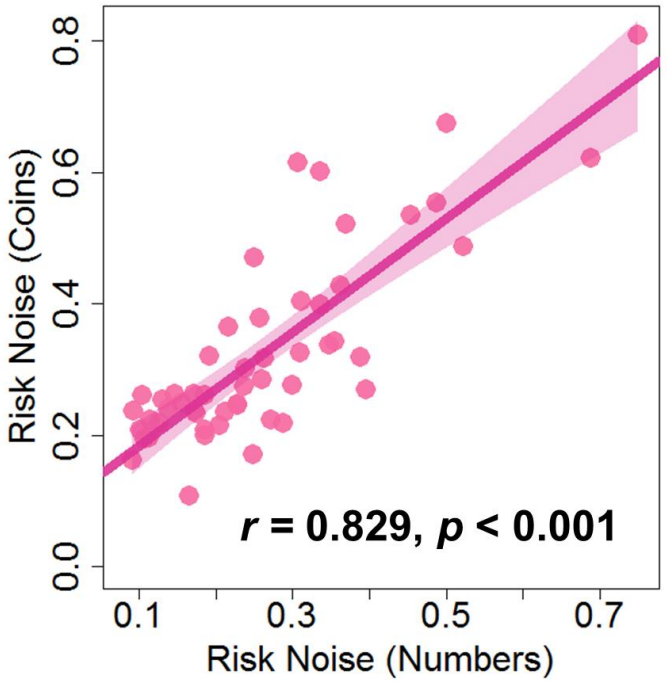
5) Are similar magnitude representations used for risky choice presented as numbers or coins?

Numbers yield more precise magnitude representations than coins (at the population level)…



… but these representations are closely related



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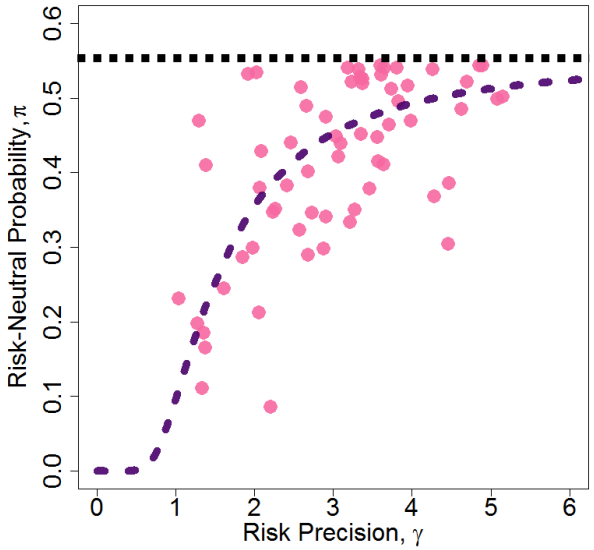
- The degree of representation noise should correlate across tasks ☑
- The degree of noise should correlate across presentation formats ☑
- **It should be possible to predict risk attitudes based on the noisiness of magnitude representation employed in basic psychophysical tasks**

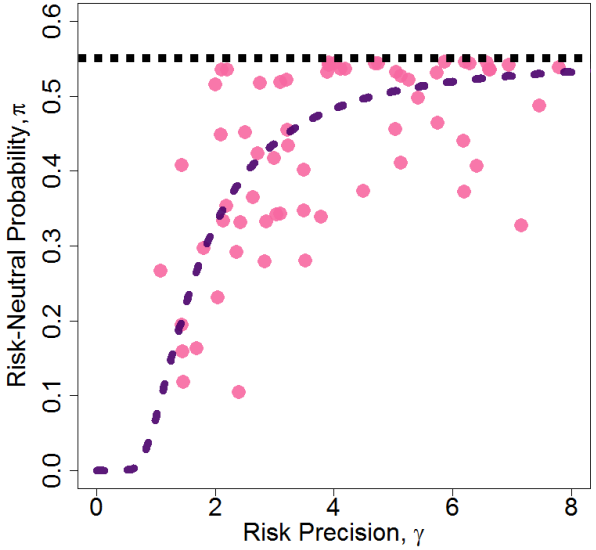
6) Do risk attitudes reflect the precision of mental magnitude representation?

$$\underset{(\gamma)}{\text{Risk Precision}} = \frac{1}{\text{Risk Noise}} \qquad \text{Risk Neutral Probability} = e^{\delta/\gamma}$$

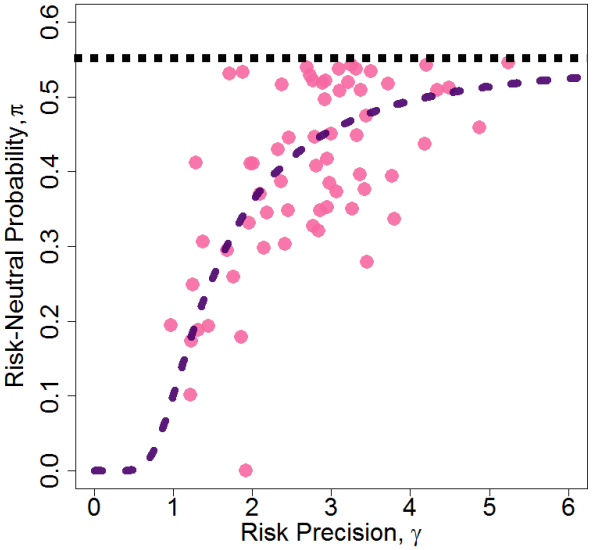
All (Numbers & Coins)



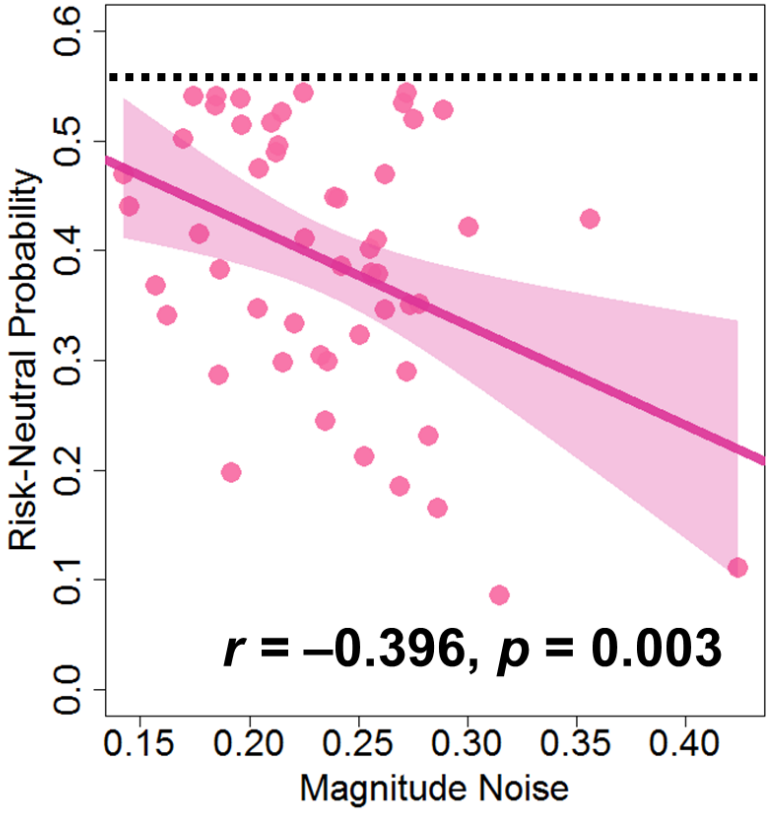
Numbers

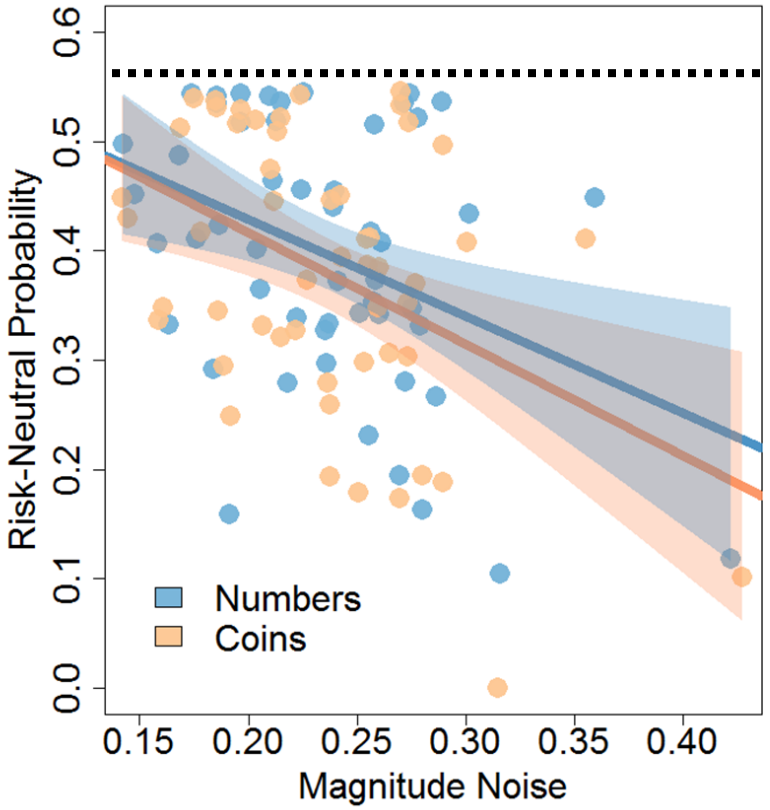


Coins



7) Can we predict people's risk attitudes based on the precision of mental magnitude representation in the psychophysical task?





People's apparent risk attitudes reflect capacity constraints in magnitude representation

- People take risky choices based on logarithmic and noisy representation of magnitude that also underly basic psychophysical performance
- We can measure the noisiness of these with basic psychophysical tasks, and use these them to predict risk attitudes from entirely different settings
- Our results substantiate an economic model of risky choice that:

-- does not rely on assumptions about individual preferences for risk

-- models choice mechanisms with psychologically meaningful, context-independent noise estimates

-- directly accounts for probabilistic nature of choice

Next Step:
From Mental to Neural Magnitude Representation

Perceptual Bias in Magnitude Comparison

ν_{mag}

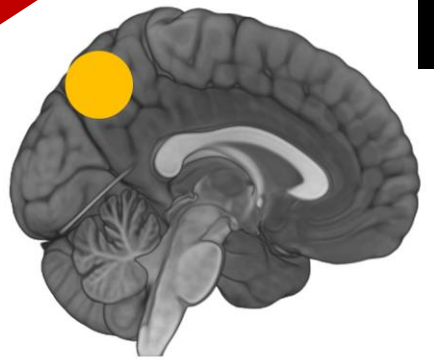
Risky Choice Behavior

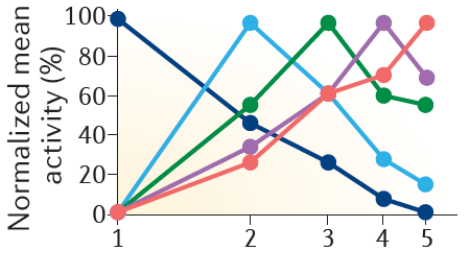
ν_{risk}

Neural Measure of Precision

ν_{neuro}

IPS

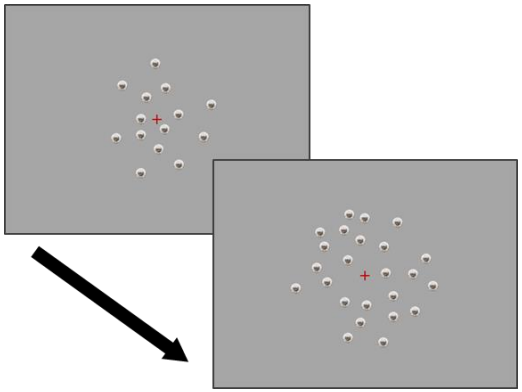


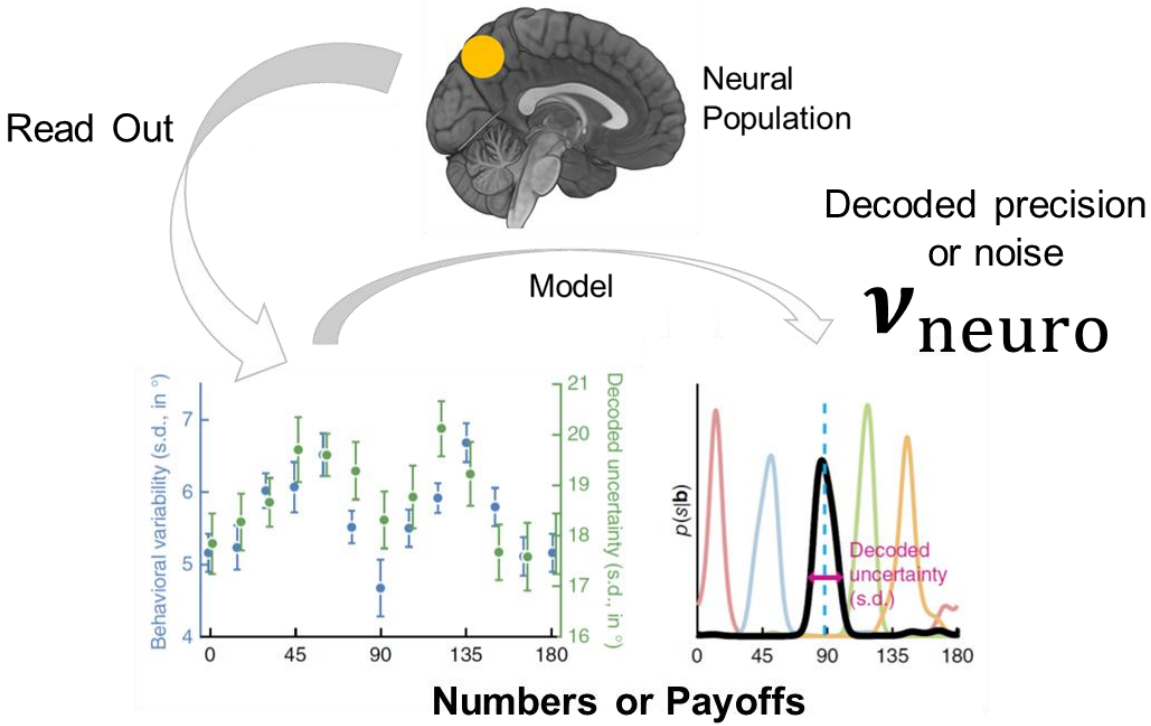


Harvey et al. (2013); Piazza et al. (2004); Nieder and Dehaene (2009)

Next Step:
From Mental to Neural Magnitude Representation

Magnitude Comparison





Van Bergen et al. (2015); Kriegeskorte et al. (2008); Lyons et al. (2015)

Next Step:
From Mental to Neural Magnitude Representation

Research Questions:

1) Can we read out the precision of an individual's mental magnitude representations from independent neural data alone?

2) Do neural data allow a better prediction of risky choice behavior than purely behavioral data?

Challenges and Open Questions

1) Do changes in neural coding change behavior in risk taking as predicted by the model (e.g., context dependence, time pressure, neural stimulation)?

2) How do people with deficits in magnitude perception (e.g., dyscalculia) behave when faced with risky choice?

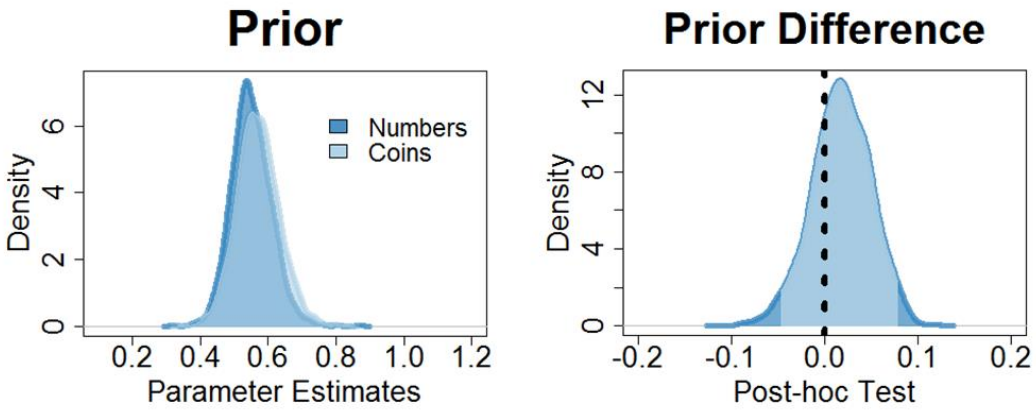
3) Can training in numerical competencies (e.g. Dillon, Duflo et al. 2017, *Science*) lead to more risk-neutral behavior where this is desirable?

4) Does risk contagion in social contexts reflect social influences on risk preferences or magnitude perception?

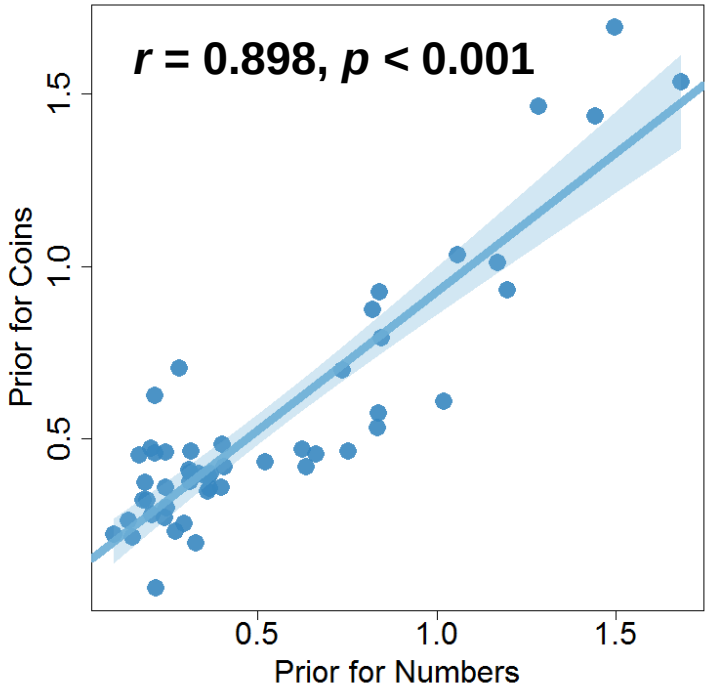
Supplementary Slides

Are the priors for the different display presentations similar?

There is no difference between estimated priors across different magnitude representations (at the population level)…

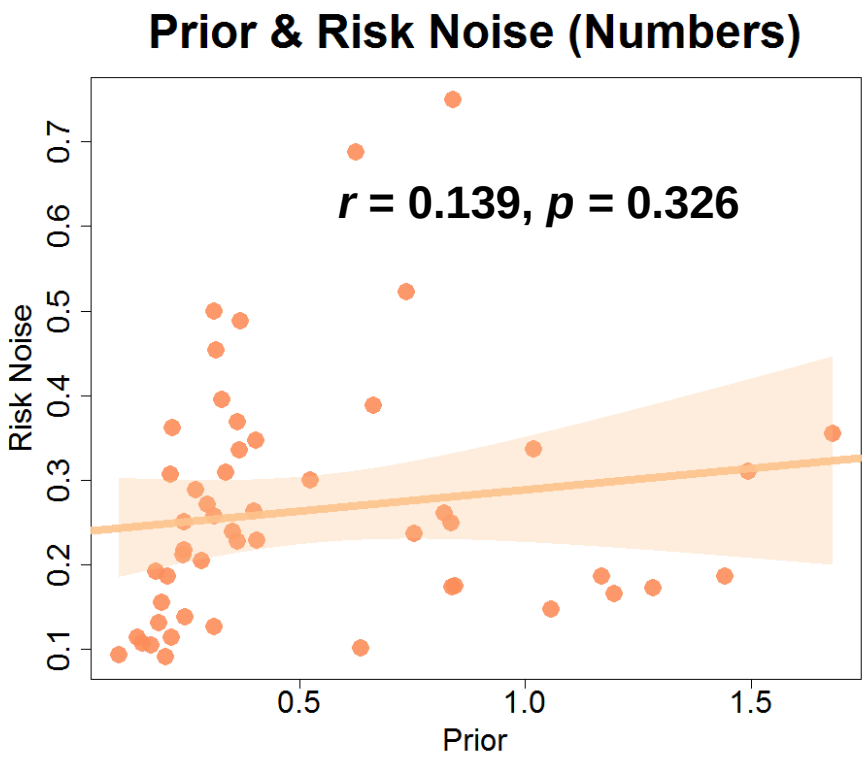


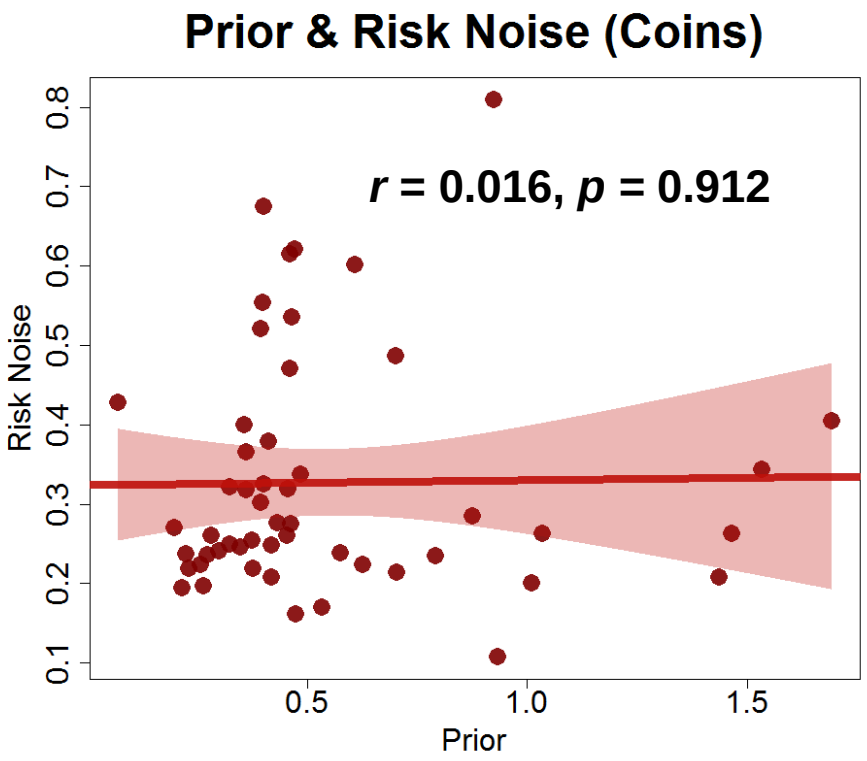
… and these priors are closely related



Are the priors correlated with the noise in the mental representation for monetary payoffs?

The prior and risk noise don't appear to be correlated across payoff representations





Are the priors correlated with the noise in the mental representation for pure magnitudes?

The prior and magnitude noise also don't appear to be correlated across payoff representations