Highway from the Danger Zone: Interactions between uncertainty and cost in spatial estimation

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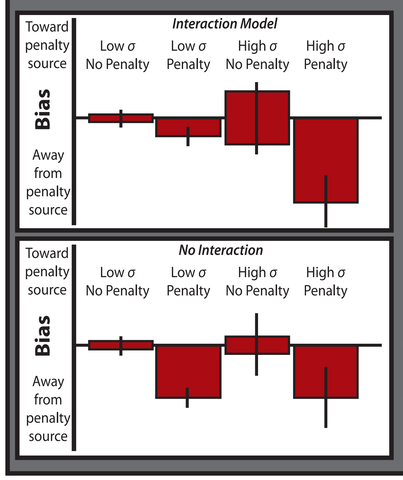
Background

Costs are incorporated during the spatial estimation and selection of a target stimulus (Wu, Delgado & Maloney, 2009). As spatial variability (i.e., sensory uncertainty) of target stimuli increases, selection variability also increases (van Beers, Baraduc & Wolpert, 2002). Furthermore, selections are biased away from optimal estimations when a penalizing distractor is simultaneously presented with a target (Landy, Trommershäuser & Daw, 2012). While spatial variability and reinforcement signals affect target estimations, it is unclear what influence sensory uncertainty may have on cost calculations during spatial sensorimotor decisions.

Hypotheses



If sensory uncertainty influences cost calculations during spatial sensorimotor decisions, then...

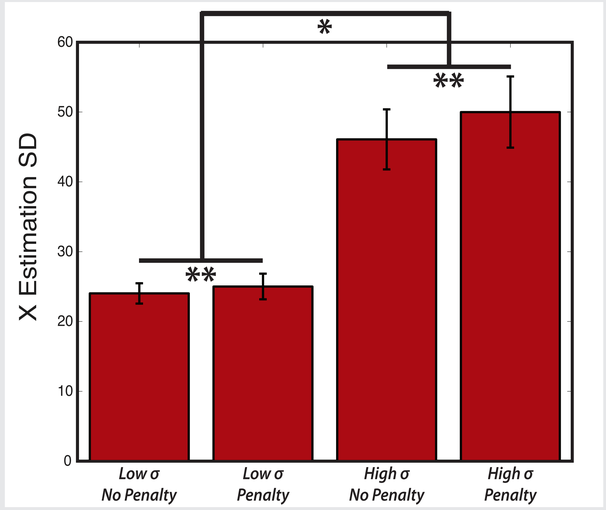
1) Estimation variance should be greater for high variability (i.e., high sensory uncertainty) targets

2) Estimations should be biased away from penalty sources

3) High sensory uncertainty and penalty should interact to strongly bias estimations

Alternatively, if there is no interaction, then there should be no significant difference in bias between penalty conditions

High sensory uncertainty & penalty increase estimation variance



2-way ANOVA	F (1, 22)	p
Variance	57.4895	*1.4214 x 10^{-7}
Penalty	12.5254	**0.0018
Variance by Penalty	0.64	(ns) 0.4323

Paired t Test	t (22)	p
Low σ/No Penalty vs. Low σ/Penalty	-2.0985	**0.0238
Low σ/No Penalty vs. High σ/No Penalty	-8.7607	*< 0.00005
Low σ/Penalty vs. High σ/Penalty	-6.0938	*<0.00005
High σ/No Penalty vs. High σ/Penalty	-1.9663	**0.0310

Results

Estimation Variance (Left)

Significant main effects of target Variance & Penalty on estimation variability

Nonsignificant Variance by Penalty interaction

Greater estimation precision in low variance or no penalty conditions

Estimation Bias (Right)

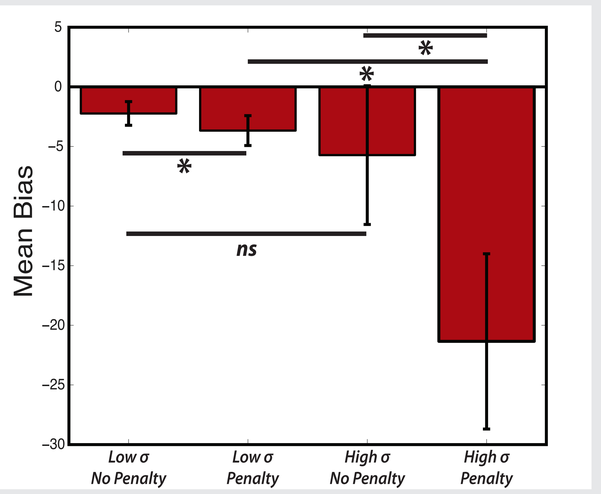
Nonzero bias away from Danger Zone

Penalty significantly biases estimation within conditions

Significant Variance by Penalty interaction in High σ condition

High variance strongly bolsters penalty

Sensory uncertainty & penalty interact to strongly bias estimation



2-way ANOVA	F (1, 22)	p
Variance	6.4371	*0.0188
Penalty	7.0876	*0.0142
Variance by Penalty	4.3607	*0.0486

Paired t Test	t (22)	p
Low σ/No Penalty vs. Low σ/Penalty	2.0423	*0.0266
Low σ/No Penalty vs. High σ/No Penalty	0.8433	(ns) 0.2041
Low σ/Penalty vs. High σ/Penalty	3.003	*0.0033
High σ/No Penalty vs. High σ/Penalty	2.3845	*0.0131

Methods

Participants

23 Carnegie Mellon University undergraduates
(10 F, 13 M), mean age = 19.6 years
CMU IRB-approved consent

Design & Analyses

2 x 2 (Low σ/High σ x No Penalty/Penalty)
4 conditions, within-subjects
Low σ/No Penalty, Low σ/Penalty
High σ/No Penalty, High σ/ Penalty

8 blocks (random) x 100 self-paced trials
80 estimation + 20 catch/block
160 estimation trials/condition

Independent Variables
Target Zone (TZ; white) - max score at true center
100 points sampled from Gaussian distribution
Random μ location
Low σ = 25, High σ = 100
Danger Zone (DZ; red) - max penalty at true center
100 points sampled from Gaussian distribution
DZ μ = TZ + 50 (along X-axis when right of TZ)
DZ μ = TZ - 50 (along X-axis when left of TZ)
Constant σ
No Penalty = 0, Penalty = 0.67 x Reward

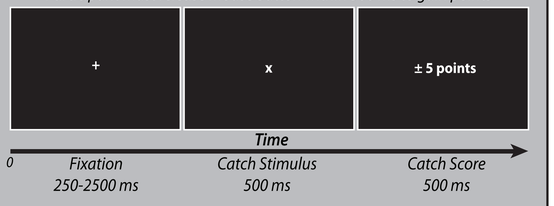
Dependent Variables
X-coordinate estimation variance
Bias = distance away from Danger Zone

2-way ANOVA w/post-hoc paired t Tests
Low σ/No Penalty vs. Low σ/Penalty
Low σ/Penalty vs. High σ/Penalty
High σ/No Penalty vs. High σ/Penalty

Stimulus Presentation

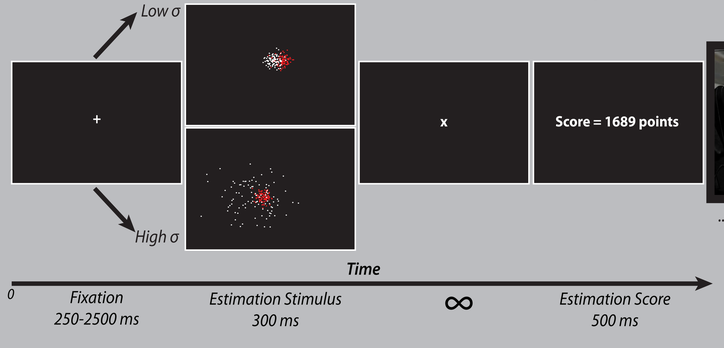
Catch Trial

Participant must release mouse button within 500 ms to gain points



Estimation Trial

Participant initiates trial with mouse click-and-hold, and indicates estimation with drag-and-release



Seriously. Call Kenny Loggins...

*...'cause you're in the **Danger Zone!!!***

Reward & Penalty Scaling

Euclidean distance of Estimation from TZ & DZ

$$TZ_{Dist} = \sqrt{\sum\left((x,y)_{Est_{end}} - (x,y)_{\mu_{TZ}}\right)^2} \qquad DZ_{Dist} = \sqrt{\sum\left((x,y)_{Est_{end}} - (x,y)_{\mu_{DZ}}\right)^2}$$

Raw scores computed from distances

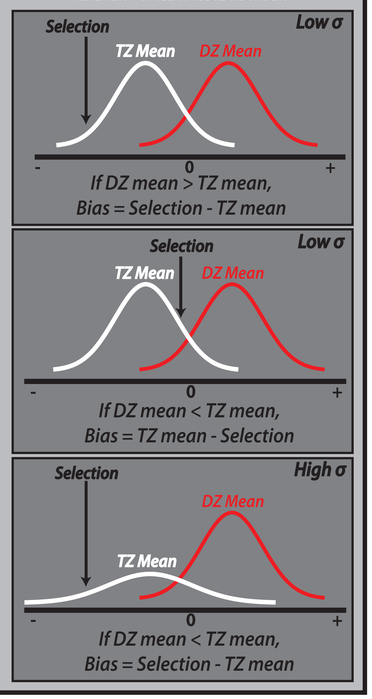
$$EstBonus_{NoPenalty} = \frac{100}{TZ_{Dist}} \qquad EstPenalty_{Penalty} = \frac{100}{DZ_{Dist}}$$

Total Score computed from scaled raw scores

$$Score_{Total} = \left(0.33 * EstBonus_{NoPenalty}\right) - \left(0.67 * EstPenalty_{Penalty}\right)$$

Scaled penalty calculated only in Penalty condition

Bias Calculations



Summary

High sensory uncertainty increases spatial selection variance

Spatial selections are biased away from distractors

Penalty signals interact with high and low sensory uncertainty to bias selections

Conclusion

Sensory variance influences cost calculations during spatial estimation

References

Wu, S.-W., Delgado, M. R., & Maloney, L. T. (2009). Economic decision-making compared with an equivalent motor task. Proceedings of the National Academy of Sciences of the United States of America, 106(15), 6088–93.

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Landy, M. S., Trommershäuser, J., & Daw, N. D. (2012). Dynamic estimation of task-relevant variance in movement under risk. The Journal of Neuroscience, 32(37), 12702–11.