Causal Learning With Delays Up to 21 Hours

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INTRODUCTION

- Delays between causes and effects are commonly found in cause-effect relationships in real life. There are still open debates in the theorizing of the impact of the delay on learning in the fields of causal, reinforcement, and associative learning.
- Initially it was believed that learning is worse with longer intervals between the conditioned stimulus and unconditioned stimulus in animal conditioning[1] and human causal learning[2].
- Subsequent studies showed that learning with delays are possible. For example, animals are capable of learning associations with food-related or fearful stimuli[3,4], and human are capable of learning delayed causal relationship with an assumption of delays[5,6].
- Previous studies have only investigated delays on the order of seconds. In the current study we tested whether people can learn a cause-effect relation with hour long delays.

METHODS

Design

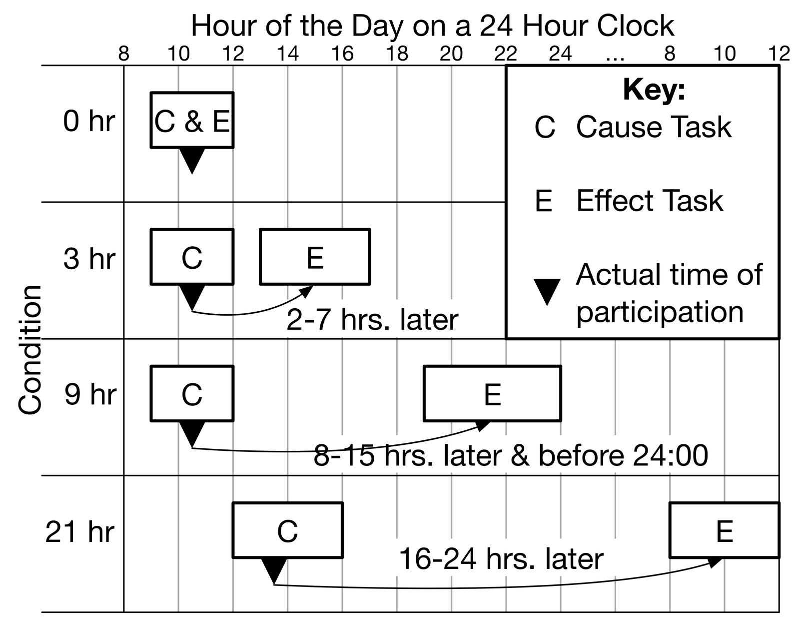
2 x 4 between-subject design; trial by trial learning; one trial per day.

- 2 types of datasets: positive correlation dataset [A=6, B=2, C=2, D=6; ΔP = +0.5]; negative correlation dataset [A=2, B=6, C=6, D=2; ΔP = -0.5][7]

		Outcome	
		Present	Absent
Cause	Present	A	B
	Absent	C	D

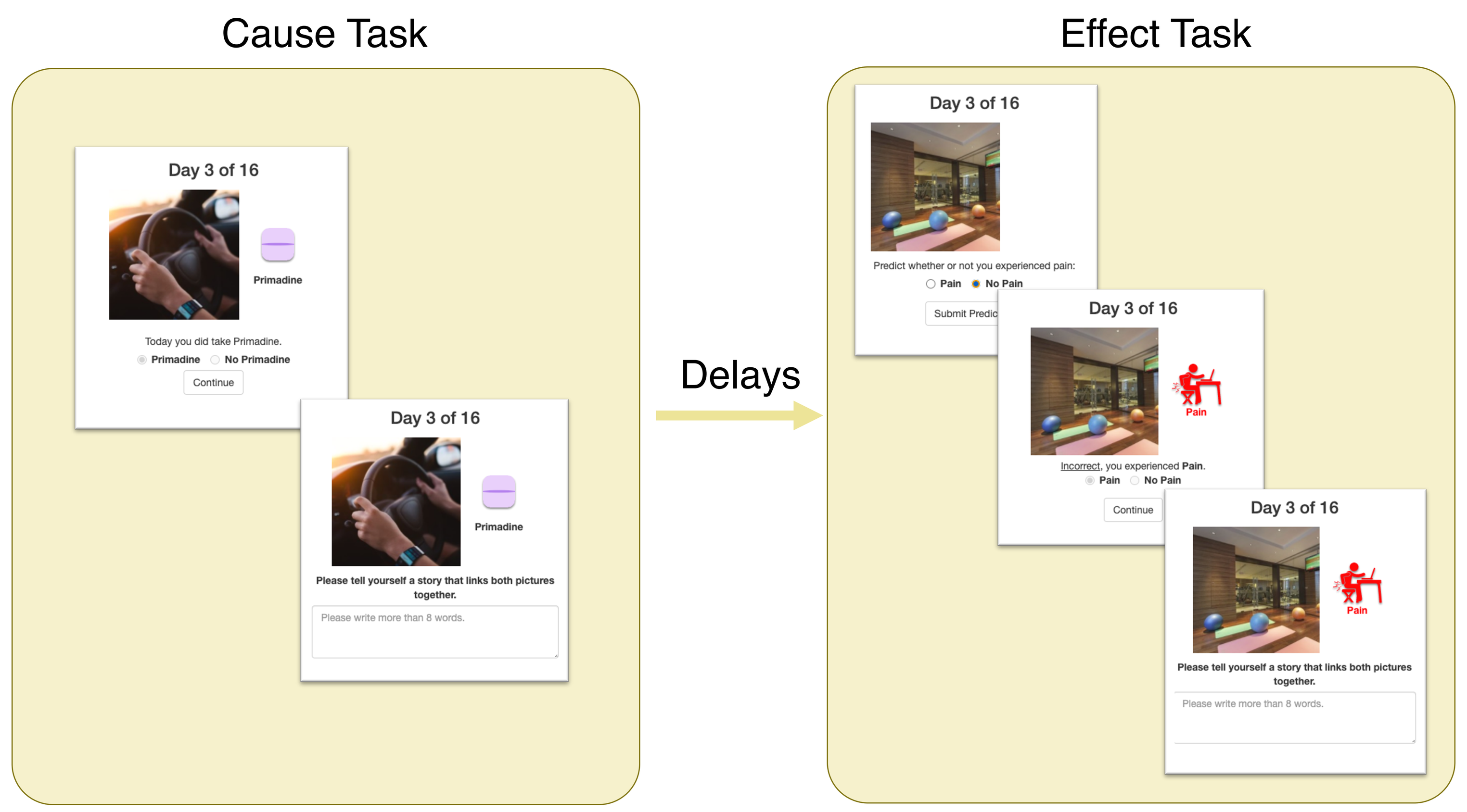
$$\Delta P = P(outcome|cause) - P(outcome|\sim cause)$$
$$= \frac{A}{A+B} - \frac{C}{C+D}$$

- 4 temporal delay conditions of roughly 0, 3, 9, or 21 hours between the cause and effect within each trial.



Procedure

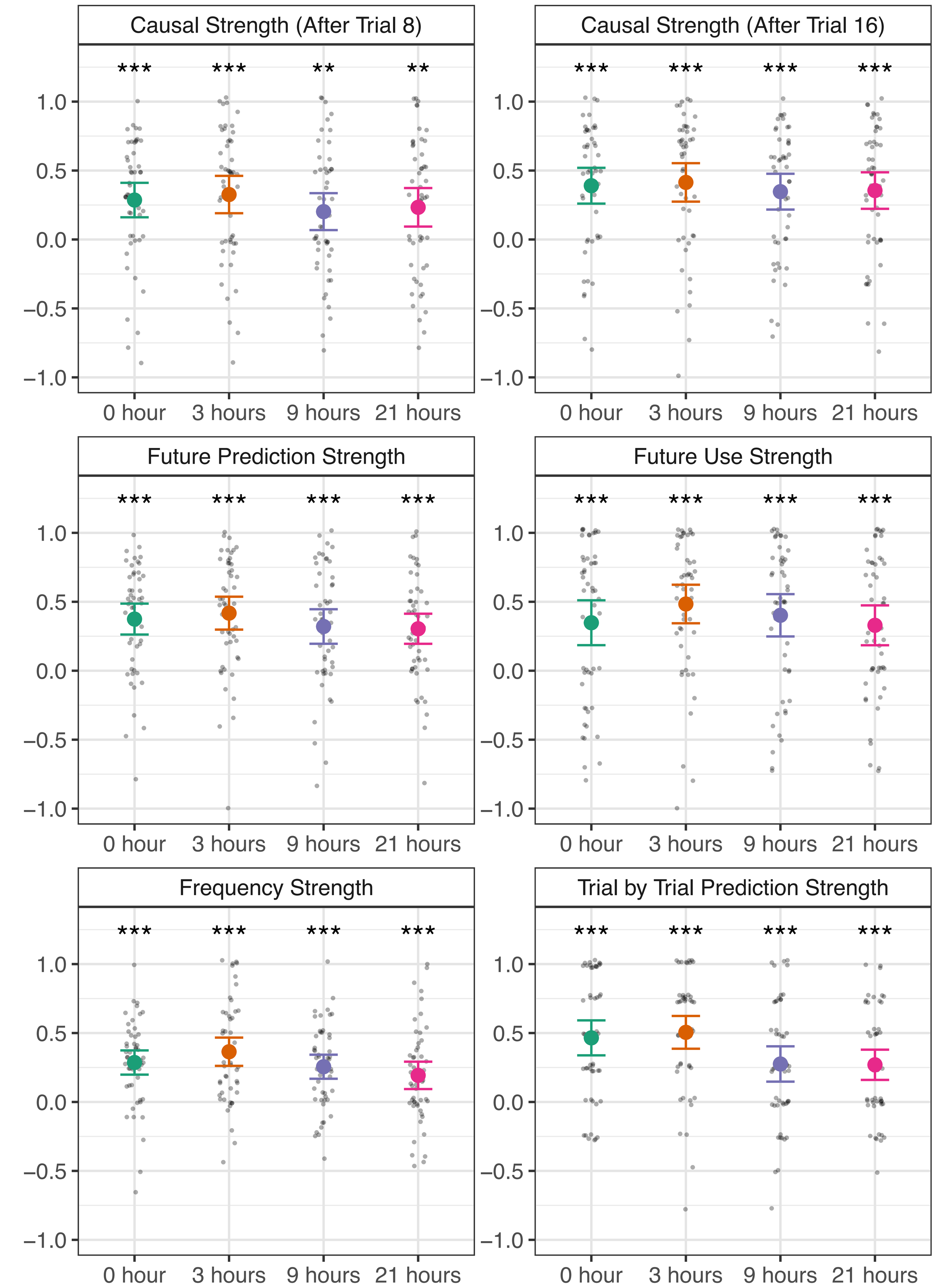
- 202 participants completed the 16-day learning study on their smartphone.
- Each day, participants received reminders to do a **cause task** in which they learned whether the cause is present or absent, a certain time later, they received reminders to do an **effect task** in which they learned whether the effect is present or not.
- On the day after Trial 16, participants completed a causal judgment task.



Dependent Measures

- **Causal Strength**: Both after Trial 8 and Trial 16, participants answered "Does the medicine worsens, improves, or has no influence on pain?" (on a scale of -10 to +10, -10 = strongly worsens, 0 = no influence, and +10 = strongly improves).
- **Future Prediction Strength**: Participants answered "Imagine that 'tomorrow' (Day 17) you take/do not take" medicine. On a scale of 0 to 100\%, what do you think is the likelihood that you would experience pain?" The future prediction strength was derived by subtracting the responses of not taking the medicine from taking the medicine - similar to the ΔP rule.
- **Future Use Strength**: Participants answered whether they believe they should continue to use the medicine on a scale of -10 to +10, -10 = definitely no, 0 = unsure, +10 = definitely yes.
- **Frequency Strength**: Participants recalled the frequencies of A, B, C, and D cells (e.g., "Of the 16 days in the study, how many days did you see a picture in which you did take the medicine and did experience pain"). The future prediction strength was computed using the delta P rule.
- **Trial by Trial Prediction Strength**: We computed "prediction strength" from participants' predictions about the presence or absence of the effect from Trial 9 to Trial 16 using a similar equation as calculating frequency strength.

RESULTS



- For ease of interpretation, we inverse coded the judgments for the negative datasets so that they are positive.
- Participants' judgments were above zero for all six measures and for all 4 conditions, which provides evidence that **participants were able to learn the contingency between the cause and effect in every condition**.
- We conducted an ANOVA for each dependent measure. If learning becomes weaker with longer delays, there should be a main effect of delay. **The only measure that found an effect of delay was the trial-by-trial prediction strength measure.**
- We conducted linear regressions to test for an effect of the actual delay that a participant experienced. The delay is coded in terms of hours. Similar to the ANOVA results, we only found a main effect of delay in the trial by trial prediction strength measure.

	ANOVA			Regression		
	F	*p*	BF	*β*	*p*	BF
Causal Strength (After Trial 8)						
Delay	0.620		††	-0.003		
Dataset	3.977	*		-0.101		
Delay:Dataset	1.125		†	-0.004		†
Causal Strength (After Trial 16)						
Delay	0.183		††	-0.002		†
Dataset	14.172	***	****	-0.241	**	*
Delay:Dataset	0.272		††	0.000		†
Frequency Strength						
Delay	2.238			-0.006		
Dataset	1.651			-0.117		
Delay:Dataset	0.462		††	0.007		
Future Use Strength						
Delay	0.853		††	-0.003		†
Dataset	12.565	***	***	-0.293		*
Delay:Dataset	0.358		††	0.004		†
Future Prediction Strength						
Delay	0.759		††	-0.004		
Dataset	14.749	***	****	-0.261	***	**
Delay:Dataset	0.570		††	0.005		†
Trial by Trial Prediction Strength						
Delay	4.284		*	-0.011	**	**
Dataset	12.119	***	***	-0.277	***	***
Delay:Dataset	0.773		†	0.009		

Note:p-values: *<0.05, **<0.01, ***<0.001
BFs in favor of alternate hypothesis: *>3, **>10, ***>30, ****>100
BFs in favor of null hypothesis: †>3, ††>10, †††>30, ††††>100

DISCUSSION

- This is the first study to investigate human causal learning in which the trials were spaced out over time (once per day) and there were considerable delays between the cause and the effect ranging from 0 to 21 hours.
- Critically, participants are capable of learning cause-effect relationships with delays up to 21 hours, and for the most part causal learning was not affected by the length of delay, ranging from 0 to 21 hours.
- Exceptions we found: delay affected the trial by trial prediction strength, which was computed from predictions from Trial 9 ~ 16. By further looking at the predictions over the whole 16 trials, we found that the the effect of delays happened to mainly occurred in the second half. The reason why we only found impact of delay in this measure need to be further investigated.

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