Summation in human causal reasoning

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Most models of causal learning and reasoning assume that the causal strength of compound causes should be equal to the nonoverlapping addition of the causal strength of their elements (see Figure 1). In other words, the probability of an outcome in presence of two causes, p(O|A&B), would be equal to p(O|A) + p(O|B). This assumption is present in many rule-based (Allan, 1980; Cheng & Novick, 1992) and associative models of causal learning (Rescorla & Wagner, 1972; Van Hamme & Wasserman, 1994).

However, according to some rule-based models, such as the Power PC theory of causal induction (Cheng, 1997), the combination of the causal impact of two events, A and B, should be computed as an overlapping probabilistic addition. So, the probability of the outcome in the presence of A and B should be computed as p(O|A&B) = p(O|A) + p(O|B) – [p(O|A) x p(O|B)]. Some associative models of causal learning also include this summation rule (Danks, Griffiths, & Tenenbaum, 2003).

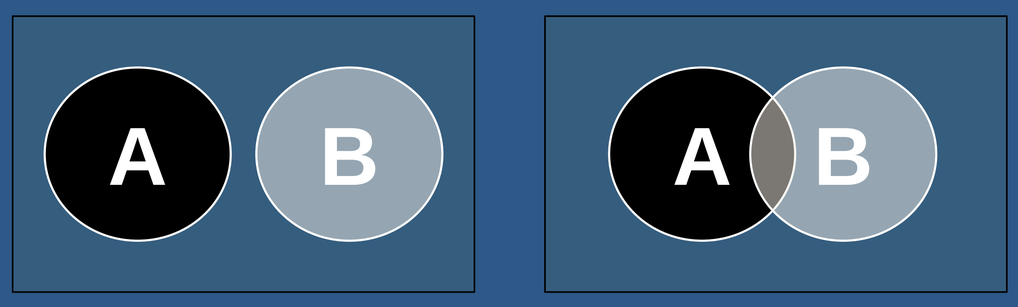

Fig. 1. Representation of nonoverlapping and overlapping probabilitistic addition. If circles A and B represent the probability of the outcome given A or B, then the p(O|A&B) = p(O|A) + p(O|B) in the left panel, but p(O|A&B) = p(O|A) + p(O|B) - [p(O|A) x p(O|B)] in the right panel.

Method

In four experiments, we tested whether people tend to summate the effect of several causes either in the former or in the latter manner. In all these studies, participants were given information about the causal influence of five cues, A-E, on a given outcome. Then, they were asked to imagine that they wanted to produce the outcome and to chose accordingly whether they would prefer the compound AB over the compound CE and, in a separate question, whether they would prefer AB over DE.

In all the experiments, the probabilities of the effect in the presence of each cue (see Table 1) were selected so that **preference of CE over AB was indicative of overlapping summation, whereas preference of AB over DE was indicative of nonoverlapping summation** (see Table 2). The probabilities used in each experiment were different, so that we could make sure that the results didn't depend on some specific properties of these probabilties (e.g., whether the simple sum of the elements was higher than 100%, whether cue E was ineffective or not, etc.).

References

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Results and Discussion

As can be seen in Figure 2, participants systematically tended to prefer AB to DE. Additionally, they showed no preference for CE over AB (in fact, a significant trend in the opposite direction is observed in some experiments).

These results are consistent with the idea that humans follow a nonoverlapping summation rule when inferring the causal value of compound cues. This is consistent with the predictions of the Δp rule (Allan, 1980; Cheng & Novick, 1992) and the Rescorla-Wagner learning algorithm, but not with those of Power PC theory of causal induction (Cheng, 1997).

	Exp. 1	Exp. 2	Exp. 3	Exp. 4
p(O|A)	40%	60%	60%	85%
p(O|B)	40%	65%	65%	40%
p(O|C)	80%	97%	95%	100%
p(O|D)	64%	86%	80%	88%
p(O|E)	0%	0%	30%	25%

Table 1. Probabilities of the outcome in the presence of cues A-E in each experiment. The cover story used was designed so that participants assumed that the probability of the outcome in the absence of any of these potential causes would be zero.

	Exp. 1		Exp. 2		Exp. 3		Exp. 4	
	Δp	Power PC	Δp	Power PC	Δp	Power PC	Δp	Power PC
AB	80%	64%	125%	86%	125%	86%	125%	91%
CE	80%	80%	97%	97%	125%	96.5%	125%	100%
DE	64%	64%	86%	86%	110%	86%	113%	91%

Table 2. Predicted sum of probabilities according to the Δp rule and the Power PC model. The Δp rule assumes a nonoverlapping summation rule and the Power PC model assumes an overlapping summation rule.

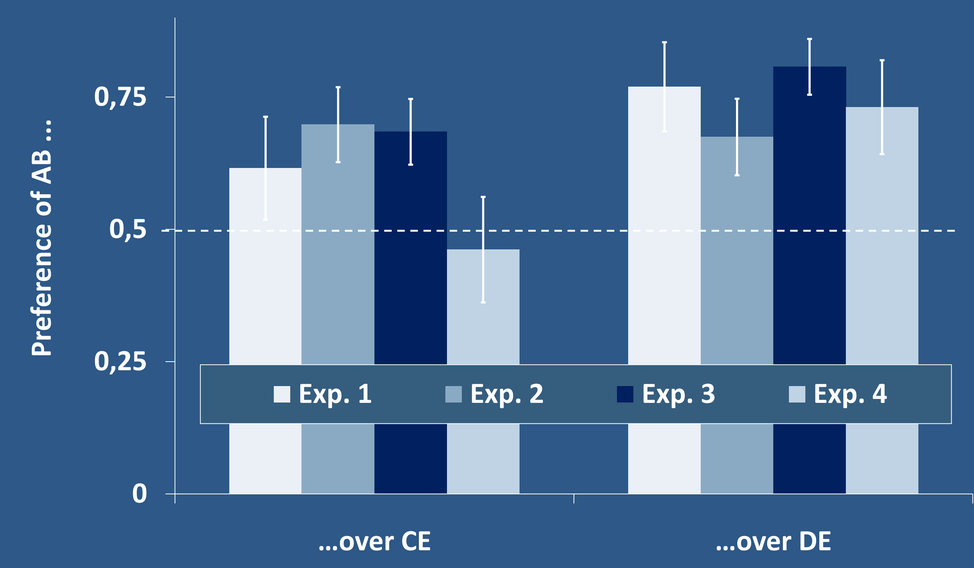

Fig. 2. Proportion of preference of AB over CE and DE. The dotted line represents indifference between AB and the other compounds. Error bars denote the standard error of the mean.

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