LETTER

Reply to Rankin et al.: The efficiency ratio of costly punishment

The letter from Rankin et al. (1) suggests there are three problems with our claim (2) that our experimental results argue against group selection in the repeated Prisoner's Dilemma (PD) game as a mechanism to explain the appearance of costly punishment in human societies. The first two problems are discussed in terms of their definition of α/β as the "efficiency ratio of punishment" because, as they point out, this ratio depends on d when these three parameters are associated with the same payoff matrix (see Eq. **2**).

In our treatments T1 and T2, subjects were told that they have three possible choices A, B, and C. They were also told the corresponding payoffs through specifying nonnegative values of b, c, d, α, β in

Option	You will get	The other person will get
A:	$-c$	b
B:	d	$-d$
C:	$-\alpha$	$-\beta$

where α and β mean paying a cost α for another individual to incur a cost β and d is the amount transferred to you from the other person if you choose B. The options A, B, C correspond to cooperation, defection, costly punishment, respectively (although these names were not used with our subjects). In our experiments, which have $d = 1$, a rational participant who wants to punish an opponent who has just defected will know clearly what "defection" means in this game. That is, this subject reacts to the immediate loss defection has inflicted and not to the absence of cooperation (i.e., $d = 0$) in a game with the same payoff matrix

$$\begin{array}{c} \\ \mathrm{C} \\ \mathrm{D} \\ \mathrm{P} \end{array} \begin{array}{c} \begin{array}{ccc} \mathrm{C} & \mathrm{D} & \mathrm{P} \end{array} \\ \begin{pmatrix} b-c & -c-d & -c-\beta \\ b+d & 0 & -\beta+d \\ b-\alpha & -\alpha-d & -\alpha-\beta \end{pmatrix} \end{array}. \qquad [1]$$

An important question is how to measure the "benefit" of punishment to predict the likelihood subjects will punish a defector. We strongly disagree with using α/β. If this were correct, for our treatments with

$$\frac{\alpha}{\beta} = \frac{2-d}{3+d}, \qquad [2]$$

it would be less conducive to punish as d decreases (3). The problem with this measure is that it only considers effects that punishing has on payoffs and ignores the payoff effects of defection (e.g., the loss $-d$ that defection imposes on the payoff $E(P,D)$ to the punisher). To include such effects, we recommend the efficiency ratio of punishment be measured by $E(P,D)/E(D,P) = (\alpha + d)/(\beta - d)$ where $E(D,P)$ is the defector's payoff against a punisher. This ratio, based on net payoffs between defectors and punishers, is obviously unique for a given payoff matrix.

We agree that Rankin el al.'s third problem raises an important issue. Their suggestion of having costly punishment "a separate decision between two rounds" is a good idea to test its evolutionary significance (see ref. 4 for this experimental approach applied to repeated public goods games). However, we expect this change will not alter the result for the repeated PD game with Chinese subjects (2) that costly punishment does not significantly increase a subject's average payoff per round. This expectation follows from recalculating our subject's average payoff per round after eliminating treatment rounds in which the subject used C. There is still no significant increase over corresponding controls. Interestingly, our recalculated averages show a trend similar to that found without elimination in the same experiment using subjects in Boston (5). If the experiments proposed by Rankin et al. show significant increases for such subjects, this is further evidence cultural differences are important in repeated PD games.

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The authors declare no conflict of interest.

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