# Supplementary Information for
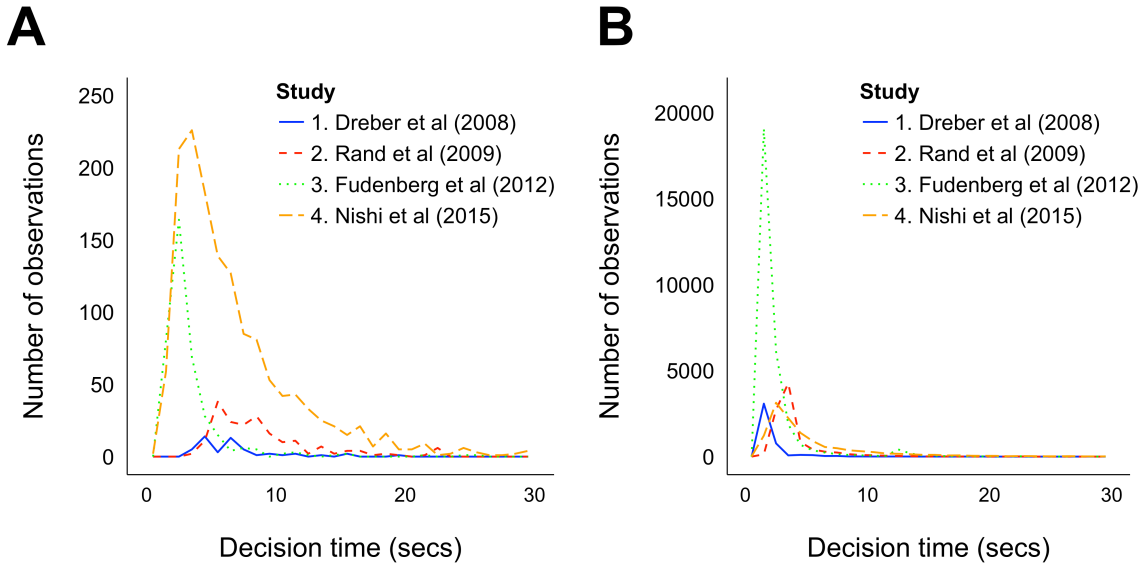## "Social Environment Shapes the Speed of Cooperation"

Akihiro Nishi, Nicholas A. Christakis, Anthony M. Evans, and A. James O'Malley,
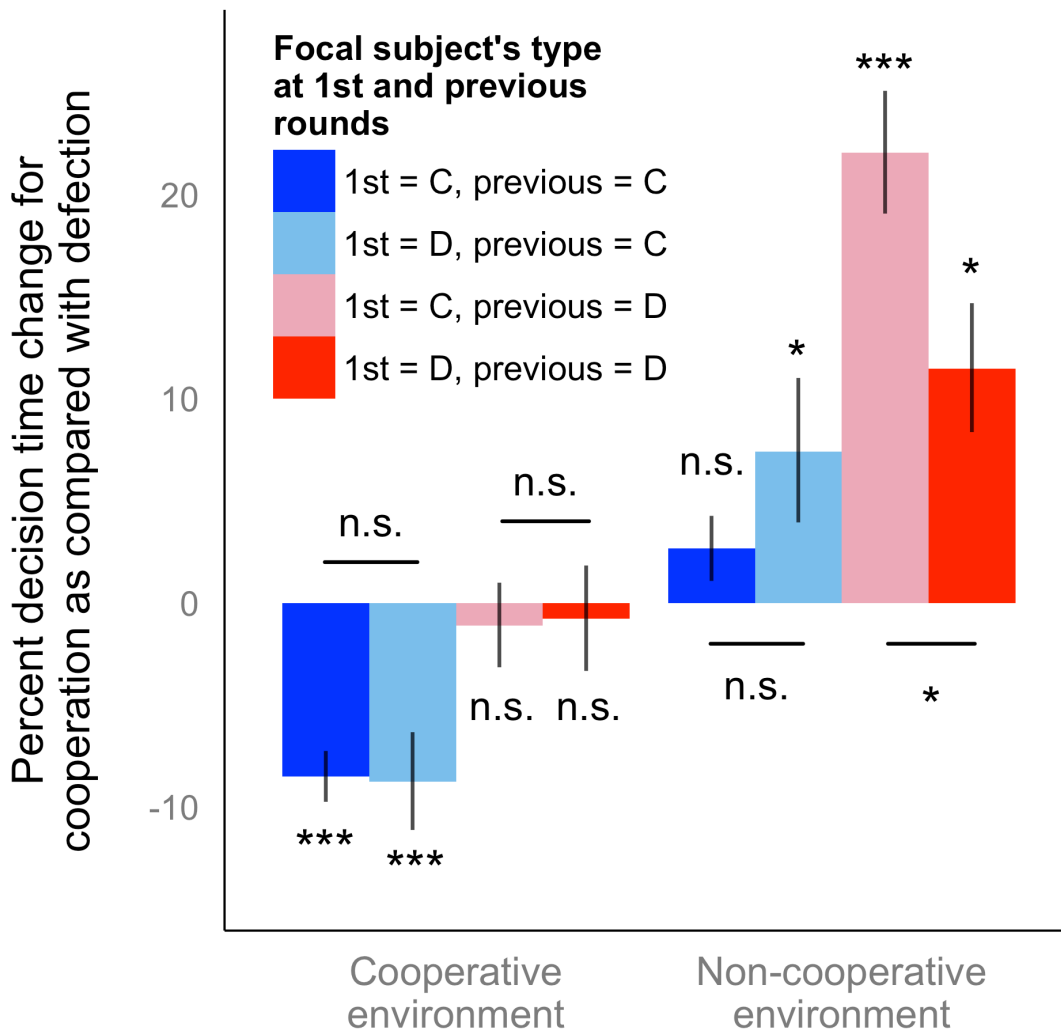David G. Rand*

*To whom correspondence should be addressed. E-mail: david.rand@yale.edu (DGR).

## A list of SI Appendix

**Fig. S1. Distributions of decision time in the four studies (frequency polygon plots). (A)** 1st round. **(B)** 2nd- rounds.

**Fig. S2. In addition to Fig. 2 (stratification by the previous-round behaviors), statistical analysis was performed stratified by the 1st-round behaviors.** C represents cooperation decisions, and D represents defection decisions. Both the result of hypothesis testing for each bar (away from 0) and that for the comparison between two bars by an interaction term are shown. Error bars, point estimates ± standard errors. n.s. for $P \geq 0.05$, * for $P < 0.05$, ** for $P < 0.01$, and *** for $P < 0.001$.
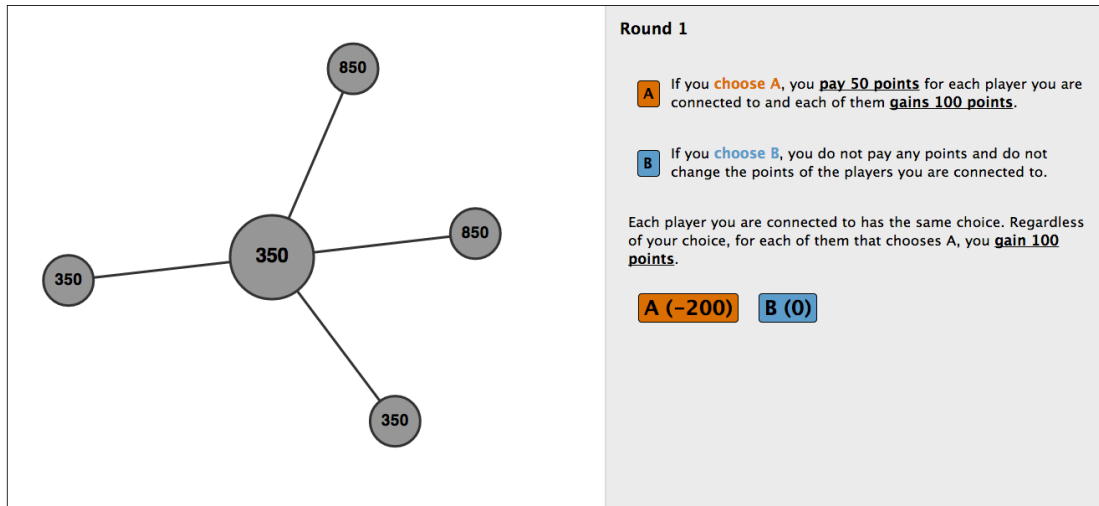
**Fig. S3. Illustrative screenshot on when the decision time is measured (from Nishi et al, 2015 [Study 4]).** In the screenshot, the focal individual having a score of 350 is asked to choose "A (-200)" (cooperate, "C") or "B (0)" (defect, ""D). Values in the circles represent the cumulative payoff at the 1$^{st}$ round of the focal individual and connecting. Decision time represents how long each individual stays at this screen. The one for the visible condition is shown (the scores of connecting neighbors are available), which was not shown in the invisible condition.
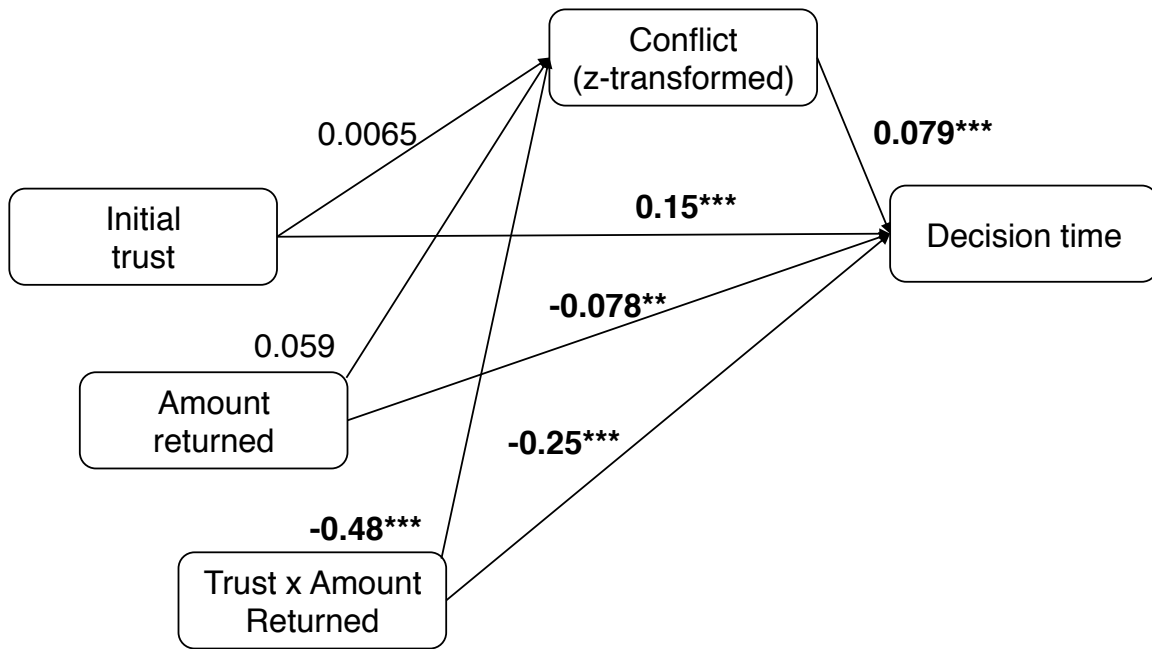
**Fig. S4. Structural equation modeling shows the association of reciprocity (trust x amount returned) with decision time is partially mediated by level of conflict.** Initial trust is the level of money sent from Player 1 (P1) to Player 2 (P2), which represents the type of the social environment of P1. Amount returned is the level of money sent back from P2 to P1, which represent the decision making of P2. The level of conflict of P2 is z-transformed, and decision time of P2 is $\log_{10}$-transformed. No sign for $P \geq 0.05$, ** for $P < 0.01$, and *** for $P < 0.001$.

|  | Study 1 | Study 2 | Study 3 | Study 4 | Combined |
|---|---|---|---|---|---|
| **Fixed effects** | | | | | |
| Cooperation | -0.150** | -0.0802** | -0.102*** | -0.0393* | -0.0579*** |
|  | (0.0556) | (0.0295) | (0.0272) | (0.0161) | (0.0128) |
| Constant | 0.866*** | 0.945*** | 0.429*** | 0.764*** | 0.725*** |
|  | (0.0564) | (0.0286) | (0.0322) | (0.0149) | (0.116) |
| **Random effects** | | | | | |
| Study-level variance | | | | | 0.0522 |
|  | | | | | (0.0431) |
| Game-level variance | 0.00208 | 0.00849 | 0.00997 | 0.00383 | 0.00486 |
|  | (0.00482) | (0.00314) | (0.00440) | (0.00133) | (0.00116) |
| Residual variance | 0.0322 | 0.0251 | 0.0575 | 0.0783 | 0.0689 |
|  | (0.00663) | (0.00296) | (0.00426) | (0.00300) | (0.00221) |
| N | 50 | 192 | 384 | 1442 | 2068 |

**Table S1. Statistical analysis at the 1$^{st}$ round (the original results for Fig. 1, left).**
Standard errors in parentheses. For fixed effects, * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$. Random intercepts model was used.

|  | Study 1 | Study 2 | Study 3 | Study 4 | Combined |
|---|---|---|---|---|---|
| **Fixed effects** | | | | | |
| Cooperation | -0.0540** | 0.00459 | -0.0400*** | -0.0235** | -0.0270*** |
|  | (0.0184) | (0.00912) | (0.00488) | (0.00733) | (0.00366) |
| Round | -0.00233*** | -0.000723*** | 0.000184*** | -0.0119*** | 0.0000133 |
|  | (0.000340) | (0.000141) | (0.0000524) | (0.00101) | (0.0000498) |
| Constant | 0.251*** | 0.513*** | 0.182*** | 0.712*** | 0.378** |
|  | (0.0564) | (0.0130) | (0.0240) | (0.0104) | (0.124) |
| **Random effects** | | | | | |
| Study-level variance |  |  |  |  | 0.0608 |
|  |  |  |  |  | (0.0502) |
| Game-level variance | 0.00561 | 0.00296 | 0.00929 | 0.00158 | 0.00321 |
|  | (0.00831) | (0.000982) | (0.00343) | (0.000614) | (0.000610) |
| Subject-level variance | 0.00256 | 0.00501 | 0.0137 | 0.0275 | 0.0220 |
|  | (0.00112) | (0.000736) | (0.00112) | (0.00149) | (0.000940) |
| Residual variance | 0.0534 | 0.0266 | 0.0443 | 0.0575 | 0.0447 |
|  | (0.00260) | (0.000464) | (0.000492) | (0.000907) | (0.000356) |
| N | 890 | 6748 | 16625 | 9418 | 33681 |

**Table S2. Statistical analysis at a cooperation-rich environment (the 2$^{nd}$- rounds) (the original results for Fig. 1, middle).** Standard errors in parentheses. For fixed effects, * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$. Random intercepts model was used.

|  | Study 1 | Study 2 | Study 3 | Study 4 | Combined |
|---|---|---|---|---|---|
| **Fixed effects** | | | | | |
| Cooperation | 0.128*** | 0.0561*** | -0.00505 | 0.0653*** | 0.0185*** |
|  | (0.0232) | (0.0105) | (0.00563) | (0.0131) | (0.00459) |
| Round | -0.00130*** | -0.00153*** | 0.000625*** | -0.00989*** | 0.000437*** |
|  | (0.000223) | (0.000273) | (0.0000673) | (0.00208) | (0.0000613) |
| Constant | 0.167** | 0.499*** | 0.144*** | 0.672*** | 0.334** |
|  | (0.0609) | (0.0176) | (0.0239) | (0.0179) | (0.124) |
| **Random effects** | | | | | |
| Study-level variance | | | | | 0.0603 |
|  | | | | | (0.0499) |
| Game-level variance | 0.00696 | 0.00418 | 0.00907 | 0.000640 | 0.00432 |
|  | (0.0103) | (0.00193) | (0.00337) | (0.000752) | (0.000964) |
| Subject-level variance | 0.00580 | 0.00656 | 0.0144 | 0.0252 | 0.0166 |
|  | (0.00144) | (0.00145) | (0.00122) | (0.00239) | (0.00105) |
| Residual variance | 0.0446 | 0.0335 | 0.0611 | 0.0548 | 0.0558 |
|  | (0.00150) | (0.000936) | (0.000768) | (0.00170) | (0.000572) |
| N | 1830 | 2660 | 13029 | 2700 | 20219 |

**Table S3. Statistical analysis at a defection-rich environment (the 2$^{nd}$- rounds) (the original results for Fig. 1, right).** Standard errors in parentheses. For fixed effects, * $P$ < 0.05, ** $P$ < 0.01, and *** $P$ < 0.001. Random intercepts model was used.

|  | Study 1 | Study 2 | Study 3 | Study 4 | Combined |
|---|---|---|---|---|---|
| **Fixed effects** | | | | | |
| Cooperation | 0.118*** | 0.0592*** | -0.0103* | 0.0488*** | 0.0126** |
| | (0.0236) | (0.00908) | (0.00490) | (0.0125) | (0.00405) |
| Cooperative environment, A | 0.0342* | 0.0398*** | 0.0121** | 0.0296*** | 0.0216*** |
| | (0.0141) | (0.00985) | (0.00438) | (0.00861) | (0.00341) |
| Cooperation x A | -0.155*** | -0.0541*** | -0.0216*** | -0.0729*** | -0.0370*** |
| | (0.0283) | (0.0124) | (0.00641) | (0.0139) | (0.00508) |
| Round | -0.00167*** | -0.00103*** | 0.000377*** | -0.0115*** | 0.000185*** |
| | (0.000184) | (0.000124) | (0.0000414) | (0.000894) | (0.0000382) |
| Constant | 0.183** | 0.477*** | 0.156*** | 0.682*** | 0.345** |
| | (0.0587) | (0.0119) | (0.0239) | (0.0116) | (0.124) |
| **Random effects** | | | | | |
| Study-level variance | | | | | 0.0606 |
| | | | | | (0.0500) |
| Game-level variance | 0.00655 | 0.00307 | 0.00945 | 0.00146 | 0.00302 |
| | (0.00956) | (0.000961) | (0.00346) | (0.000544) | (0.000559) |
| Subject-level variance | 0.00418 | 0.00543 | 0.0132 | 0.0264 | 0.0208 |
| | (0.00102) | (0.000709) | (0.00103) | (0.00131) | (0.000838) |
| Residual variance | 0.0480 | 0.0287 | 0.0523 | 0.0571 | 0.0494 |
| | (0.00131) | (0.000422) | (0.000432) | (0.000782) | (0.000307) |
| N | 2720 | 9408 | 29654 | 12118 | 53900 |

**Table S4. Statistical analysis for interactions (the 2$^{nd}$- rounds).** "Cooperation x A" is the variable of interest. Standard errors in parentheses. For fixed effects, * $P$ < 0.05, ** $P$ < 0.01, and *** $P$ < 0.001. Random intercepts model was used.

| | Cooperative environment | | | Non-cooperative environment | | |
|---|---|---|---|---|---|---|
| | All | C at previous round | D at previous round | All | C at previous round | D at previous round |
| **Fixed effects** | | | | | | |
| Cooperation at last round, A | 0.0120* | | | -0.0304*** | | |
| | (0.00604) | | | (0.00506) | | |
| Cooperation at present round, B | -0.0135* | -0.0408*** | -0.00650 | 0.0546*** | 0.0148* | 0.0688*** |
| | (0.00574) | (0.00521) | (0.00713) | (0.00764) | (0.00613) | (0.00813) |
| A x B | -0.0234** | | | -0.0360*** | | |
| | (0.00776) | | | (0.00988) | | |
| Round | 0.0000156 | 0.0000841 | -0.0000488 | 0.000431*** | -0.000220* | 0.000821*** |
| | (0.0000498) | (0.0000565) | (0.000110) | (0.0000613) | (0.0000961) | (0.0000802) |
| Constant | 0.375** | 0.386** | 0.383** | 0.342** | 0.354** | 0.317** |
| | (0.124) | (0.128) | (0.122) | (0.123) | (0.126) | (0.121) |
| **Random effects** | | | | | | |
| Study-level variance | 0.0607 | 0.0653 | 0.0582 | 0.0592 | 0.0626 | 0.0574 |
| | (0.0501) | (0.0538) | (0.0483) | (0.0491) | (0.0517) | (0.0477) |
| Game-level variance | 0.00319 | 0.00301 | 0.00450 | 0.00430 | 0.00376 | 0.00489 |
| | (0.000606) | (0.000634) | (0.00105) | (0.000965) | (0.00107) | (0.00111) |
| Subject-level variance | 0.0219 | 0.0212 | 0.0216 | 0.0163 | 0.0141 | 0.0161 |
| | (0.000938) | (0.00102) | (0.00149) | (0.00104) | (0.00133) | (0.00115) |
| Residual variance | 0.0447 | 0.0392 | 0.0590 | 0.0556 | 0.0477 | 0.0585 |
| | (0.000356) | (0.000360) | (0.00101) | (0.000570) | (0.000895) | (0.000734) |
| N | 33676 | 25651 | 8025 | 20216 | 6561 | 13655 |

**Table S5. Stratified analysis by the previous-round behaviors (the original results for Fig. 2).** Standard errors in parentheses. For fixed effects, * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$. Random intercepts model was used.

| | Cooperative environment | | | | | | Non-cooperative environment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C at previous round | | | D at previous round | | | C at previous round | | | D at previous round | | |
| | All | C at first round | D at first round | All | C at first round | D at first round | All | C at first round | D at first round | All | C at first round | D at first round |
| **Fixed effects** | | | | | | | | | | | | |
| Cooperation at first round, A | -0.0201 | | | -0.0566*** | | | -0.0131 | | | -0.0332** | | |
| | (0.0136) | | | (0.0125) | | | (0.0138) | | | (0.0109) | | |
| Cooperation at present round, B | -0.0424*** | -0.0387*** | -0.0398*** | 0.00239 | -0.00481 | 0.00341 | 0.0314* | 0.0114 | 0.0311* | 0.0474*** | 0.0865*** | 0.0472*** |
| | (0.0109) | (0.00591) | (0.0114) | (0.0108) | (0.00910) | (0.0113) | (0.0126) | (0.00674) | (0.0143) | (0.0117) | (0.0107) | (0.0123) |
| A x B | 0.00347 | | | -0.00804 | | | -0.0209 | | | 0.0416* | | |
| | (0.0124) | | | (0.0144) | | | (0.0144) | | | (0.0162) | | |
| Round | 0.0000832 | 0.0000862 | 0.0000603 | -0.0000323 | 0.0000416 | -0.0000950 | -0.000228* | -0.000219* | -0.000271 | 0.000822*** | 0.000736*** | 0.000898*** |
| | (0.0000565) | (0.0000600) | (0.000164) | (0.000110) | (0.000152) | (0.000156) | (0.0000962) | (0.000103) | (0.000239) | (0.0000802) | (0.000113) | (0.000113) |
| Constant | 0.401** | 0.385** | 0.395** | 0.414*** | 0.352** | 0.431*** | 0.364** | 0.351** | 0.367** | 0.336** | 0.307* | 0.338** |
| | (0.129) | (0.127) | (0.136) | (0.120) | (0.126) | (0.110) | (0.126) | (0.124) | (0.127) | (0.119) | (0.124) | (0.114) |
| **Random effects** | | | | | | | | | | | | |
| Study-level variance | 0.0655 | 0.0633 | 0.0723 | 0.0560 | 0.0619 | 0.0469 | 0.0628 | 0.0609 | 0.0624 | 0.0559 | 0.0602 | 0.0502 |
| | (0.0540) | (0.0522) | (0.0603) | (0.0464) | (0.0515) | (0.0394) | (0.0519) | (0.0502) | (0.0527) | (0.0464) | (0.0500) | (0.0422) |
| Game-level variance | 0.00296 | 0.00327 | 0.00333 | 0.00424 | 0.00467 | 0.00434 | 0.00361 | 0.00275 | 0.00712 | 0.00469 | 0.00444 | 0.00521 |
| | (0.000628) | (0.000744) | (0.00143) | (0.000988) | (0.00145) | (0.00150) | (0.00105) | (0.00105) | (0.00293) | (0.00108) | (0.00130) | (0.00154) |
| Subject-level variance | 0.0212 | 0.0215 | 0.0186 | 0.0204 | 0.0150 | 0.0258 | 0.0141 | 0.0146 | 0.0130 | 0.0160 | 0.0142 | 0.0186 |
| | (0.00102) | (0.00115) | (0.00233) | (0.00144) | (0.00182) | (0.00249) | (0.00133) | (0.00162) | (0.00267) | (0.00115) | (0.00149) | (0.00196) |
| Residual variance | 0.0392 | 0.0386 | 0.0426 | 0.0590 | 0.0545 | 0.0630 | 0.0477 | 0.0435 | 0.0611 | 0.0584 | 0.0528 | 0.0636 |
| | (0.000360) | (0.000385) | (0.00101) | (0.00101) | (0.00141) | (0.00145) | (0.000895) | (0.000936) | (0.00235) | (0.000734) | (0.000963) | (0.00110) |
| N | 25641 | 21658 | 3983 | 8019 | 3714 | 4305 | 6561 | 5003 | 1558 | 13655 | 6581 | 7074 |

**Table S6. Stratified analysis by the 1st-round and previous-round behaviors (the original results for Fig. S2).** Standard errors in parentheses. For fixed effects, * $P <$ 0.05, ** $P <$ 0.01, and *** $P <$ 0.001. Random intercepts model was used.

| | Threshold = 0.4 | Threshold = 0.5 | Threshold = 0.6 | Threshold = 0.7 | Threshold = 0.8 | Threshold = 0.9 |
|---|---|---|---|---|---|---|
| **Fixed effects** | | | | | | |
| Cooperation | 0.0121** | 0.0126** | 0.0179*** | 0.0183*** | 0.0163*** | 0.0143*** |
| | (0.00418) | (0.00405) | (0.00383) | (0.00360) | (0.00342) | (0.00328) |
| Cooperative environment, A | 0.0210*** | 0.0216*** | 0.0241*** | 0.0232*** | 0.0221*** | 0.0193*** |
| | (0.00336) | (0.00341) | (0.00348) | (0.00358) | (0.00369) | (0.00382) |
| Cooperation x A | -0.0351*** | -0.0370*** | -0.0475*** | -0.0502*** | -0.0489*** | -0.0470*** |
| | (0.00513) | (0.00508) | (0.00500) | (0.00491) | (0.00486) | (0.00490) |
| Round | 0.000184*** | 0.000185*** | 0.000189*** | 0.000190*** | 0.000192*** | 0.000193*** |
| | (0.0000382) | (0.0000382) | (0.0000382) | (0.0000382) | (0.0000382) | (0.0000382) |
| Constant | 0.344** | 0.345** | 0.345** | 0.346** | 0.347** | 0.347** |
| | (0.124) | (0.124) | (0.124) | (0.124) | (0.124) | (0.123) |
| **Random effects** | | | | | | |
| Study-level variance | 0.0604 | 0.0606 | 0.0609 | 0.0609 | 0.0606 | 0.0600 |
| | (0.0499) | (0.0500) | (0.0502) | (0.0502) | (0.0500) | (0.0495) |
| Game-level variance | 0.00303 | 0.00302 | 0.00301 | 0.00300 | 0.00300 | 0.00300 |
| | (0.000560) | (0.000559) | (0.000557) | (0.000555) | (0.000555) | (0.000556) |
| Subject-level variance | 0.0208 | 0.0208 | 0.0207 | 0.0206 | 0.0207 | 0.0207 |
| | (0.000839) | (0.000838) | (0.000837) | (0.000835) | (0.000836) | (0.000837) |
| Residual variance | 0.0494 | 0.0494 | 0.0494 | 0.0493 | 0.0493 | 0.0493 |
| | (0.000307) | (0.000307) | (0.000307) | (0.000307) | (0.000307) | (0.000307) |
| N | 53900 | 53900 | 53900 | 53900 | 53900 | 53900 |

**Table S7. Sensitivity analysis 1: Threshold of neighbors' cooperation rates (0.4 – 0.9; 0.5 is used for the main analysis).** "Cooperation x A" is the variable of interest. Standard errors in parentheses. The result of the threshold = 0.5 is the same as the one at Table S4, All (RI). For fixed effects, * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$. Random intercepts model was used.

|                          | C as ≥10      | C as =20      |
|--------------------------|:-------------:|:-------------:|
| **Fixed effects**        |               |               |
| Cooperation              | 0.0592***     | 0.00148       |
|                          | (0.00908)     | (0.0137)      |
| Cooperative environment, A | 0.0398***   | 0.0431***     |
|                          | (0.00985)     | (0.00775)     |
| Cooperation x A          | -0.0541***    | -0.0512***    |
|                          | (0.0124)      | (0.0148)      |
| Round                    | -0.00103***   | -0.000902***  |
|                          | (0.000124)    | (0.000125)    |
| Constant                 | 0.477***      | 0.507***      |
|                          | (0.0119)      | (0.0114)      |
| **Random effects**       |               |               |
| Game-level variance      | 0.00307       | 0.00292       |
|                          | (0.000961)    | (0.000916)    |
| Subject-level variance   | 0.00543       | 0.00518       |
|                          | (0.000709)    | (0.000679)    |
| Residual variance        | 0.0287        | 0.0287        |
|                          | (0.000422)    | (0.000422)    |
| N                        | 9408          | 9408          |

**Table S8. Sensitivity analysis 2: Threshold of continuous variable of cooperation at Rand et al (Study 2).** "Cooperation x A" is the variable of interest. Among the continuous donation to the public: 0 – 20 in the public goods game, "C as ≥10" represents that the threshold for the cooperators is a half contribution (≥10), while "C as =20" represents that the threshold is a full contribution (=20). Standard errors in parentheses. For fixed effects, * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$. Random intercepts model was used.

| | Unknown vs Cooperative | Unknown vs Non-cooperative |
|---|---|---|
| **Fixed effects** | | |
| Cooperation | -0.0312*** | 0.0619*** |
| | (0.00486) | (0.00704) |
| Indicator variable for Round = 1, A | 0.161*** | 0.234*** |
| | (0.00944) | (0.0107) |
| Cooperation x A | 0.000611 | -0.0857*** |
| | (0.0114) | (0.0139) |
| Round (continuous), B | -0.000107 | 0.000596*** |
| | (0.0000858) | (0.0000672) |
| Cooperation x B | 0.0000366 | -0.00104*** |
| | (0.0000938) | (0.000124) |
| Constant | 0.394*** | 0.330** |
| | (0.119) | (0.118) |
| **Random effects** | | |
| Study-level variance | 0.0557 | 0.0550 |
| | (0.0460) | (0.0456) |
| Game-level variance | 0.00340 | 0.00440 |
| | (0.000635) | (0.000845) |
| Subject-level variance | 0.0213 | 0.0161 |
| | (0.000891) | (0.000956) |
| Residual variance | 0.0460 | 0.0569 |
| | (0.000355) | (0.000561) |
| N | 35749 | 22287 |

**Table S9. Additional analysis for the Unknown environment (1$^{st}$ round) v.s. the Cooperative environment (2$^{nd}$- rounds) and for the Unknown environment (1$^{st}$ round) v.s. the Non-cooperative environment (2$^{nd}$- rounds).** "Cooperation x A" is the variable of interest. Standard errors in parentheses. For fixed effects, * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$. Random intercepts model was used.

|  | 1st round | 2nd round or later | | |
|---|---|---|---|---|
|  |  | Cooperative environment | Non-cooperative | All |
| **Original results (all b/c ratios [1.5 - 4])** | ref: Table S1 | ref: Table S2 | ref: Table S3 | ref: Table S4 |
| Effect of cooperation | -0.0579*** | -0.0270*** | 0.0185*** |  |
|  | (0.0128) | (0.0037) | (0.0044) |  |
| Cooperation x Cooperative environment |  |  |  | -0.0370*** |
|  |  |  |  | (0.0051) |
| N | 2068 | 33681 | 20219 | 53900 |
|  |  |  |  |  |
| **Additional results (b/c ratio = 2)** |  |  |  |  |
| Effect of cooperation | -0.0458** | -0.0146** | 0.0417*** |  |
|  | (0.0144) | (0.0050) | (0.0067) |  |
| Cooperation x Cooperative environment |  |  |  | -0.0524*** |
|  |  |  |  | (0.0076) |
| N | 1714 | 18776 | 8670 | 27446 |

**Table S10. Original results (all b/c ratios [1.5 - 4]) v.s. additional results (b/c ratio = 2).** The original results are obtained from Tables S1 to S4. The main effects in the original and additional analyses are shown. For fixed effects, * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$. Random intercepts model was used.