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# Mine and Thine: The Territorial Foundations of Human Property

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## Comments

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*Abstract*:

Research shows that many animal species have morphological and cognitive adaptations for fighting with others to gain resources, but it remains unclear how humans make fighting decisions. Non-human animals often adaptively calibrate fighting behavior to ecological variables such as resource quantity and whether the resource is distributed uniformly or clustered in patches. Also, many species use strategies to reduce fighting costs such as resolving disputes based on power asymmetries or conventions. Here we show that humans apply an ownership convention in response to the problem of severe fighting. We designed a virtual environment where ten participants, acting as avatars, could forage and fight for electronic food items (convertible to cash). In the patchy condition, we observed an ownership convention—the avatar who arrives first is more likely to win—but in the uniform condition, where severe fighting is rare, the ownership convention is absent.

*Introduction*

A wealth of theoretical and empirical research in evolutionary biology addresses how animals interact with respect to resources such as territory, food, or mates (Brown, 1964; Kokko, Lopez-Sepulcre, A., & Morrell, L. J., 2006; Maher & Lott, 2000; Maynard Smith, 1982; Parker, 1974). Broadly, this research shows that many animals make nuanced and adaptive decisions about whether, and how intensely, to fight others to secure a resource. Investigations of territorial behavior have identified as many as twenty ecological variables that affect decisions about whether to fight, including food quantity, food distribution, population density, and predation levels (Maher & Lott, 2000). Another line of research has discovered that when fights do occur, animals use a variety of strategies to reduce the costs such as fighting assessment (Parker, 1974) and conventions (Maynard Smith, 1982). However, despite a large literature on fighting in non-human animals—including mammals, birds, fish, and insects—little is known about how humans make fighting decisions.

Several scholars have applied theories from biology to understand how humans secure resources, deriving novel conclusions relevant to economics and property law (Gintis, 2007; Krier, 2009; Stake, 2004). These accounts particularly draw on Maynard Smith's (1982) concept of a fighting convention or an "uncorrelated asymmetry" in which animal fights are resolved based on an asymmetry that is uncorrelated with fighting ability. Maynard Smith's analysis led to the counterintuitive conclusion that animal fights can be more than battles of brawn: Choosing whether to fight or flee based on a conventional asymmetry, such as prior possession, can be an evolutionarily stable strategy (ESS) because individuals thereby reduce fighting costs relative to others who ignore the convention. In humans, resource disputes are decided by more than sheer power, and hence, the strategic convention model could potentially explain the foundations of human property. However, no previous research has tested this hypothesis in humans using the standard experimental methods applied to non-human species.

The idea that human property is rooted in an individually advantageous strategic convention contradicts much of the received wisdom on the subject. Scholars throughout history have offered theories of property which hinge on verbal communication, individual reputation, productive labor, legal institutions, enforcement by authority, and other complexities of human social life (Bentham, 1802; Grotius, 1625; Hobbes, 1647; Hume, 1740; Kant, 1797; Locke, 1689; Pufendorf, 1672; Rousseau, 1762). If, instead, basic features of human property can arise from very simple pairwise conflicts, as in species with minimal social interaction, then ownership reflects a core human competency which does not depend on advanced social abilities such as language, reputation, or third-party enforcement.

### *A Virtual Environment for Disputes*

We test whether human fighting decisions are sensitive to resource distribution (uniform or patchy), asymmetries in power, and asymmetries in prior possession. We designed custom software to create a virtual environment for observing human resource disputes (see Methods). In each experimental session, ten participants operate avatars in a virtual environment where they can forage and fight for food items which are convertible to cash (Supplementary Video 1). To secure resources, participants can "strike" each other, which, implemented through avatars, causes financial losses but not physical harm (Figure 1). This allows us to use methods similar to those used in non-human animal studies where animals engage in actual fighting. In the environment, avatars can move to find shrubs, enter/exit shrubs, and consume berries inside shrubs. Avatars gain one "health point" for each berry consumed, increasing their health meter (0-100 points) and offsetting health losses from metabolism which occurs at a rate of -10 points per minute. Participants' cash earnings accumulate continuously in proportion to the health of their avatars, providing financial incentives to maximize health. When two avatars enter the same shrub, they have an "interaction" in which each avatar can (1) *Leave*, allowing the other avatar to consume berries, (2) *Smile*, which produces a smile, or (3) *Strike*, which costs the striker one health point and imposes a greater cost (3 or 5 points) on the individual who is struck. Participants remain in the interaction, where they can smile or strike repeatedly, until one avatar leaves the shrub. Finally, we designed an experimenter's monitor (not observed by participants) showing the movements and interactions of all ten participants in the environment in real time and allowing experimental sessions to be replayed from complete records of participants' actions (Supplementary Videos 2 and 3).

We tested the hypothesis that resource distribution affects fighting behavior (defendability theory, Brown, 1964) by manipulating whether resources were distributed uniformly or clustered in patches, holding quantity constant. In the patchy condition, 10 brown shrubs produced 5 berries per minute and 5 green shrubs produced 20 berries per minute (total = 150 berries per minute). In the uniform condition, 30 brown shrubs produced 5 berries per minute (total = 150 berries per minute). We also tested whether participants could resolve resource disputes by using asymmetries in power (created by the experimenter) or asymmetries in prior residence. We manipulated power by randomly assigning half of participants to be Small avatars, whose strikes cause 3 health points of damage, and the other half to be Large avatars, whose strikes cause 5 health points of damage. The Large avatars appeared noticeably larger on the screen than the Small avatars (Figure 1).

*Results*

We observed more intense fighting in the patchy condition than in the uniform condition (Table 1). Participants' interactions lasted longer and they involved more strikes in the patchy condition than in the uniform condition. Participants' strikes reduced their aggregate cash payoffs by an average of $53.80 for (10-participant) sessions in the patchy condition versus $7.12 for sessions in the uniform condition. We also observed more smiles per interaction in the patchy condition. The *Smile* option was originally included so participants would not think the experimenters expected them to strike. Surprisingly, participants frequently used the "cheap talk" smiles and often in extended bouts, suggesting use as a low cost threat display. Last, we observed more deaths in the patchy condition (11/60) than in the uniform condition (0/60), $p < .001$, Fisher's exact test.

We analyzed whether asymmetries predicted the winner, defined as the avatar who remained in the shrub after the other individual exited. In the patchy condition, the prior resident defeated the intruder in 71.39% of cases ($n = 1{,}248$), significantly greater than chance ($p < .001$, binomial test). When there was a size difference, Large avatars tended to defeat Small avatars (66.76%, $n = 719$, $p < .001$). When there was a health difference, more healthy avatars tended to defeat less healthy avatars (66.37%, $n = 1{,}219$, $p < .001$). This initial analysis suggests that humans are able to use several asymmetries to resolve disputes. We observed a different pattern of results in the uniform condition. The residence effect was not only reduced, but significant in the opposite direction: Prior residents were slightly more likely to be first to exit a shrub (44.31%, $n$ = 589, $p$ = .006). Similarly, we observed no size effect (54.84%, $n$ = 341, $p$ = .08) and no health effect (49.91%, $n$ = 559, $p$ = 1.00). These results show that in the uniform condition, where severe fighting was rare, participants did not generally use asymmetries to decide conflicts. Hence, we focused further analysis on disputes in the patchy condition.

For the patchy condition, we tested whether fighting behavior differed for interactions in brown shrubs ($n$ = 234) and green shrubs ($n$ = 1014). Disputes lasted longer (seconds) for green shrubs ($M$ = 4.60, $SD$ = 5.56) than brown shrubs ($M$ = 2.10, $SD$ = 1.99), $t(1246)$ = 6.78, $p$ < .001. There were more smiles per interaction for green shrubs ($M$ = 2.43, $SD$ = 4.61) than brown shrubs ($M$ = 0.93, $SD$ = 1.60), $t(1246)$ = 4.89, $p$ < .001. There were more hits per interaction for green shrubs ($M$ = 0.50, $SD$ = 1.25) than brown shrubs ($M$ = 0.05, $SD$ = 0.29), $t(1246)$ = 5.48, $p$ < .001. Additionally, we found that asymmetries influenced conflict outcomes in green shrubs but not brown shrubs. For green shrubs, we observed a residence effect (75.54%, $n$ = 1,014, $p$ < .001), size effect (68.66%, $n$ = 584, $p$ < .001), and health effect (69.35%, $n$ = 995, $p$ < .001). However, for brown shrubs, there were no significant effects of residence (53.42%, $n$ = 234, $p$ = .33), size (58.52%, $n$ = 178, $p$ = .06), or health (53.13%, $n$ = 224, $p$ = .39). These results show that, consistent with theories about resource distribution, fighting is more severe for clustered resources, and furthermore, people selectively use asymmetries to resolve disputes over severely contested resources but not for less contested resources.

To better understand the relative effects of prior residence and fighting assessment, we concentrated on disputes over green shrubs. We examined whether the residence effect was a byproduct of a tendency for more powerful Large avatars to be residents (e.g., see Kemp & Wiklund, 2004; Pryke & Andersson, 2003). Figure 2 shows the resident effect by the sizes of resident and intruder (“Small-Large” indicates Small resident and Large intruder). When sizes are matched in Large-Large and Small-Small interactions, we observed a strong residence effect, showing that this effect cannot be reduced to a size/power effect. Additionally, when size differs (Large-Small and Small-Large), residence significantly affects the frequency of wins for Large avatars (84% vs.

46%), $\chi^2(1, n = 584) = 97.85$, $p < .001$. The relative strengths of residence and size effects can be compared by considering the Small-Large conflicts in which these two asymmetries are opposed. In our environment, neither effect dominated: When Small residents faced Large intruders there was no statistical difference in frequencies of victory. Further, we predicted that the Small-Large conflicts would be the most severe fights precisely because these asymmetries are opposed. Indeed, disputes lasted longer for Small-Large interactions ($M = 6.36$, $SD = 5.90$) than other types ($M = 4.08$, $SD = 5.35$), $f(1, 1010) = 27.04$, $p < .001$, disputes had more smiles for Small-Large interactions ($M = 3.08$, $SD = 4.30$) than other types ($M = 2.23$, $SD = 4.68$), $f(1, 1010) = 4.93$, $p = .027$, and disputes had more hits for Small-Large interactions ($M = 0.87$, $SD = 1.57$) than other types ($M = 0.39$, $SD = 1.11$), $f(1, 1010) = 24.44$, $p < .001$.

We looked more closely at the mechanics of the residence effect. In non-humans, individuals of some species do not contest residence whereas in other species residents win because they fight harder (see Kokko et al., 2006). We tested whether the residence effect occurred not only in shorter interactions but also in escalated conflicts. We categorized interactions as escalated disputes with durations in the top quartile, duration > 5 seconds ($n = 282$), or non-escalated disputes with duration ≤ 5 seconds ($n = 732$). We observed residence effects in escalated disputes (71.99%, $p < .001$) and non-escalated disputes (76.91%, $p < .001$), and the difference between these proportions was not significant, $\chi^2(1, n = 1{,}014) = 2.67$, $p = .10$. We examined whether residents were willing to incur more costs than intruders before giving up a fight over a green shrub. For fight duration, participants waited significantly longer before giving up when they were residents ($M = 5.31$, $SD = 6.15$) than when they were intruders ($M = 4.37$, $SD = 5.34$), $t(1{,}012) = 2.31$, $p = .021$. For strike costs, participants withstood greater damage in health points before giving up when they were residents ($M = 2.71$, $SD = 5.35$) than when they were intruders ($M = 1.30$, $SD = 3.46$), $t(1{,}012) = 4.82$, $p < .001$. Together, these results show that the residence effect reflects more than a tendency for intruders to yield, without contest, to prior residents. Prior residence shapes not only whether fights escalate but also how hard each side fights during an escalated conflict.

*Logit Model of Resident Wins*

We used a logit analysis to examine how our experimental manipulation of resource distribution affected the residence convention. To estimate how much of the resident effect in the patchy condition vis-à-vis uniform condition can and cannot be explained by differences in size, hits, and health of the participants, we conducted a Blinder-Oaxaca decomposition on a logit model of resident wins (Fairlie, 2005). The percentage of the residence effect that cannot be explained by the observable characteristics of the interactions can be attributed to different social processes caused by the experimental manipulation of resource distribution. For each interaction, either the resident remains in the shrub and the intruder leaves ($Y = 1$) or vice versa ($Y = 0$). We assume that a set of observable factors $\boldsymbol{x}$ listed in Table 2 explain the decision, so that $\text{Prob}(Y = 1) = \Lambda(\boldsymbol{\beta}'\boldsymbol{x})$, where $\Lambda(.)$ is the logistic distribution. The standard Blinder-Oaxaca decomposition of the patchy ($P$) / uniform ($U$) gap in the average value of $Y$ can be expressed as:

$$\overline{Y}^P - \overline{Y}^U = \left[\hat{\boldsymbol{\beta}}^{P\prime}(\overline{x}^P - \overline{x}^U)\right] + \left[(\hat{\boldsymbol{\beta}}^P - \hat{\boldsymbol{\beta}}^U)'\overline{x}^U\right], \tag{1}$$

where $\hat{\boldsymbol{\beta}}^i$ is a vector of estimated coefficients for condition $i$. The first term in brackets is the explained difference in resident wins due to the difference in observed characteristics in the two conditions, and the second is the unexplained difference due to differences in residence conventions. Following Fairlie (2005), the logit decomposition can be written as:

$$\begin{aligned}\overline{Y}^P - \overline{Y}^U = {} & \overbrace{\sum_{j=1}^{n^P} \frac{\Lambda\left(\hat{\boldsymbol{\beta}}^{P\prime} x_j^P\right)}{n^P}}^{a} - \overbrace{\sum_{j=1}^{n^U} \frac{\Lambda\left(\hat{\boldsymbol{\beta}}^{P\prime} x_j^U\right)}{n^U}}^{b} \\ & + \overbrace{\sum_{j=1}^{n^U} \frac{\Lambda\left(\hat{\boldsymbol{\beta}}^{P\prime} x_j^U\right)}{n^U}}^{b} - \overbrace{\sum_{j=1}^{n^U} \frac{\Lambda\left(\hat{\boldsymbol{\beta}}^{U\prime} x_j^U\right)}{n^U}}^{c},\end{aligned} \tag{2}$$

where $n^i$ is the number of observations for condition $i$.[1] Like those of any nonlinear regression model, the estimated coefficients are not necessarily the marginal effects. Hence, we computed the partial derivatives for the patchy condition (Table 2) and the uniform condition (Supplementary Table 1).

[1] The results are largely unaffected if we use a probit specification. Equation (2) holds exactly for the logit model with a constant term, and hence our choice in reporting that model's estimates.

Confirming the results reported above, neither resident size nor intruder size affect the likelihood that the resident wins ($p$ = .160 and .306, respectively). Each hit by a (Small) resident increases the likelihood that the resident wins by 10 percentage points ($p < .001$), and symmetrically each hit by an (Small) intruder reduces the likelihood by 10 percentage points ($p$ = .001). Moreover, hits by a Large resident and Large intruder have larger effects ($p$ = .009 and .002, respectively). The health of residents and intruders have expected signs and similar offsetting marginal effects. Also, time in residence (prior to an interaction) predicts victory: For every 10 seconds in residence the likelihood of winning increases by 2 percentage points ($p < .001$), a result which has also been found in non-human species (Alcock & Bailey, 1997; Haley, 1994). Finally, gender and the number of smiles for both residents and intruders have no significant effect. All but three of the fixed effects for periods are insignificantly different from the baseline of period 20.

Residents in the patchy condition maintain ownership of the shrub 71.4% of the time ($a$ = .714), whereas only 44.3% of uniform residents retain the shrub ($c$ = .443). Of particular interest is how much of this difference can be explained by hits, health, and size. We find that nearly exactly half of this difference, $a - b$ = .136 to be precise, can be explained by the different observed tendencies and characteristics of the residents and intruders. That leaves a rather large amount of the resident effect ($b - c$ = .135) to attribute to different social processes caused by the experimental manipulation of resource distribution.[2] When a valuable resource was concentrated, participants quickly (within a 20-minute experiment) adopted a convention of prior residence and that explains half of the difference in resident wins between the two treatment conditions.

## *Discussion*

Previous research shows that numerous animals—ranging from caterpillars (Yack, Smith, & Weatherhead, 2001) to songbirds (Carpenter & MacMillen, 1976) to elephant seals (Haley, 1994)—have evolved cognitive mechanisms which adaptively manage resource disputes. Importantly, these regulatory mechanisms are not generally well-described as "fixed instincts" or as "hardwired," but oppositely, research reveals sophisticated computational control systems which process information about ecological variables and specific adversaries to adaptively deploy offensive, defensive, and evasive

[2] With a probit specification the estimate of $b - c$ is 53.1% of $a - c$.

maneuvers (reviewed by Kokko et al., 2006; Maher & Lott, 2000). These discoveries raise questions about the mental competencies that humans bring to bear on resource disputes. Ethnographic studies have investigated the sensitivity of human territoriality to key ecological variables (Baker, 2003; Cashden, 1983; Dyson-Hudson & Smith, 1978). Also, recent laboratory studies indicate that humans are able to assess fighting ability (Sell et al., 2009) and that this information regulates anger toward antagonists (Sell, Tooby, & Cosmides, 2009). However, no previous research has applied the standard experimental methods from the non-human literature to investigate human fighting decisions.

We report experimental evidence showing that human fighting decisions are sensitive to resource distribution, asymmetries in power, and asymmetries in prior residence. The human residence effect shown here is of particular importance given centuries of debate about the foundations of human property. We observed an ownership convention in an experimental environment which allowed minimal social behavior—dyadic hitting and smiling—without language use, reputation, or third-party intervention. Ownership did not go uncontested, but rather, residents tended to fight harder than intruders, and further, participants applied the convention selectively for green shrubs but not brown shrubs. This evidence supports recent proposals that the foundation of human property is the ability to apply strategic conventions, or "uncorrelated asymmetries" (Maynard Smith, 1982), to reduce the costs of severe fighting (Gintis, 2007; Krier, 2009; Stake, 2004).

Many scholars have argued for the fundamental importance of property in human societies (Alchian & Demsetz, 1973; De Soto, 2000; Demsetz, 1967; Ellickson, 1991; North, 1981; Ostrom, 1990). If humans have specialized cognitive abilities for managing resource disputes, then these computational systems shape individual behavior and population-level patterns (e.g., Lopez-Sepulcre & Kokko, 2005) like in non-human species (Mougeot et al., 2003). This puts a high priority on understanding the cognitive competencies behind ownership and how they interact with the complexities of social life to generate the human world of "mine" and "thine."

*Methods*

We recruited *N* = 120 undergraduate participants (50% female) for an hour-long experiment, although the actual duration was less than 40 minutes. Participants were paid $7 for showing up and they earned additional money as a result of their decisions in the experiment (*M* = $20.09, *SD* = $8.92). Participants were randomly assigned to one experimental condition, either the patchy condition or the uniform condition. There were six sessions per experimental condition with ten participants each. Participants were taken into the laboratory and seated at computer stations separated by partitions to preserve anonymity. Participants were presented with a virtual environment on their computer screens. Ten participants were placed together in the same virtual environment. They read a set of experimental instructions describing the environment and the capabilities of their avatars (Supplementary Methods) and then the experiment began. The experiment lasted for 20 periods (one minute each) but participants did not know the number of periods in advance in order to eliminate potential end-game effects. After the experiment, participants were individually and anonymously paid their show-up payment plus experimental earnings and then dismissed.

**Virtual environment software**. We designed custom software which creates a virtual environment for observing human resource disputes (Supplementary Videos 1-3). The software is written in Visual Basic and is available from the authors upon request. In the environment, avatars can move to find shrubs, enter/exit shrubs, and consume berries inside shrubs. Shrubs produce berries continuously during one minute periods and berries that are not consumed disappear at the onset of the next period. Avatars have a health meter (0-100 points) which begins at 90 points, decreases through metabolism at a rate of -10 points per minute, and increases when berries are consumed. Participants' cash earnings accumulate continuously during the experiment in proportion to their avatar's health (Supplementary Methods). At maximum health, additional berries add "bonus points" which increase cash earnings but do not further increase health; this feature was designed to limit the health available for fighting to limit health asymmetries. If participants reach zero health, then their avatars die, participation in the experiment ends, and they receive their accumulated earnings but cannot earn additional money.

Participants cannot see others' avatars unless two individuals enter the same shrub (for discussion, see Maher & Lott, 2000). In this case, the two participants are taken to an "interaction" screen. During an interaction, other avatars cannot enter the shrub; clicking causes a message indicating that the shrub is full. On the interaction screen, the prior occupant is in front of the shrub and the newcomer is shown approaching (Figure 1). Each participant has three options: (1) *Leave*, which causes the avatar to exit the shrub, allowing the other avatar to pick berries, (2) *Smile*, which has no effects aside from causing the avatar to smile, and (3) *Strike*, which causes the avatar to hit the other avatar, costing the striker one health point and imposing a greater cost (3 or 5 points) on the other individual. After a strike, there is a three second delay before another strike can be delivered; this feature was designed to eliminate advantages based on clicking speed. The three second strike delay was also imposed at the outset of the interaction to eliminate the potential for surprise attacks. Similarly, after a participant exited a shrub, there was a five second delay before they could enter the same shrub.

The software allows the experimenter to control the number, location, color, and productivity of the shrubs as well as the size and capabilities of the avatars. We manipulated resource distribution in two experimental conditions (6 sessions each). In the patchy condition, there were 10 brown shrubs, which produced 5 berries per minute, and 5 green shrubs, which produced 20 berries per minute (total = 150 berries per minute). After each period, one of the five green shrubs was randomly selected and changed to a brown shrub and a corresponding brown shrub changed to a green shrub. This feature was designed to increase turnover in residence in green shrubs. In the uniform condition, there were 30 brown shrubs which produced 5 berries per minute (total = 150 berries per minute). We manipulated power by randomly assigning half of participants to be Small avatars, whose strikes cause 3 health points of damage, and the other half to be Large avatars, whose strikes cause 5 health points of damage. The Large avatars appeared considerably larger on the screen than the Small avatars (Figure 1).

The software produces data files which record all of the participants' actions in the virtual environment. During the experiment, participants' actions are displayed on an experimenter's monitor showing all participants' avatars in the environment, and experimental sessions can be replayed from the data (Supplementary Videos 2 and 3).

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Table 1

*Session Summary Statistics by Condition*

| | Patchy | | Uniform | | | |
|---|---|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* | *t*(10) | *p* |
| % of berries extracted[a] | 74 | 3 | 57 | 2 | 11.99 | <.001 |
| % time moving | 46 | 4 | 71 | 2 | 14.19 | <.001 |
| % time in shrubs | 40 | 4 | 25 | 2 | 8.57 | <.001 |
| % time in interactions | 14 | 2 | 4 | 1 | 15.76 | <.001 |
| # interactions | 208 | 34 | 98 | 13 | 7.46 | <.001 |
| Time/interaction (sec) | 4.24 | 0.90 | 2.33 | 0.34 | 4.89 | <.001 |
| Smiles/interaction | 2.23 | 0.84 | 1.20 | 0.37 | 2.75 | .021 |
| Strikes/interaction | 0.43 | 0.15 | 0.11 | 0.09 | 4.56 | .001 |
| Total strike costs (points) | 451 | 139 | 52 | 35 | 6.80 | <.001 |
| Total strike costs ($) | 53.80 | 20.21 | 7.12 | 6.44 | 5.39 | <.001 |
| Total earnings ($) | 226.86 | 32.73 | 174.91 | 9.75 | 3.73 | .0039 |

*Note.* Summary statistics from six experimental sessions in each condition. Each of the twelve sessions had ten participants (*N* = 120).

[a]Percentage of the total (3,000) available berries extracted by participants.

Table 2

*Patchy Condition: Logit Analysis of Resident Wins*

| Variable | Coefficient | Standard error | *p* |
|---|---|---|---|
| Hits by resident | 0.0995 | 0.0312 | .001 |
| Smiles by resident | -0.0047 | 0.0063 | .451 |
| Health of resident | 0.0020 | 0.0005 | <.001 |
| Hits by Large resident | 0.1357 | 0.0516 | .009 |
| Hits by intruder | -0.1037 | 0.0313 | .001 |
| Hits by Large intruder | -0.1219 | 0.0387 | .002 |
| Smiles by intruder | 0.0103 | 0.0067 | .125 |
| Health of intruder | -0.0016 | 0.0005 | .001 |
| Time in shrub by resident | 0.0021 | 0.0002 | <.001 |
| Marginal effect for dummy variable is P\|1 - P\|0 | | | |
| Large resident | 0.0381 | 0.0271 | 0.160 |
| Large intruder | -0.0279 | 0.0272 | 0.306 |
| Large resident*Large intruder | 0.0247 | 0.0350 | 0.480 |
| Female resident | 0.0319 | 0.0274 | 0.244 |
| Female intruder | -0.0235 | 0.0262 | 0.369 |
| Female resident*Female intruder | -0.0385 | 0.0418 | 0.358 |
| Period1 | -0.1011 | 0.0946 | 0.285 |
| Period2 | -0.0972 | 0.0926 | 0.294 |
| Period3 | -0.1710 | 0.1107 | 0.123 |
| Period4 | -0.1092 | 0.0911 | 0.231 |
| Period5 | 0.0339 | 0.0505 | 0.501 |
| Period6 | -0.0497 | 0.0729 | 0.496 |
| Period7 | -0.0629 | 0.0752 | 0.403 |
| Period8 | -0.0307 | 0.0675 | 0.649 |
| Period9 | 0.0533 | 0.0451 | 0.237 |
| Period10 | 0.0632 | 0.0437 | 0.148 |
| Period11 | 0.0648 | 0.0414 | 0.117 |
| Period12 | 0.0247 | 0.0537 | 0.646 |
| Period13 | 0.0761 | 0.0354 | 0.032 |
| Period14 | 0.0114 | 0.0537 | 0.832 |
| Period15 | 0.0371 | 0.0488 | 0.448 |
| Period16 | -0.0626 | 0.0814 | 0.442 |
| Period17 | 0.0204 | 0.0589 | 0.729 |
| Period18 | 0.0741 | 0.0397 | 0.062 |
| Period19 | 0.0965 | 0.0345 | 0.005 |

*Note*. Partial derivatives of probabilities with respect to the vector of characteristics for patchy condition. Values are computed at the means of the continuous variables and at zero for all dummy variables ($n$ = 1248).

*Video 1*. Demonstration of virtual environment. The video shows the computer interface for the virtual environment as it was experienced by participants. It shows a Small avatar moving to find shrubs and consume berries. It also shows the avatar in interactions with others and using smiles and strikes.

*Video 2*. Experimenter's monitor for patchy condition. The video shows a monitor of participants' actions in the virtual environment as observed by the experimenter (not the participants). It shows actual data replayed from session 1 of the patchy condition.

*Video 3*. Experimenter's monitor for uniform condition. The video shows a monitor of participants' actions in the virtual environment as observed by the experimenter (not the participants). It shows actual data replayed from session 1 of the uniform condition.

Video Download Links

WMV Format:
Video 1: http://dl.dropbox.com/u/4745232/PropertyDemoA.wmv
Video 2: http://dl.dropbox.com/u/4745232/PatchySession1.wmv
Video 3: http://dl.dropbox.com/u/4745232/UniformSession1.wmv

MP4 Format:
Video 1: http://dl.dropbox.com/u/4745232/PropertyDemoA.mp4
Video 2: http://dl.dropbox.com/u/4745232/PatchySession1.mp4
Video 3: http://dl.dropbox.com/u/4745232/UniformSession1.mp4

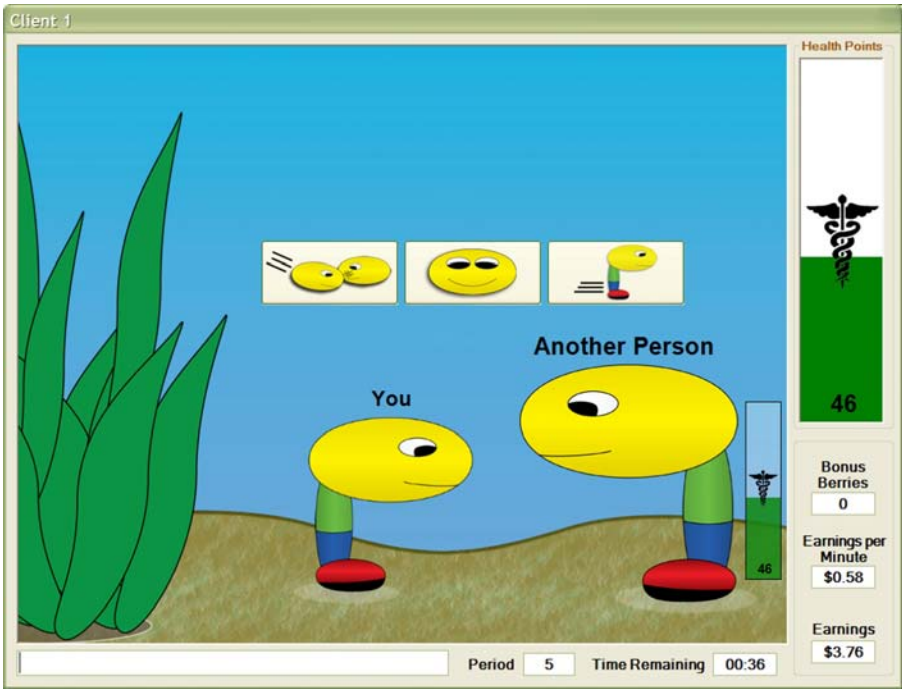



*Figure 1*. Interaction between avatars. The screenshot shows the perspective of a Small resident who is having an interaction with a Large intruder. The participant controls the avatar by clicking on one of the three buttons showing strike, smile, or leave.

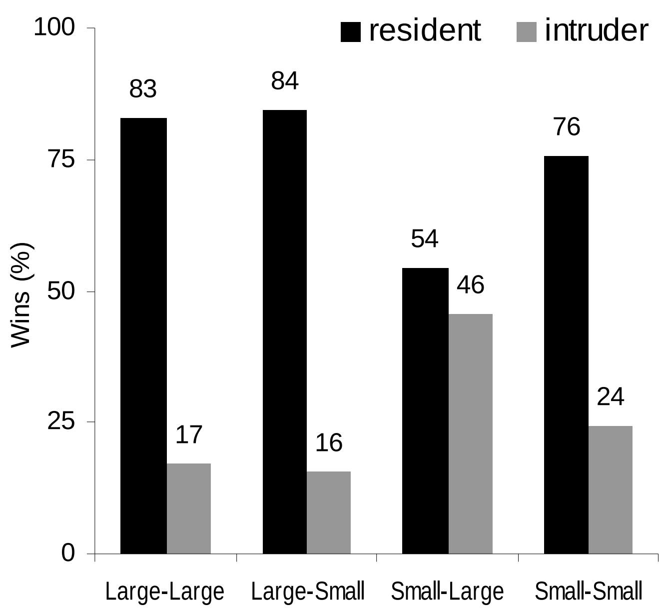



*Figure 2*. Resident and intruder wins by resident-intruder sizes for disputes over green shrubs in the patchy condition. Residents have significantly more wins in fights that are Large-Large ($n$ = 240, $p$ < .001, binomial test), Large-Small ($n$ = 352, $p$ < .001), and Small-Small ($n$ = 190, $p$ < .001). For Small-Large fights, the difference between Small residents and Large intruders is not significant ($n$ = 232, $p$ = .21).

Supplementary Table 1. Uniform Condition: Logit Analysis of Resident Wins

Supplementary Table 1

*Uniform Condition: Logit Analysis of Resident Wins*

| Variable | Coefficient | Standard error | *p* |
|---|---|---|---|
| Hits by resident | 0.2169 | 0.1866 | 0.245 |
| Smiles by resident | 0.0622 | 0.0383 | 0.104 |
| Health of resident | 0.0034 | 0.0017 | 0.043 |
| Hits by Large resident | 0.1278 | 0.2411 | 0.596 |
| Hits by intruder | -0.0126 | 0.2155 | 0.953 |
| Hits by Large intruder | -0.5105 | 0.2467 | 0.039 |
| Smiles by intruder | -0.1636 | 0.0313 | 0.000 |
| Health of intruder | -0.0016 | 0.0017 | 0.349 |
| Time in shrub by resident | 0.0482 | 0.0079 | 0.000 |
| Marginal effect for dummy variable is P\|1 - P\|0 | | | |
| Large resident | 0.0835 | 0.0672 | 0.214 |
| Large intruder | 0.0232 | 0.0640 | 0.717 |
| Large resident*Large intruder | 0.0269 | 0.0962 | 0.780 |
| Female resident | 0.1372 | 0.0688 | 0.046 |
| Female intruder | 0.0358 | 0.0712 | 0.614 |
| Female resident*Female intruder | -0.1544 | 0.0890 | 0.083 |
| Period1 | -0.3540 | 0.0810 | 0.000 |
| Period2 | -0.2172 | 0.1267 | 0.087 |
| Period3 | -0.0048 | 0.1540 | 0.975 |
| Period4 | -0.0929 | 0.1478 | 0.530 |
| Period5 | -0.1600 | 0.1364 | 0.241 |
| Period6 | -0.2516 | 0.1120 | 0.025 |
| Period7 | -0.2445 | 0.1170 | 0.037 |
| Period8 | -0.1120 | 0.1590 | 0.481 |
| Period9 | -0.1206 | 0.1350 | 0.372 |
| Period10 | -0.1420 | 0.1263 | 0.261 |
| Period11 | -0.0474 | 0.1328 | 0.721 |
| Period12 | -0.0993 | 0.1293 | 0.442 |
| Period13 | -0.1964 | 0.1144 | 0.086 |
| Period14 | -0.1293 | 0.1255 | 0.303 |
| Period15 | 0.0114 | 0.1282 | 0.929 |
| Period16 | 0.0418 | 0.1331 | 0.754 |
| Period17 | 0.1389 | 0.1289 | 0.282 |
| Period18 | 0.1396 | 0.1401 | 0.319 |
| Period19 | -0.1560 | 0.1208 | 0.197 |

*Note*. Partial derivatives of probabilities with respect to the vector of characteristics for uniform condition. Values are computed at the means of the continuous variables and at zero for all dummy variables (n = 589).

Supplementary Methods. Experiment Instructions for Large Avatar

<page 1>

**Welcome**

This is an experiment in the economics of decision making. The instructions are simple, and if you follow them carefully and make good decisions you can earn a considerable amount of money which will be paid to you in CASH at the end of the experiment.

In this experiment, you will be represented by the avatar you see in the middle of the screen. You and the 9 other people in the experiment each have the ability to move around the environment, enter shrubs, and pick berries. The experiment will consist of many periods each lasting **60 seconds**.

<page 2>

**Movement**

You can move around the environment by left clicking on the spot you wish to move to (try clicking in the grassy area now). Notice that a red X marks the spot your avatar is moving towards. You can see shrubs in the environment, but you cannot see the other people who are also moving in the same environment.

In the top left portion of the screen there is a mini map that displays the environment including the location of the shrubs you have discovered and your current location represented by a black square. Areas of the environment that you have not yet visited are blacked out. Try moving around to see how the mini map works.

You can also enter and exit the shrubs in the environment. Move around until you find a shrub. Move your avatar completely on top of one of the shrubs and stop. Once your avatar stops on a shrub you enter it and a new screen appears showing the shrub in an expanded view.

<page 3>

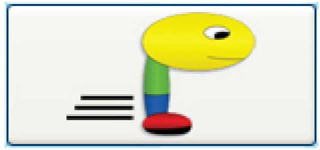
**Inside a Shrub**

You can earn points and money by picking berries inside the shrubs.

During a period, shrubs grow berries. The berries remain in the shrub until the end of the period. At the end of the period, any remaining berries will disappear and new berries will begin to grow.

To pick a berry, left click on it (try this now). Each berry is worth 1 point. The points you get will be added to your health points. If you reach the maximum 100 health points, then your points will go into your bonus points. The points you get will determine your cash earnings, which we will explain shortly.

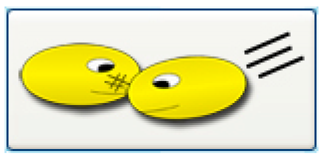
Green shrubs produce more berries, and brown shrubs produce less berries. Depending on the environment, you might find all green, all brown, or a mixture of green and brown shrubs. To exit a shrub, click on the exit button:



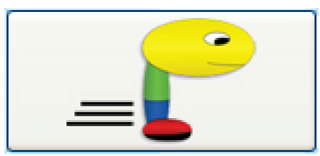
in the top right area of your screen.

<page 4>
**Interaction**
If you are in a shrub and another person attempts to enter the same shrub, then both of you will be involved in an interaction. You will see a new screen with your avatar in front of the shrub and another person who has approached the shrub. Both people will have three options:

Smile at the other person



Strike the other person



Leave the shrub

If you strike the other person, you will reduce your own health points by 1 point(s) and you will cause the other person to lose 5 health points. Larger avatars cause more damage per strike than smaller avatars.

This interaction will continue until one person leaves the shrub. The remaining person can go back to picking berries. You cannot enter a shrub in which two people are already having an interaction.

(Interactions will be disabled until the experiment starts.)

<page 5>
**Earnings and Your Health**
Your health will decrease over time. Think of it as metabolism. Every **6 seconds** your health points will go down by one point.

NOTE: If your health falls to zero, then your avatar will die and your participation in the experiment will end.

Each *second* your health points are multiplied by 0.0002 and added to your Earnings. For example, when your health is 25, you are earning 31.25 cents per minute. When your health is 75, you are earning 93.75 cents per minute. Each berry picked as a bonus is worth 25 cents and added to your earnings when the berry is picked. If you die by reaching zero health points, then you stop earning money.

<page 6>

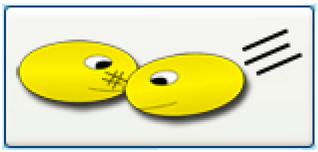
**Summary**

This is the end of the instructions. The important points are:

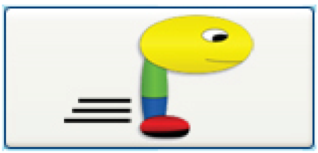
(1) Berries add to your health points. Once you reach maximum health, they give you bonus points.

(2) When someone enters a shrub with another person in it, an interaction screen will appear. During an interaction, both people can:

Smile



Strike



Leave

Striking others and being hit by others reduces your health.

(3) If your health points fall to 0, then your avatar will die, and you can no longer earn money in this session.

If you have any questions please raise your hand and a monitor will come by to answer them. If you are finished with the instructions please press Start. The instructions will remain on your screen until everyone is ready and the experiment starts. Your health points will reset to **90** when the experiment begins.

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