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### Title

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### Permalink

<https://escholarship.org/uc/item/2jf1k700>

### Journal

Nature, 481(7382)

### ISSN

0028-0836

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### Publication Date

2012

### DOI

10.1038/nature10736

Peer reviewed



# HHS Public Access

Author manuscript

*Nature*. Author manuscript; available in PMC 2012 July 26.

Published in final edited form as:

*Nature*. ; 481(7382): 497–501. doi:10.1038/nature10736.

## Social Networks and Cooperation in Hunter-Gatherers

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### Abstract

Social networks exhibit striking structural regularities<sup>1,2</sup>, and theory and evidence suggest that they may have played a role in the development of large-scale cooperation in humans<sup>3–7</sup>. Here, we characterize the social networks of the Hadza, an evolutionarily relevant population of hunter-gatherers<sup>8</sup>. We show that Hadza networks exhibit important properties also seen in modernized networks, including a skewed degree distribution, degree assortativity, transitivity, reciprocity, geographic decay, and homophily. Moreover, we demonstrate that Hadza camps exhibit high between-group and low within-group variation in public goods game donations. Network ties are also more likely between people who give the same amount, and the similarity in cooperative behaviour extends up to two degrees of separation. Finally, social distance appears to be as important as genetic relatedness and physical proximity in explaining assortativity in cooperation. Our results suggest that certain elements of social network structure may have been present at an early point in human history; that early humans may have formed ties with both kin and non-kin based, in part, on their tendency to cooperate; and that social networks may have contributed to the emergence of cooperation.

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Humans are unusual as a species in the extent to which they form longstanding, non-reproductive unions with unrelated individuals – namely, we have friends. Cooperation is a defining feature of these friendships<sup>9</sup>. And humans learn from and influence each other, evincing an exceptional reliance on cultural transmission<sup>10</sup>. These facts contribute to the

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### Author Contributions

C.L.A., J.H.F., and N.A.C. designed the study and experiments; C.L.A., and F.W.M., collected data; C.L.A., J.H.F., and N.A.C. analysed the data; C.L.A., J.H.F. and N.A.C. wrote the manuscript; F.W.M. provided technical support; J.H.F. and N.A.C. secured funding.

propensity of humans to form social networks, which can range in size from dozens to millions of people<sup>1</sup>.

Social networks display certain empirical regularities – in settings as diverse as villages, schools, and workplaces – in terms of variation in the degree distribution (number of social ties), transitivity (the likelihood that two of a person's friends are in turn friends), degree assortativity (the tendency of popular people to befriend other popular people), reciprocity (the increased likelihood of an outbound tie to be reciprocated with an inbound tie from the same person), and homophily (the tendency of similar people to form ties). Some properties (such as a fat-tailed degree distribution) may be seen in many contexts (e.g., neuronal, electronic, and social networks). Other properties are more distinctively social, and may have adaptive significance. For instance, degree assortativity may constrain the spread of pathogens<sup>11</sup>; high transitivity may help reinforce social norms (although it can also reduce the flow of new information); and homophily may facilitate collective action<sup>12</sup>.

However, technological advances (e.g., in communication, transportation, and agricultural systems), demographic changes (e.g., in population density, inter-group marriage, and dispersal), and social innovations (e.g., in formal institutions) have all changed the social landscape of humans from that, in which they evolved. This raises the question of whether features observed in modernized social networks are ancient or contemporary in origin. Yet, the observed regularities in social networks, coupled with the fact that networks can affect diverse individual-level outcomes, suggests that natural selection may have played a role in the formation of human networks. Indeed, some egocentric network attributes, such as the number or kind of friends a person has, or a person's tendency to be central in a network, may have a partially genetic basis<sup>13,14</sup>.

The evolutionary relevance of social networks is also suggested by their role in cooperation. Evolutionary theories of cooperation rely on explicit or implicit assumptions regarding social structure<sup>3</sup>. Direct reciprocity presumes that the same individuals will encounter each other repeatedly<sup>4</sup>. Similar conclusions have been reached regarding indirect reciprocity<sup>15</sup>. Other theoretical models of kin selection, generalized assortativity<sup>5</sup>, group competition<sup>6</sup>, and social networks<sup>7</sup> have also explicitly recognized the importance of population structure, showing that cooperation can evolve if individuals tend to interact with others of the same type (cooperators with cooperators and defectors with defectors). Yet, if real world interactions do not actually exhibit such assortativity, then none of these theories can explain the widespread cooperation in humans that we observe today.

The possibly adaptive origins of human social networks, and their relationship to cooperation, suggest exploring network features in an evolutionarily relevant setting. While cooperation is widespread in human societies, modern hunter-gatherers possibly exemplify this feature best – with their pervasive sharing of food, labour, and childcare. It is likely that the high levels of cooperation observed in modern hunter-gatherers were also present in early humans<sup>16</sup>. To date, little work has focused on networks in hunter-gatherers. Related topics have included estimation of the total size of hierarchical social units<sup>17</sup>; examination of the role of resource production on social organization and residence patterns<sup>18</sup>; and evaluation of food sharing<sup>19</sup>. We know of no study that has attempted to map the complete

social network of a foraging population to study its dyadic building blocks (ties between pairs of people) and macroscopic structure, as well as the role of cooperation.

Therefore, we performed a comprehensive, socio-centric network study of the Hadza hunter-gatherers of Tanzania. Connections between individuals were identified in two ways: subjects were asked with whom they would like to live in the next camp (the “campmate network”), and to whom they would give an actual gift of honey (the “gift network”) (see Methods). We studied 205 individuals, and there were 1,263 campmate ties and 426 gift ties. By measuring a comprehensive set of statistics, we evaluated whether Hadza networks differ quantitatively from random networks in the same ways that modernized networks do.

Cumulative distributions of in-degree (the number of times an individual is nominated) are shown in Fig. 1a. As is typical of networks<sup>2</sup>, the degree distributions have significantly fatter tails than a similarly-sized group composed of individuals randomly forming the same number of social ties (Kolmogorov-Smirnov test,  $p < 10^{-15}$  for all comparisons). Degree distributions for the male and female campmate networks did not differ (Kolmogorov-Smirnov test,  $p = 0.86$  for in-degree and 0.59 for out-degree).

As in modernized societies<sup>20</sup>, we find that the probability of a social tie decreases with increased geographic distance (see SI, Fig. S6a). Of significance to kin selection theory, we also find that the probability that two individuals are connected increases as the genetic relatedness between the pair increases, in both the campmate and the gift networks (see SI, Fig. S6b).

We used regression analysis to evaluate the relationship between personal characteristics and degree (see SI). In both the campmate and gift networks, age, height, weight, and marital status are positively and significantly related to both out-degree and in-degree (see SI, Fig. S7a,b). For example, an 8.7 cm (1 SD) increase in height is associated with a 125% increase in out-degree and a 173% increase in in-degree, suggesting that taller people are both more socially active and more socially attractive. The significance of these associations survives when we add numerous controls to the models, including camp-level fixed effects, geographic distance, genetic and affinal relationships, spouse relationships, age, and sex (see SI). Other characteristics associated with degree in at least one of the models include body fat, muscle mass, handgrip strength, the value placed on meat, and reproductive success, but none of these survive controls in both the campmate and gift networks, except body fat for in-degree and handgrip strength for out-degree (see SI).

The selection of physically fit *reproductive* partners (in both traditional and modernized societies) makes sense from an evolutionary perspective given the gains in resources and genetic benefits that can be passed on to offspring. But hunter-gatherers also prefer to form connections to *non-reproductive* partners who are physically fit, suggesting that this tendency might also be both common and ancient in origin. Food acquisition and processing in foragers is labour and time-intensive, requiring strength and stamina, as well as skill and knowledge<sup>21</sup>. Thus, forming connections with physically fit individuals likely translates into increased resources.

Hadza networks also resemble modernized human networks insofar as they too differ from random networks with respect to reciprocity<sup>16,22</sup>. An “ego” (the naming person) is 44.2 times (95% C.I. 37.6 to 51.4) more likely to name an “alter” (the named person) in the campmate network, and 14.3 times (95% C.I. 12.2 to 16.4) more likely to name an alter in the gift network, if the alter reciprocated the social tie by also naming the ego as a friend (indeed, this happens even though nominations are private). Reciprocity remains significant even when controlling for genetic and non-genetic family ties, suggesting that reciprocity also exists between unrelated individuals.

Hadza networks also evince degree assortativity. People with higher in-degree name more social contacts, and people with higher out-degree are more likely to be named (see SI, Fig. S7a,b), even in models with controls (including a control for reciprocity). In other words, individuals who nominate more friends are popular even among those they themselves did not nominate.

Yet another property Hadza networks have in common with modernized human networks is that they have higher transitivity than expected in random networks<sup>23</sup>. In the campmate networks, transitivity is 0.17 for females and 0.16 for males, while in the gift networks, the average transitivity is 0.41 (see SI, Fig. S7c). By comparison, in random networks with the same number of nodes and edges, transitivity is always less than 0.01.

Turning to homophily (Fig. 1b), in both the campmate and gift networks, social ties are significantly more likely when two people are similar in age, height, weight, body fat, and handgrip strength. Thus, as in other human networks, hunter-gatherers who are socially connected tend to resemble one another. For example, a 7.5 kg (1 SD) increase in the similarity of weight is associated with a tripling of the probability (+201%) that two people are connected. There is also evidence of homophily on marital status, muscle mass, and the value placed on meat and baobab, but these relationships do not survive in the models with controls, except for the value of meat in the campmate network (see SI).

Hunter-gatherer life is characterized by imbalances in productivity and consumption (e.g., due to differences in strength which varies across the life-cycle), and this is reflected in divisions of labour<sup>24</sup>. Thus, one might expect that choices of campmates would reflect complementarity (heterophily) rather than homophily. On the other hand, homophily may facilitate collective action because similar individuals are more likely to share assumptions, experiences, and goals<sup>25</sup>, and also because similarity increases empathy, which in turn facilitates cooperation<sup>12</sup>. We find no significant heterophily on any attribute examined.

We also directly compared the measured Hadza parameters to values for 142 sociocentric networks of adolescent students in the USA and to two sociocentric networks of adult villagers in Honduras. The Hadza parameters fall within the observed ranges in these other networks, often near the center of the distribution (see SI). However, comparison of the precise values is limited by, among other things, variation in how ties were ascertained. Further research will be needed to clarify how details of human social network structure might vary across settings, if at all.

Graphs of the Hadza social networks (Fig. 1c,d) show that they tend to be structured in a way that is relevant for cooperative behaviour, as elicited in public goods games. In particular, there is homophily on cooperation: cooperators tend to be connected to other cooperators, and non-cooperators to non-cooperators.

While natural selection is said to favour defection in unstructured populations where all individuals have an equal chance of interacting with one another, cooperation can evolve if population structure permits clustering<sup>5</sup>. This feature allows cooperators to grow in the population because they benefit from the public goods provided by fellow cooperators with whom they interact. A key prediction of some evolutionary models is thus that there should be relatively more variance in cooperative behaviour between groups as compared to within groups<sup>6</sup>. But it was not known whether such assortment in cooperative behaviour actually exists in populations thought to resemble those from which humans evolved.

In Fig. 2a, we show a comparison of the observed variance in donations to the public good to the variance obtained when we keep the population structure fixed and randomly reshuffle the observed distribution of donations across all individuals. Compared to chance, there is significantly more between-camp variation ( $p=0.01$ ) and significantly less within-camp variation ( $p=0.01$ ) in cooperative behaviour.

We investigated the role of network connections with respect to group-level variation in cooperation by studying the tendency of cooperative individuals to be connected to other cooperators. We regressed public good donations on the donations of a person's friends (see SI). Each extra stick of honey donated is associated with an extra 0.13 sticks (0.05 to 0.21) donated by each friend in the campmate networks and an extra 0.21 sticks (95% C.I. 0.10 to 0.32) donated by each friend in the gift networks. Moreover, in the gift networks, the association extends to two degrees of separation; each friend's friend donates an extra 0.15 sticks (0.07 to 0.25) for every stick a person donates (Fig. 2b). And, interestingly, at three degrees of separation, there is significant anti-correlation in the campmate networks ( $-0.04$  sticks, 95% C.I.  $-0.00$  to  $-0.06$ ), suggesting that cooperative and non-cooperative clusters tend to be polarized (though this might also reflect a finite-size effect, given the small size of Hadza society).

Dyadic analyses of social ties show that people who donate more do not have higher out-degree or in-degree (Fig. 2c); in fact, in the gift networks, there is a weakly significant negative association between donations and in-degree, though this relationship does not survive in the models with controls (see SI). This suggests that we can reject the hypothesis that hunter-gatherers unconditionally prefer to form ties with cooperators. However, there is significant homophily on cooperation in both the campmate and gift networks, and the relationship survives in the model with controls for the campmate network: cooperators are preferentially connected to other cooperators.

To determine whether social network structure may help to explain variation in cooperative behaviour, we conceptualized three different kinds of proximity that could be generating the similarity. If the physical environment is an important source of variation, then *geographic* proximity should help to predict similarity in cooperative behaviour. Additionally, people

who live in the same camp should be more similar than those who do not. If genes are an important source of variation, then *genetic* proximity (measured as relatedness) should help to predict similarity in cooperative behaviour. But if social networks are a source of variation, then *social* proximity (measured separately for the campmate networks and gift networks by the inverse of the degrees of separation between two people) should help to predict similarity in cooperation. In separate regression models, each kind of proximity is significantly related to similarity in cooperation (see SI). In contrast, age and sex similarity are not significant predictors. However, when we include all the proximity measures in one model, geographic proximity ceases to matter (Fig. 2d). Moreover, social proximity, as measured in both the campmate network and the gift network, appears to be just as important as genetic proximity and camp co-residence, suggesting that cooperative behaviour may be best understood as a process influenced by a combination of not just genes and environment, but also by social networks.

The Hadza represent possibly one of the most extreme departures from life in industrialized societies, and they remain relatively isolated from modern cultural influences. Yet, all the examined properties of social networks seen in modernized societies also appear in the Hadza. Compared with random networks, Hadza networks, like modernized networks, exhibit a characteristic degree distribution; greater degree assortativity, transitivity, reciprocity, and homophily than expected due to chance; and a decay with geographic distance.

To the extent that the Hadza represent our late Pleistocene ancestors<sup>8</sup>, the network properties and social preferences in the Hadza may indeed reflect elements of human sociality along with which high levels of human cooperation evolved. Whether certain aspects of human social network structure existed still further back in our hominid past is unclear. Evaluating the resemblance between non-human and human primate networks is difficult, in part because the qualitative nature of dyadic ties can vary considerably across species<sup>26</sup>. Nevertheless, some network properties may be quite old. For instance, age and sex predict both the quantity and quality of many primate interactions, and primate networks may demonstrate homophily<sup>26</sup>. Possibly, certain aspects of social network structure might appear in any vertebrate species that forms social networks<sup>27</sup> since structural features might address problems (e.g., coordinated action, infection resistance, information transmission) that might be common to such species.

Humans' ability to trace descent bilaterally and form strong relationships with both sets of kin not only maximizes their kin ties but also increases their ability to move freely; once an organism is able to recognize paternal kin, potential inbreeding can be avoided without the need for evolution to favour a sex-biased dispersal pattern. While chimpanzee females disperse and males typically spend their lives in their natal community, hunter-gatherers of both sexes can stay in or leave their natal group<sup>18</sup>, with individuals changing camp membership throughout their lives. It is thus possible that relaxed constraints on social mobility patterns provided humans a greater capacity to seek out friends, which in turn allowed cooperators more opportunities to form ties with other cooperators and break ties with defectors.

Although the Hadza have a preference for kin as both campmates and gift recipients (indicating a potential for kin selection), the Hadza also actively form many ties with non-kin. In fact, recent work examining co-residence patterns across hunter-gatherer societies suggests that first-order relatives make up less than 10% of residential camps<sup>18</sup>, raising the question of how high levels of cooperation are maintained in groups of mostly unrelated individuals. The pervasive sharing of food that characterizes hunter-gatherer life is one plausible evolutionary mechanism<sup>24</sup>, but theories of kin selection and reciprocal altruism, used to explain food sharing, have been criticized on the grounds that they require producer control over resource distribution<sup>24</sup>. On the other hand, regardless of whether foragers have producer rights, they do maintain flexibility in choosing their friends and campmates, thus providing some control over resource distribution.

In summary, Hadza networks are structured in a way that is consistent with the evolution of cooperative behaviour. Cooperators tend to be connected to cooperators at both the dyadic and network level, conditions necessary to sustain cooperation<sup>28</sup>. This phenomenon cannot be explained by camp-level differences in the contextual environment since it persists in a model that controls for camp-level fixed effects. However, it might be explained by two alternative hypotheses. One is that cooperators tend to preferentially form ties with other cooperators, leaving defectors no choice but to form ties to the remaining non-cooperators<sup>29</sup>. Another is that people may influence the cooperative behaviour of their networks, as demonstrated in experimental studies<sup>30</sup>. But regardless of the causal mechanism, homophily on cooperation and selective formation of network ties create conditions that would make it easier for cooperative behaviour to evolve<sup>28</sup>. This suggests that social networks may have co-evolved with the widespread cooperation in humans that we observe today.

## Methods Summary

We surveyed 205 adults in 17 Hadza camps. Cooperation was elicited by examining subjects' contributions to a public good using sticks of honey. Both women and men donated slightly more than half of their endowment.

We collected network data at both the population level and the camp level. We discerned same-sex network ties across the entire Hadza population by asking each individual: "With whom would you like to live after this camp ends?" We call this the *campmate network*. On average, women chose  $6.0 \pm 1.9$  SD campmates and men chose  $7.1 \pm 2.1$  SD campmates. To facilitate this, we used posters containing facial photographs of a census of 517 adult Hadza for (see SI).

We discerned network ties in an additional way. Every adult in each camp (100%) was given three sticks of honey, which they could anonymously distribute to other adults, of either sex, in their camp. Participants could give all the honey to one person or distribute it to up to three different people. We call this the *gift network*. On average, both women and men chose to give to  $2.2 \pm 0.8$  SD recipients.

Anthropometry measures were also collected, as well as marital status, reproductive histories, and many other measurements, and we computed the genetic relatedness of all pairs of people. The data were analysed with regression models and other methods (see SI).



## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

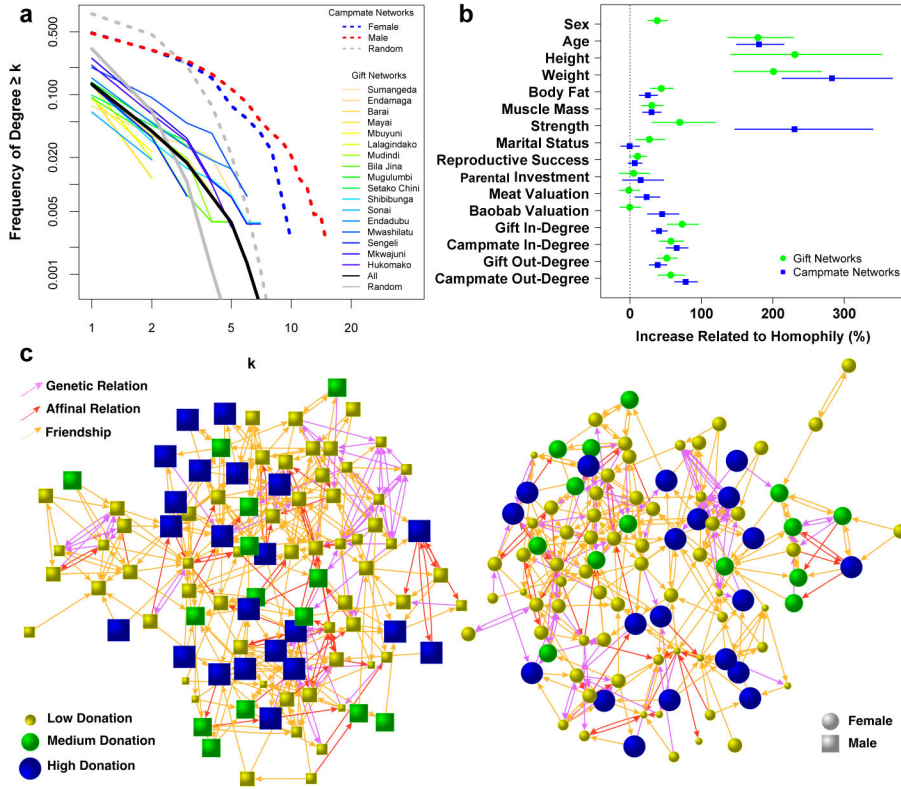
## Acknowledgments

This work was supported by grant P01-AG031093 from the National Institute on Aging and by the Science of Generosity Initiative of the University of Notre Dame (supported by the John Templeton Foundation). We are grateful for helpful comments from Sam Bowles, Dan Eisenberg, Feng Fu, Herb Gintis, Joe Henrich, Paul Hooper, Daniel Hruschka, Martin Nowak, Dave Rand, Peter Richerson, and Corina Tarnita. We thank Audax Mabulla, Ibrahim Mabulla, Mika Peterson, Cam Bauchner, and Laurie Meneades for help with data collection and preparation. We are grateful to Derek Stafford and Alex Hughes for sharing data regarding two villages in Honduras, as used in the SI.

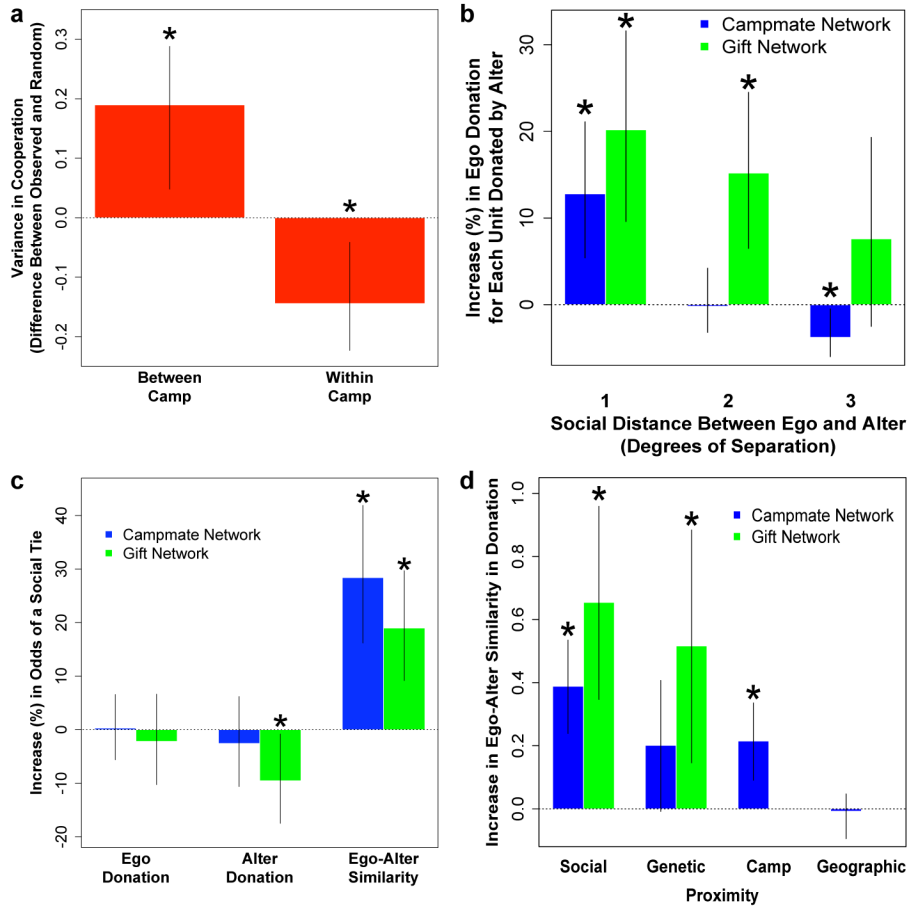
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**Figure 1.** (a) Cumulative in-degree distributions for the campmate and gift networks are significantly different from random networks with the same number of nodes and edges (Kolmogorov-Smirnov test,  $p < 10^{-15}$ ) and have fatter tails; the random distributions are shown in gray, separately for campmate and gift networks. The gift networks within each camp (ordered by size of camp from smallest, yellow, to largest, blue) show similar distributions of in-degree. (b) Estimates based on dyadic models of social ties (see SI) show that a 1SD change in similarity in characteristics between two people significantly increase the likelihood of a social tie (homophily). Horizontal lines indicate 95% confidence intervals. For the campmate networks, sex is not included because all ties are same sex; homophily for height is not shown due to scale (the estimate is 801%, 95% C.I. 549%–1148%); and homophily for cooperation is shown in Figure 2c. (c) Graphs of the campmate networks show that cooperators tend to be connected to cooperators and cluster together (see also Figure 2b). Node colour and size indicates donation, shape indicates sex. Arrows point from an ego (the naming person) to an alter (the named person). Arrow colours indicate whether the ego and alter are related genetically, affinally (by marriage), or not at all (friendship).



**Figure 2.** Donations in the public goods game are associated with social network characteristics. A comparison of variance in observed donations with variance in 1000 simulations where donations were randomly shuffled between all individuals in the population (a) shows that between-group variance in cooperation is significantly higher than expected, and within-group variance is significantly lower than expected, at the camp level. An analysis of cooperative behaviour across all camps (b) shows that correlation in cooperation extends to one degree of separation in the campmate networks and two degrees (to one’s friend’s friends) in the gift networks. Moreover, there is anti-correlation at three degrees of separation in the campmate network, suggesting polarization between cooperators and non-cooperators. This correlation cannot be explained by cooperators being more likely to form or attract social ties (c). Instead, subjects with *similar* levels of giving are significantly more likely to be connected at the dyadic level (c). Finally, several measures of proximity are independently associated with similarity in donations, but social proximity (the inverse of the degree of separation between two people in the network) appears to be just as important as genetic proximity (relatedness) and physical proximity (residence in the same camp) in a multivariate test (d). (Gift networks are defined only within camps and so are not presented for “camp” and “geographic” proximity in 1d.) Vertical lines indicate 95% confidence intervals and stars indicate estimates with  $p < 0.05$ . See SI for details of the models.