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Supporting Online Material

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An Experimental Study of Homophily in the Adoption of Health Behavior

Damon Centola

How does the composition of a population affect the adoption of health behaviors and innovations? Homophily—similarity of social contacts—can increase dyadic-level influence, but it can also force less healthy individuals to interact primarily with one another, thereby excluding them from interactions with healthier, more influential, early adopters. As a result, an important network-level effect of homophily is that the people who are most in need of a health innovation may be among the least likely to adopt it. Despite the importance of this thesis, confounding factors in observational data have made it difficult to test empirically. We report results from a controlled experimental study on the spread of a health innovation through fixed social networks in which the level of homophily was independently varied. We found that homophily significantly increased overall adoption of a new health behavior, especially among those most in need of it.

Social networks are a primary channel for the spread of health behaviors (1–3). However, it is not just the existence of social ties between individuals that matters for diffusion. Just as important are the demographic composition of the population and the distribution of individual characteristics throughout the social network (4–6). Homophily—the tendency of social contacts to be similar to one another—can affect the extent of a behavior's adoption in a population (7–12). At the dyadic level, research on diffusion has suggested that homophilous ties can promote the spread of behavior between individuals (11–13). This is because actors are more likely to be influenced by alters who are similar to themselves. However, research on social influence has also suggested that the effects of status can interact with those of homophily (12, 14, 15). Homophily among high-status individuals may help to promote diffusion, but low-status individuals may be more likely to be influenced by heterophilous ties to high-status

alters than by homophilous ties to similarly low-status individuals (12, 15).

Although these accounts of homophily may be in tension with one another at the dyadic level, at the network level both views support the thesis that homophily will reduce overall adoption, thereby increasing health inequalities across diverse populations (12–14, 16). This network-level effect emerges from the fact that homophily can result in less healthy individuals having fewer social ties to healthier early adopters, which limits their level of exposure to health innovations (3, 7, 11, 12). Moreover, fewer ties to healthy individuals also means that the exposure that the less healthy individuals do receive is less likely to come from healthier members of the population—who may be more effective at influencing others to adopt new behaviors (7–11)—thereby reducing the likelihood of adoption among those less healthy individuals who are ultimately exposed to the innovation (15, 17).

This network thesis has important implications for obese members of a population because the homophilous “clustering” of health characteristics in social networks (1, 3, 18, 19) can result in

obese individuals both receiving less exposure to valuable health innovations and having fewer sources of positive social influence, resulting in lower levels of adoption (8, 9, 16, 18). By contrast, populations in which obese individuals are better socially connected to healthier individuals should provide greater access to health innovations (5, 6, 11, 20) and more social support for adopting new behaviors (7, 8, 16, 21), thereby increasing both overall levels of adoption and the use of health innovations among the obese population (8, 9, 21, 22).

An empirical test of these individual and network-level effects of homophily has proven difficult because homophily in observational data is usually confounded with other relevant factors such as the topological structure of social networks (5, 11, 23), interpersonal affect in relationships (12, 24), and shared history and frequency of interaction among connected individuals (11, 12, 24). Moreover, individual-level factors can be difficult to distinguish from relational ones: Are obese individuals simply less likely to adopt a health behavior, or is it their social environment that reduces their likelihood of adoption (25, 26)? Addressing these difficulties requires the ability to independently control the degree of homophily in a social network while simultaneously holding the topology of the network, and the distribution of individual- and population-level parameters, constant.

We addressed these issues by studying the effects of homophily on adoption experimentally. We conducted an Internet-based social network experiment (27) in which we manipulated the level of homophily in people's social networks. Our study focused on the spread of a health behavior through a World Wide Web social networking environment composed of 710 participants, all of whom were recruited from an online fitness program (28). We constructed two types of online social networking communities: (i) homophilously structured populations, in which

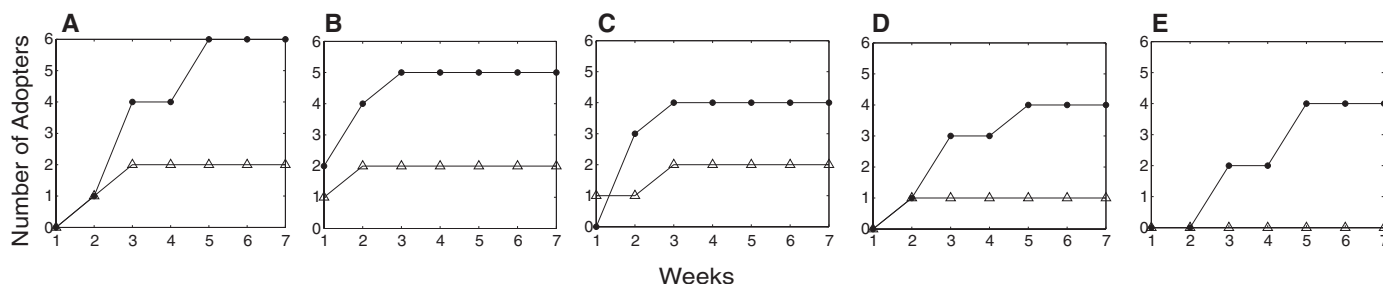


Fig. 1. (A to E) Time series showing the number of adopters in each of the five trials. Adoption levels are shown for all homophilous (solid circles) and unstructured (open triangles) networks.

individual traits [gender, age, and body mass index (BMI)] were “clustered” in the social network (28, 29), and (ii) unstructured populations, which had fully “integrated” neighborhoods in which participants were mixed at random regardless of their individual characteristics.

Each participant in the study created an anonymous online profile, which included the participant's gender, age, BMI, fitness level, diet preferences, and favorite exercise (28). Subjects were then matched with other participants in the study—referred to as “health buddies”—as members of an online health community. Each participant was provided with a personalized online “health dashboard” that displayed real-time health information (e.g., daily exercise minutes) as well as basic profile information (as listed above) for each participant and his or her health buddies (28). The health dashboards also displayed a record of any health behaviors that the participants and their health buddies adopted.

Participants arriving to the study were randomized to one of the two experimental conditions—a homophilous population condition and an unstructured population condition—that were distinguished only by the clustering of health characteristics in the social network neighborhoods. The occupants of the immediately adjacent nodes in the network (i.e., the network neighbors) constituted a participant's health buddies. All networks in the study had the same size ($N = 72$), neighborhood structure (hexagonal lattice network, clustering coefficient = 0.4), and degree distribution ($Z = 6$), which ensured that every individual within and between conditions had an identical number of health buddies (28). Random assignment of subjects to experimental conditions ensured that each network in the study had equivalent distributions of individual characteristics. Consequently, at the start of the study, the only difference between conditions was the level of homophily within the social networks.

We report results from five independent trials of this experimental design. Each trial consisted of two social networks, one from each experimental condition. All five trials of the study ran concurrently for 7 weeks.

Participants in the study made decisions about whether to adopt an Internet-based diet diary (28). The diet diary was not known, or accessible, to anyone except participants in the experiment. This ensured that the only way a participant could learn about or adopt the behavior was to receive a health dashboard notification from one of his or her health buddies.

Adoption was initiated using a healthy “seed node” in each network—a member of the online community with above average fitness, high exercise minutes, and a low BMI (28). This ensured that in every network the behavior originated from a “healthy” individual (28, 30). The study began by triggering the seed nodes to adopt the behavior. Once each seed was triggered, a notification appeared on the health dashboards of each of the seed's neighbors, indicating that their health buddy had started using the diet diary. Clicking on

the notification allowed these neighbors to sign up. If they completed the sign-up procedure, this would result in each of the adopters' neighbors also receiving notifications about the diet diary.

At the beginning of week 1, we simultaneously activated seed nodes in each of the 10 networks. We then observed the spread of adoption for a total of 7 weeks.

The results (Fig. 1) show that homophilously structured social networks exhibited significantly more adoption than unstructured networks. Despite low overall levels of adoption, by the third week of the study there was already a noticeable difference between conditions: In each of the five trials, there were greater numbers of adopters in the homophilous condition than in the unstructured condition. By week 4, adoption levels were significantly different across experimental conditions ($P < 0.05$, Mann-Whitney U test). This difference increased in week 5 ($P < 0.01$) and maintained this level of significance in weeks 6 and 7. At the end of week 7, the total number of adopters across all homophilous networks was more than 3 times the total number of adopters in the unstructured networks. Additional analyses examining the effects of conditions on subjects' participation in the study found no significant differences in subjects' use of the environment across experimental conditions (28) (fig. S9).

To evaluate the spread of the behavior to the members of the population most “in need”

of adopting it, Fig. 2 compares adoption levels among the “obese” (i.e., BMI ≥ 30) and “non-obese” (BMI < 30) members of the population. Within the homophilous condition, a significantly greater number of non-obese than obese individuals adopted the behavior ($P < 0.05$, Mann-Whitney U test) (Fig. 2A). This is expected because of the high ratio of non-obese to obese individuals in the population (6:1) (28) (table S1). However, the fraction of obese adopters was significantly greater than the fraction of non-obese adopters ($P < 0.05$) (Fig. 2B), indicating that relative to their population sizes, homophilous networks promoted greater uptake of the behavior among obese individuals than among non-obese individuals. By contrast, in the unstructured condition, both the number (Fig. 2A) and the fraction (Fig. 2B) of non-obese adopters was significantly greater than that of obese adopters ($P < 0.05$). Not one obese individual signed up for the diet diary in the unstructured networks, which suggests that obese members of the population were very reluctant to adopt the behavior.

The comparison across conditions shows that homophily significantly increased adoption both among the obese ($P < 0.01$) and non-obese ($P < 0.05$) members of the community (Mann-Whitney U test). Among non-obese individuals, adoption levels more than doubled in the homophilous networks. Among obese individuals, the average fraction of adopters increased from zero in the

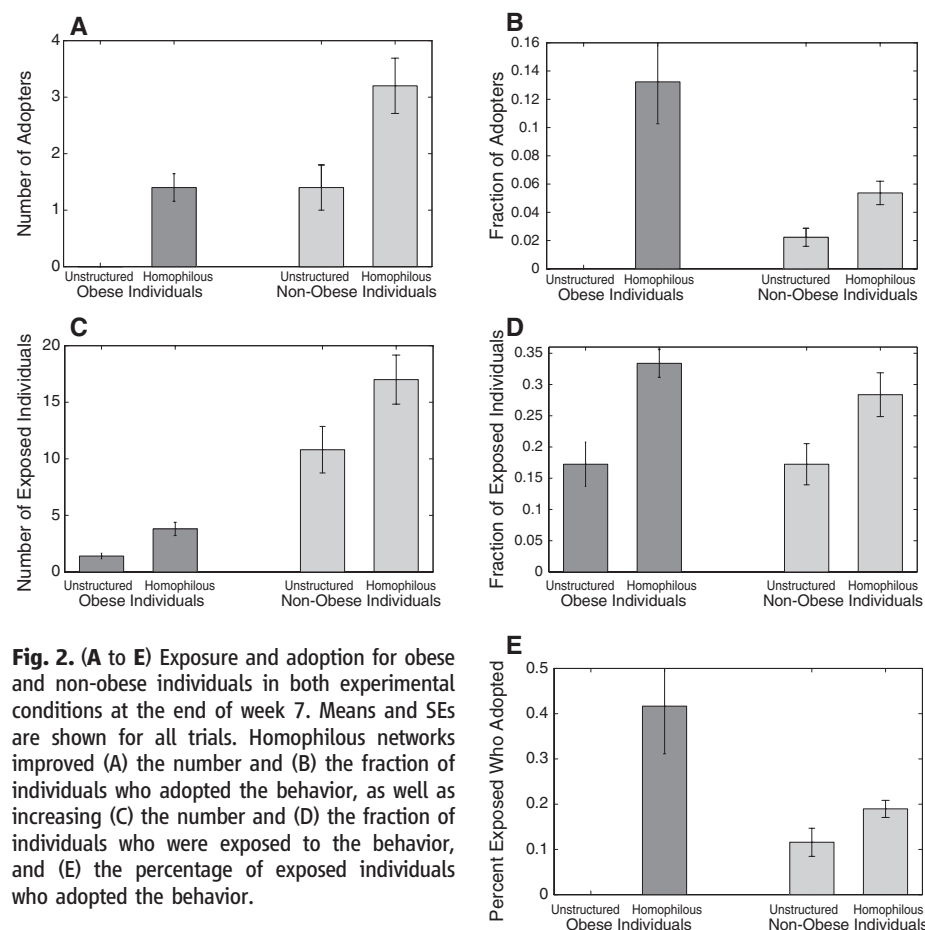


Fig. 2. (A to E) Exposure and adoption for obese and non-obese individuals in both experimental conditions at the end of week 7. Means and SEs are shown for all trials. Homophilous networks improved (A) the number and (B) the fraction of individuals who adopted the behavior, as well as increasing (C) the number and (D) the fraction of individuals who were exposed to the behavior, and (E) the percentage of exposed individuals who adopted the behavior.

unstructured networks to more than 12% of the obese population in the homophilous networks (Fig. 2B). Remarkably, the number of obese adopters in the homophilous networks was equal to the number of non-obese adopters in the unstructured networks (Fig. 2A). Homophily thus did not restrict adoption of the health behavior to only the more fit individuals, but instead significantly increased uptake by the less fit members of the population.

Although these results demonstrate a significant effect of homophily on adoption, they do not identify the mechanism responsible for the success of the homophilous networks. Did obese individuals have higher adoption rates because more obese individuals were exposed to the behavior, or because homophilous networks increased the likelihood of adoption among those who were exposed? To address this question, Fig. 2, C and D, shows the levels of exposure among obese and non-obese individuals in each condition. Within both conditions, there were no significant differences in the fraction of exposed obese and non-obese individuals (Fig. 2D).

Across conditions, homophily significantly improved obese individuals' access to the health innovation. A significantly greater number ($P < 0.01$) and fraction ($P < 0.05$) of obese individuals were exposed to the behavior in the homophilous networks than in the unstructured networks. Exposure increased from an average of 17% in the unstructured networks to an average of 33% of the obese population in the homophilous networks (Fig. 2D). These findings are particularly striking given that, by construction, obese individuals initially had greater exposure to the health innovation in the unstructured networks than in the homophilous networks (28) (Fig. S10).

Putting these results together, Fig. 2E reports the effect of homophily on the likelihood that exposed individuals would ultimately adopt. Homophily had no significant effect on the likelihood of adoption among non-obese individuals exposed to the behavior. However, homophily significantly increased the likelihood of adoption among exposed obese individuals ($P < 0.01$, Mann-Whitney U test). In the homophilous networks, an average of more than 40% of exposed obese individuals adopted the behavior, as compared with zero in the unstructured networks.

Homophily thus not only significantly increased obese individuals' access to the health innovation, but also significantly increased their likelihood of adoption once they were exposed to it.

Our experimental design did not permit causal identification at the individual level; however, dyadic-level analyses of the correlations between homophilous ties and the likelihood of behavior spread indicate that partial overlap on traits between neighbors may be sufficient to significantly increase the likelihood of transmission (28) (fig. S11). Although these correlations do not imply causal effects of specific traits, they do suggest that a minimal level of overlapping characteristics between social contacts may improve the spread of behaviors through social networks (28). To formalize this intuition, we develop a simple model of homophily and behavioral influence in which we assume that actors will influence each other if they have a sufficient number of their traits in common (28). The results (Fig. 3) indicate that increased influence of homophilous ties—based on relational similarity (6, 12), rather than based on individual characteristics (4, 15)—offers a good approximation of the empirically observed adoption dynamics (28).

Our findings suggest two primary conclusions. First, homophily significantly improves the adoption of health behavior. Homophily can allow a behavior to spread more successfully across a heterogeneous population, providing greater levels of exposure to individuals with diverse health characteristics. Second, homophily can significantly increase the likelihood of adoption across dyadic ties, in particular among obese individuals. Our findings suggest that obese individuals may be more dependent than healthier individuals on the composition of their social networks for making decisions about adopting health behaviors. This indicates that low adoption levels of health innovations among less healthy individuals (7, 8, 16, 20) may be a function of social environment rather than a baseline reluctance for adoption (25, 26).

More generally, the experimental approach developed here provides four principal advances in our understanding of homophily. First, our results indicate that the positive effects of homophily on adoption do not depend on the mechanisms that generate homophilous relationships [e.g.,

individual choices for homophilous tie formation (4, 11, 31, 32), having a shared history or context (5, 6, 33), or meeting through mutual friendships (6, 11, 33)]. Rather, we find that the simple fact of homophilous relations can provide a significant foundation for social influence.

Second, these findings distinguish the effects of choice homophily in the dynamics of tie formation from the role of observed homophily in the dynamics of behavioral adoption. This was accomplished through our experimental design, which permitted manipulation of the level of homophily while holding network structure constant.

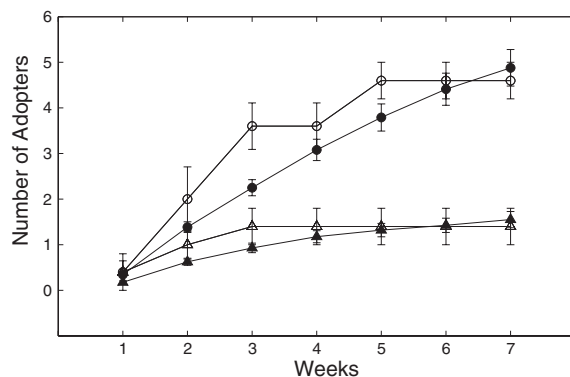
Third, our use of the lattice network substrate for this study provides two important advantages over observational network data: (i) The uniform structure of the lattice network allowed us to identify the individual-level effects of homophily on adoption without the confounding effects of heterogeneous neighborhood structure on individual adoption behavior; and (ii) holding the lattice network constant across conditions allowed us to identify the aggregate effects of homophily independent of topology. In particular, recent studies on the diffusion of behavior have shown that the lack of “wide bridges” in social networks can significantly inhibit the level of adoption in a population (23, 27). By keeping bridge width constant among all of the neighborhoods in all of the networks, our design prevented these topological effects from confounding the effects of homophily.

To test the robustness of our experimental findings for alternative network structures, we replicated our formal model of homophily (Fig. 3) on more complex topologies (34) (fig. S12). We found that the effects of homophily on diffusion were equally pronounced in heterogeneously structured social networks (fig. S13).

Finally, at the dyadic level, our findings suggest that some minimal level of similarity may be necessary for alters to influence one another, indicating a possible “threshold” effect of homophily on adoption. Our results indicate that if this minimal level of similarity is satisfied, partial overlap in traits may be sufficient to significantly increase the likelihood of behavioral influence. This suggests that “hemiphilous” ties between partially similar individuals, who bridge diverse social clusters, may be effective in transmitting behavior across heterogeneous populations.

In sum, we found not only that exposure and adoption levels were greatest in homophilous networks, but that the most effective social environment for increasing the “willingness” of obese individuals to adopt the behavior was the one in which they interacted with others with similar health characteristics. With respect to the design of interventions and the promotion of new health innovations, our results indicate that homophilous ties can increase access to health innovations better than providing direct access to diverse individuals across a community. These findings may be particularly important for the

Fig. 3. Comparison of the average number of adopters in the homophilous (open circles) and unstructured (open triangles) conditions, across all 10 experimental trials, with the average adoption levels for the model given in equation S1 (28), using homophilous (solid circles) and unstructured (solid triangles) social networks (averaged over 200 realizations). Error bars indicate SE.



design of online health communities, where the structure of social relations can be explicitly determined on the basis of individuals' health characteristics.

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Supporting Online Material

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Specialized Face Learning Is Associated with Individual Recognition in Paper Wasps

Michael J. Sheehan* and Elizabeth A. Tibbetts

We demonstrate that the evolution of facial recognition in wasps is associated with specialized face-learning abilities. *Polistes fuscatus* can differentiate among normal wasp face images more rapidly and accurately than nonface images or manipulated faces. A close relative lacking facial recognition, *Polistes metricus*, however, lacks specialized face learning. Similar specializations for face learning are found in primates and other mammals, although *P. fuscatus* represents an independent evolution of specialization. Convergence toward face specialization in distant taxa as well as divergence among closely related taxa with different recognition behavior suggests that specialized cognition is surprisingly labile and may be adaptively shaped by species-specific selective pressures such as face recognition.

The cognitive mechanisms underlying learning abilities are surprisingly similar across taxa as diverse as mammals, birds, insects, and mollusks (1). Although the mechanisms that underlie learning are broadly generalized across animals, there is increasing evidence that learning abilities are adaptively shaped by species' ecology and can be highly specialized (2). One of the most striking examples of specialized cognition is specialized face learning found in some mammals, including humans (3–5). Individual face recognition is an important aspect of human social

interactions, and our brains process the images of normal conspecific faces differently than any other images (6). Further, individual recognition is a type of complex social behavior that could favor specialized cognition (7) because it requires flexible learning and memory and has the potential to dramatically increase cognitive demands. However, the claim that face specialization is an adaptation to facilitate individual recognition has been contentious, in part because it is unclear whether face learning is based on conserved mechanisms or has evolved independently in multiple mammalian lineages (8, 9). If face specialization is an adaptation to facilitate face recognition, we predict that specialization will be associated with the evolution of facial individual recognition across distant taxa.

Paper wasps are a good system for examining the evolution of face specialization because closely related wasp species differ in their ability to individually recognize conspecific faces. The paper wasp, *Polistes fuscatus*, has variable facial features that are used to recognize individual conspecifics (10, 11). Visual recognition is possible in *Polistes* wasps because they have acute vision (12) and live in well-lit nests. *P. fuscatus* nests are often initiated by groups of cooperating queens, in which relative reproduction is determined by a strict linear dominance hierarchy (13, 14); individual recognition stabilizes social interactions and reduces aggression within these cooperative groups (15). Some wasp species, such as *Polistes metricus*, typically nest alone (16) and therefore lack competition among queens. Solitary nest founding is associated with a lack of facial pattern variability (17), and experiments have shown that *P. metricus* does not recognize conspecifics as individuals (18).

We tested the adaptive evolution of specialized face learning by comparing face specialization in *P. fuscatus* and *P. metricus*. We predicted that *P. fuscatus* will learn normal face images faster and more accurately than nonface images or manipulated faces (Fig. 1), whereas *P. metricus* will not. Comparing learning of normal and manipulated face images (Fig. 1) provides a particularly good test of face specialization because manipulated faces are composed of the same colors and patterns as those of normal faces (table S1), but alteration may prevent the perceptual system from identifying the stimuli as faces. We tested learning by training wasps to discriminate between two images using a negatively reinforced

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