Cultural Dispositions, Social Networks, and the Dynamics of Social Influence: Implications for Public Opinion and Cultural Change

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Abstract

Cultures differ in dispositional tendencies that have implications for social relationships and social influence. What are the further implications of these cultural differences for changes in public opinion and popular beliefs over time? We used computational modeling methods to address this question. We modeled (a) cultural differences in extraversion and conformity, (b) the effects of extraversion on the emergent geometry of social networks, and (c) the further effects of both extraversion and conformity on the dynamics of social influence within these social networks. By doing so, we examined effects of cultural differences on two population-level outcomes that emerged over time: (a) The consolidation of opinion majorities into bigger majorities; and (b) the spread of initially unpopular beliefs. Results (compiled across more than 100000 computer simulations) revealed effects of both extraversion and conformity on these outcomes. More highly extraverted cultures were more prone to the consolidation of majorities, and were more resistant to the spread of initially unpopular beliefs. More highly conformist cultures were more prone to the consolidation of majorities, and (perhaps counterintuitively) were more susceptible to the spread of initially unpopular beliefs. These results suggest that contemporary cultural differences in psychological traits may have non-obvious consequences for the temporal dynamics of cultural evolution and societal change. They also highlight the utility of computational models as a means of predicting these long-term consequences.

Keywords: extraversion, conformity, social networks, social influence, culture, cultural evolution, computational modeling, dynamical systems

Cultural Dispositions, Social Networks, and the Dynamics of Social Influence: Implications for Public Opinion and Cultural Change

Attitudes and personality traits differ, not only across individuals, but also across entire cultural populations. Compared to North Americans, for instance, people in India and China are generally less extraverted and also endorse less individualistic values (Hofstede, 2001; McCrae, Terracciano, & 79 Members of the Personality Profiles of Cultures Project, 2005). These differences have implications for behavioral outcomes (e.g. extraverts have more acquaintances and individualists are less likely to conform to majority opinion (Asendorpf & Wilpers, 1998; Pollet, Roberts, & Dunbar, 2011)). The psychological study of cultural differences typically focuses on these kinds of individual-level outcomes.

Individual level behavioral outcomes can have further consequences that transcend a psychological level of analysis—emergent consequences that, over time, play out across entire populations (Kameda, Takezawa, & Hastie, 2003; Kenrick, Li, & Butner, 2003; Latané, 1996; Mason, Conrey, & Smith, 2007; Oishi, 2014; Smaldino, 2013; Talhelm et al., 2014; Vallacher, Read, & Nowak, 2002). These consequences are of interest not only to psychologists but also to other scholars who study the things that define societies and cultures (public opinion, political ideologies, religious beliefs, etc.), and the speed with which those things change over time. The purpose of this article is to identify the effects that cultural differences in basic behavioral dispositions may plausibly have on these kinds of long-term societal outcomes, and to do so in an analytically rigorous manner.

The analytical method we employ is computational modeling. We report outcomes compiled from tens of thousands of computer simulations, each of which simulated tens of thousands of interactions between individuals within a cultural population. Our models were informed by results of previous empirical research on social interaction and social influence—including results documenting cultural differences in extraversion and conformity. These models reveal predictable implications of these cultural differences for the emergent properties of the social networks that govern interpersonal interactions, and further implications for the societal outcomes of interpersonal influence within those social networks. We focus on two specific kinds of societal outcomes: (a) the consolidation of majority opinion (the extent to which existing opinion majorities become bigger majorities over time); and (b) the diffusion of innovations (the extent to which new opinions, radical beliefs, and other new ideas spread within a population over time). The results of these models therefore reveal specific ways in which cultural differences in psychological traits may have long-term consequences for cultural stability and cultural change.

Cultural Differences in Extraversion and Conformity

Numerous results reveal cross-cultural differences in personality traits (Heine & Buchtel, 2009). A trait of particular relevance here is extraversion. Multiple studies—employing multiple methods to assess the personality traits of tens of thousands of individuals in dozens of countries worldwide—have revealed cultural differences in mean levels of extraversion (McCrae, 2002; McCrae et al., 2005; Schmitt, Allik, McCrae, & Benet-Martínez, 2007). These cultural differences are associated with differences in conceptually relevant behavioral outcomes (e.g., emotional expressivity; Matsumoto, Yoo, & Fontaine, 2008). The magnitude of cultural differences in extraversion is not huge, but nor is it trivial. For example, individuals living in Morocco have mean extraversion scores that are approximately half a standard deviation lower than the worldwide mean, whereas individuals in Northern Ireland have mean extraversion scores that are approximately half a standard deviation higher than the worldwide mean (McCrae et al., 2005).

Given these cultural differences in extraversion, one would also expect cultural differences in interpersonal behavior and the measurable outcomes of interpersonal behavior.

One of the most obvious outcomes associated with extraversion is the formation of social connections with other people. Compared to more introverted individuals, extraverts have more friends and acquaintances (Kalish & Robins, 2006; Pollet et al., 2011) and the social networks of extraverts grow more rapidly over time (Asendorpf & Wilpers, 1998). These individual differences are reflected in population differences: In cultural populations characterized by relatively higher levels of extraversion, people generally have larger networks of friends and acquaintances (Chua & Morris, 2006; Harihara, 2014).

While cultural differences in extraversion have implications for the nature of individuals' interpersonal relationships, other cultural differences have implications for social influence within those relationships. Many different dispositional tendencies are relevant to social influence processes, including basic personality traits (such as openness to experience), authoritarian attitudes, and the endorsement of individualistic versus collectivistic values. There are well-documented cultural differences on these constructs (Farnen & Meloen, 2000; Hofstede, 2001; McCrae et al., 2005). These cultural differences have many implications for individual behavior (Gelfand et al., 2011; Heine & Buchtel, 2009).

One implication is of particular relevance here: The tendency to either conform to, or to deviate from, others' attitudes and actions. Lower openness, higher authoritarianism, and more collectivistic values all imply a greater tendency to conform to perceived social norms; whereas higher openness, lower authoritarianism, and more individualistic values all imply an increased tendency to resist conforming. Much empirical research shows that, in prototypically collectivistic countries—which are also characterized by lower levels of trait openness and greater endorsement of authoritarian attitudes—people more readily conform to perceived majority opinion (Bond & Smith, 1996; Gelfand et al., 2011).

The preceding paragraphs identified cultural differences in behavioral outcomes that are typically measured at an individual-level of analysis (the sizes of individuals' friendship networks, and the tendency of individuals to conform to perceived majority opinion). When aggregated across individuals within any cultural population, and also aggregated across multiple opportunities for interpersonal interaction, these individual-level outcomes can have implications that transcend the individual-level of analysis and must be measured at the level of the populations. Given the implications that extraversion has for the size of individuals' friendship networks, cultural differences in extraversion are likely to have further implications for the structural geometry of the social networks that define entire cultural populations. And, given the implications that conformist attitudes have for actual conformity to majority opinion, cultural differences in conformity are likely to have further implications for the societal outcomes of interpersonal influence within these social networks.

Implications for the Structure of Social Networks

How might the mean level of extraversion within a cultural population affect the structure of the population-wide social network? To address that question, it is first necessary to consider the geometric properties of these networks of interpersonal connections within human populations. Empirical evidence from many different kinds of populations (including small scale aboriginal societies as well as massive online communities such as Facebook; Apicella, Marlowe, Fowler, & Christakis, 2012; Henrich & Broesch, 2011; Ugander, Karrer, Backstrom, & Marlow, 2011) show that human social networks have several defining structural properties. One property refers to the frequency distribution of the number of acquaintances that people within a population have (in the network sciences, this is often referred to as a "degree distribution"). Within real human populations, most individuals have at least a few acquaintances, but relatively few individuals have an extremely large number of friends. Consequently, human social networks are characterized by a degree distribution skewed to the right. A second property refers to the likelihood that any two acquaintances of any individual will also be acquainted with each other. Within real human populations, this likelihood is non-zero, which is reflected in indices that assess the "clustering" of social connections within the network. A third property refers to the average smallest number of social connections required to trace a path from any one individual within the population to any other individual within the population. (This is sometimes referred to as "average path length" or, in common parlance, "degrees of separation.") While there is considerable within-population variability in the path length separating any two individuals, in human social networks the mean shortest path length is typically between 3 and 4.

These network properties are emergent consequences of individuals' behavioral actions—specifically, their tendencies to make acquaintances with other individuals. Cultural differences in extraversion have an obvious implication. In populations characterized by higher mean levels of extraversion, a greater number of people are likely to make a greater number of acquaintances, and this will result in denser social networks (specifically, a less skewed degree distribution, a higher level of clustering, and a lower mean path length).

Social connections are the conduits through which socially contagious things spread throughout human populations. The category of contagious things includes not only socially transmitted diseases, but also socially transmitted information of any kind: ideas, technologies, opinions, beliefs, patterns of behavior, and so forth (Berger, 2013; Eubank et al., 2004; Fowler, Christakis, Steptoe, & Roux, 2009; Rogers, 1995). Thus, if cultural differences in extraversion have implications for the structure of social networks, these cultural differences—along with cultural differences in individuals' tendency to either conform or deviate from the majority opinion—may have further implications for the societal outcomes of social influence. It is to these further implications that we now turn.

Implications for Societal Outcomes of Social Influence Processes

Within the psychological sciences, the study of social influence typically focuses on the processes through which individuals are influenced by, or exert influence on, other individuals, and on variables that affect those individual-level outcomes (Cialdini & Goldstein, 2004)). People are neither simply the targets of influence nor simply the sources of influence; they are both. Over time, people have repeated opportunities to be influenced by, and to exert influence on, other people within their social networks. Thus, when considered within the context of whole populations, social influence is a bi-directional dynamic process, and this has consequences for the patterns of belief and behavior that define populations. It is through this dynamic social influence process that fads and fashions wax and wane, that pockets of public opinion propagate across entire populations, and that radical ideas sometimes catch on and sometimes don't (Harton & Bourgeois, 2004; Kashima, Wilson, Lusher, Pearson, & Pearson, 2013; Latané, 1996). We focus here on two specific population-level phenomena that depend on this dynamic process through which people influence each other, and which are themselves of considerable interest within the social sciences.

Consolidation of Existing Opinion Majorities

We focus first on the tendency for existing opinion majorities to become bigger over time—the phenomenon that Latané (1996) labeled *consolidation*. Consolidation of majority opinion emerges as a consequence of the individual-level psychology of social influence, whereby people are inclined to conform to the actions, attitudes and opinions that they perceive in the majority of others (MacCoun, 2012). Individuals who already are in agreement with the perceived majority tend to maintain that opinion over time; individuals whose personal opinions are at variance with the perceived majority feel pressure to change and to adopt the majority opinion instead. Thus, in the absence of countervailing pressures, the size of opinion majorities within a population tends to become incrementally greater over time.

This consolidation phenomenon is relevant to many specific outcomes of considerable societal importance. For instance, it has implications for intergroup prejudice. To the extent that a particular prejudice is perceived to be popular, people are more likely to express that prejudice themselves (Crandall & Eshleman, 2003). In doing so, they reify that existing prejudice and perpetuate it within the society. Consolidation also lies at the root of "bandwagon effects" in electoral politics, in which information about others' voting intentions may cause previously uncommitted voters to adopt the perceived majority opinion (Kenney & Rice, 1994; Nadeau, Cloutier, & Guay, 1993)—with potentially nontrivial consequences for election outcomes.

Diffusion and Spread of New Ideas

Second, we focus on the extent to which new ideas, radical beliefs, and novel ways of doing things spread through a population—the phenomenon that sociologists refer to as the *diffusion of innovations* (Rogers, 1995). If consolidation of majority opinion represents a sort of cultural entrenchment, the diffusion of innovations is a hallmark of cultural change. Not all innovations do spread, of course. Indeed, the conformist social influence processes that underlie consolidation of majority opinion can pose a substantial psychological barrier to the spread of unpopular attitudes and practices (Eriksson, Enquist, & Ghirlanda, 2007). And yet, as psychological research on minority influence reveals, this barrier can be breached (Wood, Lundgren, Ouellette, Busceme, & Blackstone, 1994); and, as the sociological literature reveals, some innovations do diffuse widely throughout entire populations (Rogers, 1995; Wejnert, 2002).

Because there are so many different kinds of "innovations"—new opinions, new beliefs, new technologies, etc.—the process by which innovations spread (or fail to spread) has implications for many different kinds of societal outcomes. Diffusion processes are of substantial relevance to consumer behavior (e.g., research on "word of mouth"; Berger &

Schwartz, 2011; Brown & Reingen, 1987), to the success or failure of public health interventions (Haider & Kreps, 2004), and to the popular ascendance of novel ideologies and religious beliefs (e.g. Collar, 2007), among other specific societal implications.

Obvious and Non-obvious Effects of Cultural Differences

How might cultural differences in extraversion and conformity affect the dynamic social influence processes that underlie consolidation of existing opinion and also underlie the diffusion of innovations? At the individual-level of analysis, some initial implications are obvious: Within more extraverted cultures—characterized by denser social networks—a greater number of individuals have the opportunity to influence, and be influenced by, a greater number of acquaintances. And, within more conformist cultures, individuals are more likely to conform to the actions and attitudes expressed by the majority of their acquaintances. But, with perhaps one exception (consolidation of existing opinion majorities is likely to occur more rapidly in more conformist cultures), it is difficult to confidently intuit or logically deduce what further effects these individual-level outcomes might have for the speed with which opinion majorities consolidate within the population, or for the likelihood that radical new ideas might successfully diffuse throughout a population. Indeed, one of the hallmarks of the non-linear nature of dynamical social influence (and of complex dynamical systems more generally) is that emergent population-level outcomes not only defy intuitive appraisal, they also cannot reliably be predicted on the basis of the linear *if-then* rules that govern deductive analysis (Kameda et al., 2003; Latané, 1996; Mason et al., 2007; Vallacher et al., 2002). In order to plausibly identify the implications that cultural differences might have for consolidation and diffusion, it is helpful to employ the powerful analytic tools of computational modeling.

Computational Modeling of Social Interaction and Social Influence

Theorizing in psychological sciences typically begins with the identification of some set of assumptions and then proceeds to identify further implications that follow logically from those assumptions. In many cases, natural language structures (e.g., words and their accepted meanings) are suitable for this task. For more complicated psychological processes, it may be preferable to translate psychological constructs into mathematical symbols and equations to ensure the necessary analytic rigor. And in some cases, the level of conceptual complexity may transcend the limitations of natural language and linear algebra, in which case a rigorous approach to the problem may require what Ostrom (1988) called the "third symbol system": computational modeling.

Computational models are especially useful tools for identifying the ways in which processes that unfold over time at one level of analysis might produce emergent properties measurable at another level of analysis. These tools have proven indispensable in the study of evolutionary biology, behavioral ecology, epidemiology, and meteorology (Bower & Bolouri, 2001; Epstein, 2006; Johnson, 2002; Kitano, 2002; Mangel & Clark, 1988), as well as in the study of cognitive and social psychology (Hastie & Stasser, 2000; Kenrick et al., 2003; Monroe & Read, 2008; Nowak & Latané, 1994; Pfau, Kirley, & Kashima, 2013). Computational models have been extensively employed in the psychological sciences to study group-level and population-level outcomes of interpersonal influence processes (Hastie & Kameda, 2005; MacCoun, 2012; Nowak, Szamrej, & Latané, 1990; Tanford & Penrod, 1983, 1984). For example, in developing dynamic social impact theory, Latané and colleagues (Latané, 1996; Latane & Bourgeois, 2001; Latané, Liu, Nowak, Bonevento, & Zheng, 1995) programmed cellular automata models to simulate human populations governed by a few rudimentary social psychological facts (e.g., people are more likely to communicate with other people who are closer in geographical space; people mutually influence each other during the course of communication). Although conceptually unremarkable at an individual level of analysis, these models produced notable population-level outcomes, some of which were relatively straightforward (consolidation of majority opinion) and others that were more subtle and surprising (over time, previously uncorrelated beliefs and behavioral patterns become correlated). These outcomes represented a set of scientific hypotheses—arrived at rigorously via computational means—that consequently were tested by empirical evidence (Cullum & Harton, 2007; Harton & Bourgeois, 2004; Harton & Bullock, 2007).

Analogously, in order to address our research questions, we too needed to computationally simulate a set of empirical facts evident in the psychological literature—including cultural differences in dispositional tendencies toward extraversion and conformity, the effects of individuals' dispositional tendencies on the forging of acquaintances, as well as the effects of their dispositional tendencies on conformity to perceived majority opinion. And we too needed to measure a set of population-level outcomes produced by these models: (a) structural properties of emergent social networks, (b) consolidation of majority opinion over time, and (c) spread of innovations over time.

Overview of Our Computational Modeling Methods

Cultural differences in extraversion should have implications for the geometric properties of the social networks that emerge within different cultural populations. And cultural differences in conformity should have implications for the emergent consequences of interpersonal influence within those social networks. To address our research questions, our models therefore required two distinct phases. Phase 1 was designed to model the process through which individuals form acquaintances and, as a consequence, social network structure emerges within a population. It was within the context of this phase that we examined how cultural differences in extraversion may have an impact on the emergent structure of social networks. The second phase (Phase 2) built upon the results of the first, and was designed to model the process through which individuals influence, and are influenced by, other individuals to whom they are connected within a social network. It was within the context of Phase 2 that we used additional methods to measure the consolidation of majority opinion and the diffusion of initially unpopular beliefs, and examined how these outcomes may be affected by cultural differences in both extraversion and conformity.

In the following sections, we describe these methods, and the emergent consequences, in detail. We first describe the manner in which our models operationalized both within-culture and between-culture differences in dispositional tendencies toward extraversion and conformity. We then describe Phase 1 of our models (the emergence of social network structure) along with the results that emerged from this first phase. The methods (and results) described in these sections are simply preliminary steps toward the two main parts of our analysis, both of which focus on Phase 2 of our models (during which we model the population-level consequences of interpersonal influence within social networks). In one section, we describe implications for the consolidation of existing majorities. Results of these models reveal that the speed with which small majorities become larger majorities is likely to be affected not only by cultural differences in conformity, but also by cultural differences in extraversion. In a subsequent section, we describe implications for the diffusion of innovations. These results reveal that the speed with which initially unpopular beliefs spread within a population is likely also to be affected by cultural differences in extraversion and conformity (and the exact nature of these effects may strike some readers as somewhat surprising).

Simulation of Individual Differences and Cultural Differences

In our models, we created populations comprised of 900 individuals—a size large enough to be plausibly analogous to meaningful cultural populations (e.g., small-scale societies of the sort studied by ethnographers), while not so large as to be computationally intractable. Each individual within a simulated population was assigned a numerical value representing a dispositional tendency toward *extraversion*, and another numerical value representing a dispositional tendency toward *conformity*. Both extraversion and conformity were operationalized as behavioral probabilities. An individual's extraversion value represented the probability that they would make a new acquaintance when given the opportunity. An individual's conformity value represented the probability that they would change a preexisting attitude (or belief or behavioral practice or any other thing that might be responsive to social influence) upon discovering that the majority of their acquaintances had a different opinion (or belief, etc.).

In assigning these values, we attempted to accomplish two objectives. (1) Within any single simulation, the distribution of values should plausibly mimic individual differences in behavioral dispositions that exist within any human population; and (2) across different sets of simulations, these distributions should plausibly mimic differences between different cultural populations (i.e., realistically represent the magnitude of actual cultural differences). To accomplish these objectives, we drew upon the *beta distribution* (Gupta & Nadarajah, 2004), which can be used to model both within-population and between-population variability (e.g. Balding & Nichols, 1995; Batchelder, 1975). The beta distribution is a family of probability frequency distributions, the shapes of which are controlled by two parameters (denoted [α, β]). By adjusting these parameters, it is possible to create a wide range of realistic distributions that vary in shape and central tendency. Beta distributions are defined over the probability interval [0, 1], which makes them useful for modeling any underlying variable bounded by two known endpoints. It is especially useful in models—such as ours—in which individual differences are operationalized as behavioral probabilities, allowing us to use a beta distribution without any transformation.

In order to assign extraversion values to individuals within our simulated populations, we created 3 different beta distributions with the following parameter values: [4, 4], [2.5, 3.5], and [3.5, 2.5]. The first set of parameters creates a bell-shaped distribution that is symmetrical around a mean value at the midpoint of the probability scale. It represents a kind of "baseline" population in which there are an equal number of introverts and extraverts. The second set of parameters creates a distribution that is skewed right (i.e., introverts outnumber extraverts), and has a mean value approximately 0.5 standard deviations less than the baseline population. The third set of parameters creates a distribution that is skewed left (i.e., extraverts outnumber introverts), and has a mean value approximately 0.5 standard deviations higher than the baseline population. (See Figure 1 for a graphical representation of the three beta distributions.)

[INSERT FIGURE 1 HERE]

For each simulation, each of the 900 individuals within the population was randomly assigned an extraversion value drawn randomly from one of these three beta distributions. For some simulations, values were drawn from the β[4,4] distribution; consequently, these simulations represent cultural populations with a moderate level of extraversion. For other simulations, values were drawn from the β[2.5, 3.5] distribution and represent cultural populations with a relatively low level of extraversion. And for still other simulations, values were drawn from the β[3.5, 2.5] distribution, and represent cultural populations with a relatively high level of extraversion. This ensured a realistic representation of individual differences within each simulated population. Also, because differences between the means of the 3 beta distributions mathematically mimic the magnitudes of actual cross-cultural differences in extraversion (McCrae et al., 2005), this procedure also created realistic representations of different cultural populations with either moderate, low, or high mean levels of extraversion.

We used an identical procedure to also assign each individual a probability value corresponding to a dispositional tendency toward conformity. Thus, within each individual simulation, the procedure simulated individual differences in conformist tendencies; and, across all simulations, the procedure created realistic representations of different cultural populations characterized by either moderate, low, or high mean levels of conformity.

In reality, cultural tendencies toward extraversion and cultural tendencies toward conformity are inversely correlated (Cultures that show greater evidence of conformist attitudes and behaviors also tend to have lower mean levels of extraversion; Hofstede & McCrae, 2004; Schaller & Murray, 2011). By definition, however, these constructs are distinct, and they are likely to have conceptually separable consequences on societal outcomes. Therefore, we assigned Extraversion values and Conformity values independently. Across the full set of simulations, we created 9 conceptually distinct types of cultural populations by crossing the 3 levels of Extraversion and the 3 levels of Conformity in 3 x 3 factorial design. For each of these 9 types, we employed our sampling methods to create 10 different 900-individual populations, ensuring that the simulation results would not be idiosyncratic to any single population of 900 individuals.

Phase 1: Emergent Differences in the Structure of Social Networks

Following the creation of a population, the first phase of our simulations was designed to model a small set of decision rules that govern the formation of social connections between individuals and thus, over time, lead to the emergence of social network structure within the entire population. Within the network sciences, there exist many computational algorithms that can lead to the emergence of some kind of network structure (for review see Jackson, 2010); but many of these algorithms fail to produce the structural properties of real human *social* networks, or fail to do so in a manner that is behaviorally realistic (Schnettler, 2009). For our purposes, it was necessary that our model generated structurally realistic social networks (i.e., social networks with realistic degree distributions, realistic levels of clustering and realistic mean path lengths), and did so through a process that plausibly mimicked the mechanisms through which human social networks form in the real world (i.e., as an emergent property of individuals' behavioral decisions). Furthermore, in order to examine the implications that cultural differences in extraversion may have on emergent social network structure (and, consequently, on the process through which social influence propagates through a population), it was necessary to model the effect that individual differences in extraversion have on the formation of social connections.

Each simulation began with the 900 individuals located in space on a grid lattice in the geometric shape of a torus. Each individual was initially assigned exactly four acquaintances: their four closest "neighbors" on the lattice (i.e., the individuals to their immediate east, west, north, and south). We then allowed the model to iterate. On each iteration, each individual (*i*) had a probability (p_i)—varying between 0 and 1—of moving to an adjacent space on the lattice. If two or more individuals occupied the same space on any iteration, they "met" and formed an "acquaintance." These acquaintances were maintained throughout the rest of the simulation and so, over repeated iterations, individuals had the opportunity to accumulate more and more acquaintances. The formation of acquaintances was computationally constrained in two important ways, both of which are informed by the empirical literature on social interaction:

First, the formation of acquaintances was constrained by proximity. Empirical research shows that individuals are more likely to form acquaintances with other individuals who are closer in geographic space (Festinger, Schachter, & Back, 1950; Harton & Bullock, 2007; Latané et al., 1995). It was important to model this constraint because it contributes to the emergence of realistic social network structure. Our model did so by limiting the movement of individuals: On any given iteration, individuals were allowed only to move to an *adjacent* space on the lattice. Thus, from an initial starting configuration, an individual was more likely to befriend those closer in geographic proximity than those further away.

Second, the probability of forming an acquaintance was constrained by individual differences in extraversion. Empirical research shows that more highly extraverted individuals are more likely to form acquaintances with other individuals (e.g. Asendorpf & Wilpers, 1998; Paulhus & Trapnell, 1998; Selfhout et al., 2010). To operationalize this principle, each individual's probability (p_i) of moving to a randomly-chosen adjacent space (and thus potentially forming a new acquaintance) was identical to that individual's extraversion value (drawn from the beta distribution; see above). These p_i values remained constant across iterations, thus mimicking the effects that chronic individual differences in extraversion have on the likelihood of forming new acquaintances. In sum, the algorithm represents a random walk over a grid lattice where the probability of taking a step in one of four cardinal directions—and thus potentially forming a new acquaintance—is given by an individual’s level of extraversion[1].

Social network structure emerges as the model iterates; and as it iterates further—and individuals within population meet more new acquaintances—the social network structure becomes denser. (As the number of iterations approaches infinity, the algorithm generates a network where everyone is directly connected to everyone else.) Given the objectives of this

[1] Mathematically, the individual’s position (z) after N iterations can be expressed in phasor notation (i.e. a complex number as an exponent) as:

$$z = \sum_{j=1}^{N} e^{i\theta_j}$$

Where the angle θ is restricted to one of four cardinal directions $\left(0, \frac{\pi}{2}, \pi, \frac{3\pi}{2}\right)$ on a 2 dimensional complex plane representing the 2 dimensions of the grid lattice. (A complex number is a useful way of representing the 2D space, since it has two components—the real portion and the imaginary portion.)

phase of the model, it was necessary to impose a "stopping rule" before the network structure became unrealistically dense. In order to meaningfully compare emergent network structures across different cultural populations (characterized by either low, moderate, or high mean levels of extraversion) that stopping rule had to be identical for every simulation. The stopping rule we chose was simple: We stopped Phase 1 of each simulation after 50 iterations. This stopping rule was informed by the results of preliminary exploratory simulations. These results revealed that—regardless of the mean level of extraversion within a simulated cultural population—50 iterations was sufficient for the emerging social network to attain structural properties (degree distribution skew, clustering, path length) that lay within the realistic range of the structural properties that characterize real human social networks.

Recall that for each of the 9 types of cultural populations we created (see above), we created 10 distinct populations. Of these 90 total populations, 30 represented cultures with low, moderate, or high mean levels of extraversion, respectively.

The key question addressed in this phase of the model was this: Did the mean level of extraversion within a simulated cultural population influence the structural properties of the social networks that emerged within that population? The answer is provided by results are presented in Table 1, which—for each level of extraversion—summarizes mean values for the 3 defining properties of social networks (degree distribution skew, clustering, path length). There are two important aspects to these results. First, the mean values are comparable to values obtained from empirical measurements of the network structure of real cultural populations (Apicella et al., 2012; Henrich & Broesch, 2011; Ugander et al., 2011). This provides reassurance that our modelling methods did lead to the emergence of realistic network structures across all simulated populations. Second, these results reveal “cultural” differences in the density of the social networks that emerged in the different sets of simulated populations. Within simulated populations with relatively higher mean levels of extraversion, the emergent social networks were characterized by less skewed degree distributions, higher levels of clustering, and lower mean path length. Treating each individual simulation as the unit of analysis, a multiple regression model reveals each of these effects to be statistically significant (p's < .001).

[INSERT TABLE 1 HERE]

In sum, the first phase of our model produced emergent network structures that closely mimicked the structures of real social networks with real human cultural populations, and the structural properties of those emergent social networks were influenced by cultural differences in extraversion. These results are consistent with empirical evidence documenting cultural differences in social network properties (Chua & Morris, 2006; Harihara, 2014), which further bolsters confidence in the verisimilitude of our computational model. Furthermore, conceptually, these results represent a means through which cultural differences in extraversion may have further implications for the population-level consequences of interpersonal influence.

Phase 2: Interpersonal Influence within Social Networks

The social network structures that emerged during the first phase of the simulation were kept intact (i.e., we did not allow the structure of those networks to change any further) throughout the second phase—in which we modeled the effects of interpersonal influence within the social networks that characterize different cultural populations. Specifically, we modeled the process whereby (a) individuals obtain information about the opinions and beliefs of their acquaintances, and potentially (b) update their own opinions and beliefs accordingly (depending upon the extent to which their acquaintances' opinions differ from their own, and depending also upon their own dispositional tendency toward conformity). Our methods were designed to realistically model the potential consequences that individual and cultural differences in extraversion may have on social influence processes: Because more extraverted individuals accumulate more acquaintances (as documented in Phase 1), more extraverted individuals also sample the opinions and beliefs of a greater number of other people. Our methods were also designed to realistically model the potential consequences that individual and cultural differences in conformity have on the outcomes of social influence processes: Individuals who are more chronically disposed toward conformity have a higher likelihood of adopting the opinions and beliefs that they perceive to be held by the majority of their acquaintances.

We initiated the second phase of each simulation by assigning one of two possible opinions to each of the 900 individuals within the population. These opinions were binary (0 or 1), and so could conceptually represent any opinion, belief, or behavioral tendency that might be subject to social influence. To ensure that our results were not idiosyncratic to the particular initial assignment of opinions, we ran 10 different starting positions for each of the 90 populations we created. The specific rules for assigning opinions to individuals differed depending upon whether the simulations were designed to model consolidation of majority opinion or to model diffusion of innovation. (We provide additional details on these assignment rules below.)

We then allowed the model to iterate. On each iteration a single individual was randomly selected to be a target of social influence and so it required 900 iterations for each individual to have, on average, one opportunity to be the target of influence. For the sake of exposition, we may consider every set of 900 iterations to represent one opportunity for influence.

Being the target of influence meant two things: The individual sampled the opinions of their acquaintances in order to determine majority opinion, and then the individual had a probability—varying between 0 and 1—of adopting that majority opinion as well. The sampling of other individuals' opinions was computationally constrained so as to mimic the empirical finding that individuals are influenced not so much by global majorities but by *local* majorities—the opinions that are most popular among the individuals they actually interact with (e.g. Cullum & Harton, 2007; Kashima et al., 2013). We modeled this as the majority opinion among the set of acquaintances that the individual had acquired during Phase 1 of the model (see above). The probability that an individual would actually adopt the perceived majority opinion was a joint product of (a) the size of the majority (individuals were more likely to conform to the local majority as the size of that majority increased), and (b) individual's dispositional tendency toward conformity (the value drawn from the beta distribution; see above). The latter values—conformity values—remained constant across iterations, thus mimicking the effects that chronic individual differences in conformity have on the likelihood that individuals will adopt the opinions of the majority of their acquaintances[2].

Using these methods, we operationalized individual differences in both extraversion and conformity: Individuals with higher extraversion values were likely to have more acquaintances' opinions to sample when computing the majority opinion; and individuals with higher conformity values were more likely to actually adopt that majority opinion. These individual differences also manifested as cultural differences: In cultures with higher mean

[2] Mathematically, the probability (P_j) of an individual acquiring the majority opinion j is given by the following function:

$$P_j = c \cdot \frac{b_j}{b_0 + b_1}$$

Where *c* represents individuals' conformity value (drawn from the beta distribution, with a value lying within a range from 0 to 1), b_0 is the number of acquaintances who hold opinion 0, and b_1 is the number of acquaintances who hold opinion 1, and b_j represents whichever of those latter two numbers (b_0 or b_1) is greater.

levels of extraversion, individuals' opinions were (on average) influenced by a greater number of acquaintances' opinions; and in cultures with higher mean levels of conformity, individuals were (on average) more likely to adopt the majority opinion expressed by their acquaintances. In the following two sections, we describe in detail the implications that these cultural differences had on the tendency for population-wide opinion majorities to grow larger over time, and on the long-term prospects for new (and initially unpopular) opinions to spread more widely within populations.

Simulated Effects of Cultural Differences on Consolidation of Majority Opinion

What implications might cultural differences in extraversion and conformity have for the consolidation of majority opinion over time? To address this question, we ran a total of 900 simulations (100 simulations for each of the 9 different cultural populations created by crossing 3 levels of extraversion and three levels of conformity). We initialized each simulation by randomly assigning one of two opinions to each of the 900 individuals within the population. Given that assignment was random, it was very rare that each opinion was held by exactly 50% of individuals. Instead, each simulation began with one of the two opinions being held by a very small majority (typically between 50% and 55% of the total population). As the model began to iterate—and individuals had the opportunity to be influenced by their acquaintances—initial small majorities did not always endure. Regardless, as the model continued to iterate, one of two opinions eventually not only endured as the majority, but also became an increasingly larger majority. The key question here is whether—across all 900 simulations—the speed of this consolidation phenomenon differed across different cultural populations.

There are several complementary analytic approaches that can address that question. One approach is to choose some threshold for the size of a "super-majority," to measure how many opportunities for influence transpired before a super-majority of that size emerged, and to examine the effects that mean population-wide levels of extraversion (3 levels: low, moderate, high), and mean population-wide levels of conformity (3 levels: low, moderate, high) have on that measure. We conducted analyses for a variety of different super-majority thresholds (e.g., 75%, 90%), and the results were similar regardless of which specific threshold is chosen. We report here the results for a 2/3 super-majority[3].

Figure 2 depicts, for each of the 9 cultural populations (100 simulations for each), the mean opportunities for influence required before majority opinion eventually reached the 2/3 super-majority threshold. Two distinct effects can be detected from these results, one of which is more obvious than the other. The obvious effect is a main effect for the mean level of conformity within a cultural population: Opinion majorities more quickly reached the super-majority threshold in populations characterized by relatively higher values of conformity. Less obviously, there appeared also to be a main effect for the mean level of extraversion within a population: Opinion majorities also consolidated into super-majorities more quickly in cultural populations characterized by relatively higher values of extraversion.

These effects are substantiated by the results of a multiple regression analysis that tested the effects of cultural differences in conformity and extraversion on the number of influence opportunities required for the 2/3 supermajority to emerge. These results are reported in Table 2. Across all 900 simulations, the main effects of conformity ($p < .001$) and extraversion ($p = .002$) were both statistically significant.[4] Drawing on the results of

[3] The 2/3 super-majority corresponds to a decision rule that is commonly used in many real-world decision-making contexts. E.g., in the world's two most populous democracies (India and the United States), constitutional amendments require a 2/3 super-majority vote within the relevant voting bodies.

[4] Results were similar when we conducted analyses that focused on other super-majority thresholds. For thresholds of 75% and 90%, the main effect of conformity was associated with *b*'s of -88.00 and

these regression analyses, these effects can be illustrated as follows: Compared to cultural populations with high levels of conformity, low-conformity populations required approximately 70 more influence opportunities before majority opinion consolidated to the 2/3 super-majority threshold. And, compared to populations with high levels of extraversion, low-extraversion populations required approximately 30 more influence opportunities before the super-majority threshold was reached.

[INSERT FIGURE 2 AND TABLE 2 HERE]

Although the means presented in Figure 2 offer some hint of an interaction between extraversion and conformity (effects of cultural differences in conformity appeared to be especially pronounced in cultures with relatively low mean levels of extraversion), the inferential statistical results (Table 2) provide no substantiation for that apparent interaction. It is worth noting that the statistical power of this analysis is constrained by the number of simulations we conducted.

The second analytic approach was designed to focus on specific periods of elapsed "time" (defined computationally by elapsed opportunities for influence), to measure the size of the majority after each period of time, and to examine the effects that mean levels of both extraversion and conformity have on that measure. This analytic approach allowed us to track the consolidation of majority opinion as it emerged temporally, while also examining the effects that cultural differences in extraversion and conformity had on the consolidation process. Moreover, this approach treated each opportunity for influence as an additional predictor variable in statistical analyses, resulting in a statistically powerful means of identifying even very small effects.

-227.66 (both *p*'s $< .001$); and the main effect of extraversion was associated with b's of -23.72 and -42.78, (*p*'s were .029 and .139, respectively.)

Figure 3 depicts, for each of the 9 cultural populations (100 simulations each) the mean size of the majority opinion as it changed across each of the first 500 opportunities for influence. These plots are best interpreted by referring also to Table 3, which reports results from a regression analysis that regressed the size of majority opinion on population-wide mean levels of conformity (3 levels: low, moderate, high), population-wide mean levels of extraversion (3 levels: low, moderate, high), elapsed opportunities for influence (500 levels, corresponding to each of the 500 influence opportunities), and the interactions between these variables. Given the enormous statistical power afforded by the inclusion of influence opportunities as a predictor variable, every effect (all main effects plus interaction terms) was statistically significant.

[INSERT FIGURE 3 AND TABLE 3 HERE]

Of primary conceptual interest are the main effects for (a) population-wide mean level of conformity and (b) population-wide mean level of extraversion. These effects are conceptually consistent with the main effects that emerged in the previous analysis (described above): Consolidation of majority opinion occurred more quickly in cultural populations with higher mean levels of conformity and, somewhat more weakly, also in cultural populations with higher mean levels of extraversion.

There was also a statistically significant interaction between extraversion and conformity, but the size of this effect was comparatively tiny, and so perhaps of little meaningful consequence. The other effects all pertained to opportunities for influence, and are of negligible conceptual interest. The main effect of opportunities for influence reflects the fact that majority opinion did indeed consolidate over time (i.e., the size of majority opinion increased as more opportunities for influence elapsed). This phenomenon has been well-documented by previous research (Latané, 1996). The interactions involving opportunities for influence simply show that the effects of conformity and extraversion (both main effects and their interaction) became more pronounced as more opportunities for influence elapsed.

Summary and Discussion

These simulation results show how cultural differences in extraversion and conformity may have implications not only for individual-level outcomes, but also for the population-level phenomenon in which existing opinion majorities become larger over time. The main effect of conformity is unsurprising and its explanation is straightforward: Given that the phenomenon itself—consolidation of majority opinion—is dependent upon individuals' tendency to conform to majority opinion, it follows logically that consolidation will occur more rapidly within populations containing a higher number of conformists. The main effect of extraversion is less obvious. In order to make sense of it, it is useful to refer to previous work on the population-level consequences of interpersonal social influence processes. Research on dynamic social impact theory shows that even as opinion majorities grow bigger over time, there still persist subpopulations of people holding the minority opinion (Harton & Bullock, 2007; Latané, 1996). These clusters of unpopular opinion persist in part because the people who comprise those clusters interact primarily with each other, and so are less susceptible to influence by the broader population of people who hold the global majority opinion. In populations with low levels of extraversion, many people are likely to have such circumscribed networks of acquaintances. But, as the mean level of extraversion within a population increases, the number of people who fit this profile decreases. Instead, as extraversion increases, there is also an increase in the percentage of people for whom the local majority (i.e., the majority opinion expressed within one's personal network of acquaintances) is more diagnostic of the global majority; and so, by conforming to the local majority, they conform also to the global majority, with the consequence that the global majority consolidates more quickly.

Simulated Effects of Cultural Differences on the Diffusion of Innovations

Although consolidation of majority opinion is defined by some incremental change in popular opinion, it also represents a form of cultural stability—or at least a sort of cultural resistance to the spread of novel or unpopular beliefs. Does this mean that novel and unpopular beliefs are always doomed to failure? Clearly not. Despite their numerical disadvantage, some initially unpopular beliefs do successfully spread within human populations—especially when initial adherents have unshakeable faith in those beliefs and have the motivation and means to influence others (Moscovici, 1980; Wood et al., 1994).

How might the spread of initially unpopular beliefs differ, depending on the mean levels of extraversion and conformity within a cultural population? Intuitively, one might assume that, if consolidation of majority opinion is facilitated by higher levels of conformity and extraversion (as we have just seen), then initially unpopular beliefs are most likely to spread widely in cultures characterized by low levels of both conformity and extraversion. As we shall show, computer simulations reveal this intuition to be wrong (as is often the case for intuitions about the outcomes of non-linear dynamical systems). We conducted two sets of simulations, each of which examined diffusion outcomes that resulted from somewhat distinct starting conditions. One set of simulations examined outcomes within a "lone ideologue" context: A situation in which, initially, there is just a single individual espousing an unpopular belief (and doing so with unshakeable faith). The second set of simulations examined diffusion outcomes within a context in which the ideologue is accompanied by a small band of "disciples" who also share the initially unpopular belief (but not their ideological acquaintance's unshakeable faith).

The "Lone Ideologue" Context

We ran a total of 9000 simulations. Specifically, for each of the 9 different kinds of cultural populations—created by crossing 3 levels of extraversion and 3 levels of conformity—we created 100 separate populations within which we simulated the spread of an initially popular belief 10 times each. We initialized each simulation by assigning everyone in the population the same belief, with the exception of 1 individual (i.e., in each simulation, 899 people received one belief and 1 person received a different belief.) In a set of pilot simulations, we discovered that we could not simply choose this 1 lone individual randomly; if we did so, the likelihood of spreading the initially unpopular belief approached zero. Therefore, we did two things to boost the chances that the initially unpopular belief might spread to others. First, we assigned the unpopular belief to the individual within each population who had the highest extraversion value (drawn from the relevant beta distribution, as described above). Second, we re-assigned this individual a conformity value of 0. By taking these two steps, we ensured that this individual had the means to potentially influence many others (because, as a consequence of an unusually high extraversion value, this individual had acquired an unusually large network of acquaintances in Phase 1 of the model), and that this individual was resistant to any pressure to conform to the beliefs expressed by others (all of whom initially held a different belief). As the model iterated—and individuals had the opportunity to be influenced by their acquaintances—there was considerable variability across simulations in the extent to which the initially unpopular belief spread from the lone ideologue to others within the population. The key question here is whether—across all 9000 simulations—the success of this diffusion phenomenon differed across different cultural populations.

As with our examination of the consolidation phenomenon (described above), we employed two different analytic approaches to address this question. One approach was to choose a specific threshold that defines "successful" diffusion, to measure the percentage of simulations that eventually reached that threshold, and to examine the effects that mean population-wide levels of extraversion (3 levels: low, moderate, high), and mean population-wide levels of conformity (3 levels: low, moderate, high) had on that measure. In taking this approach, we defined successful diffusion as 50% penetration—the point at which an unpopular belief is transformed into a popular one. Therefore, we examined the effects that cultural differences in conformity and extraversion had on the likelihood that an initially unpopular belief eventually reached this crucial threshold of popular penetration.

Figure 4 depicts, for each of the 9 cultural populations, the percentage of simulations (out of a total of 1000 simulations per population) that reached this 50% threshold. Table 4 summarizes the results of a binary logistic regression analysis that statistically tests the effects of cultural differences in conformity and extraversion, and their interaction, on the likelihood of reaching this threshold. These results reveal main effects of both conformity and extraversion.

Interestingly (and perhaps contrary to intuition), the effect of conformity was *positive*. An unpopular belief (held initially by just a single well-connected and highly-committed individual) was more likely to successfully spread in cultures characterized by *higher* mean levels of conformity. This effect can be illustrated by calculating likelihood values from the odds ratios reported in Table 4: In low-conformity populations, the likelihood was 25% that the initially unpopular belief eventually reached the 50% threshold; but in high-conformity populations, this likelihood increased to 45%.

The results also revealed a *negative* effect of extraversion. An initially unpopular belief was more likely to spread in cultures characterized by *low* levels of extraversion. This effect too can be illustrated by calculating likelihood values: In low-extraversion populations, the likelihood was 40% that the initially unpopular belief eventually reached the 50% threshold; but in high-extraversion populations, this likelihood decreased to 30%.

[INSERT FIGURE 4 AND TABLE 4 HERE]

For our second analytic approach, we measured the percentage of the population that held the initially unpopular belief after each of the first 500 opportunities for influence, and examined the effects that population-wide mean levels of extraversion and conformity had on that measure. This approach allowed us to document diffusion as it emerged over time, while also examining effects that cultural differences in extraversion and conformity had on the diffusion process. And, by treating opportunities for influence as an additional predictor variable in statistical analyses, this approach provided a much more statistically powerful means of identifying even very small effects.

Figure 5 depicts, for each of the 9 cultural populations (1000 simulations each) the mean percentage of the population holding the initially unpopular belief, across each of the first 500 opportunities for influence. We also conducted a regression analysis that regressed this percentage on population-wide mean levels of conformity, population-wide mean levels of extraversion, elapsed opportunities for influence, and the interactions between these variables. Given the enormous statistical power, all main effects and interactions were statistically significant. The main and interactive effects of influence opportunities are of no real conceptual interest (revealing simply that, after more opportunities for influence elapse, initially unpopular beliefs tend to spread more widely and that the effects of extraversion and conformity on that spread become more pronounced). Therefore, in summarizing the results of this regression analysis, Table 5 presents only the results bearing on the main and interactive effects of extraversion and conformity.

[INSERT FIGURE 5 AND TABLE 5 HERE]

These results reveal a positive main effect for conformity and a negative main effect for extraversion, both of which are consistent with the effects that emerged in the previous analysis: Initially unpopular beliefs spread more readily in cultures characterized by higher levels of conformity, and by lower levels of extraversion.

The results reported in Table 5 also show an Extraversion x Conformity interaction. Given that this interaction was virtually nonexistent in the previous analysis, we are reluctant to interpret this effect as meaningful. More generally, before discussing any of these effects further, it is instructive to examine the extent to which they emerge also under simulated circumstances in which the initially unpopular belief is held not simply by a lone ideologue, but by an ideologue accompanied by one or more disciples.

The "Ideologue Accompanied by Disciples" Context

We ran an additional 108,000 simulations to examine a diffusion context in which, rather than being the only initial adherent to an unpopular belief, the ideologue is accompanied by a small set of disciples who also initially hold the same unpopular belief. Rather that arbitrarily choosing a specific number of disciples, we ran separate sets of simulations corresponding to circumstances in which the ideologue was accompanied by different numbers of disciples, ranging from a single disciple to 12 disciples.

We did so as follows: First, just as in the "lone ideologue" simulations, we assigned the unpopular belief to the individual with the highest extraversion value (and also assigned this individual a conformity value of 0). We then assigned the same belief to 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, or 12 randomly chosen acquaintances ("disciples") of that individual. These disciples' conformity values were unchanged from the values initially drawn from the relevant beta distribution. (Therefore, while they shared the ideologue's unpopular belief, the disciples not share the ideologue's unshakeable faith in that belief.) The remaining 887 – 898 individuals (the exact number varied, depending on the number of disciples that the ideologue was assigned) were assigned the opposite belief. We ran 9000 simulations (1000 simulations for each of the 9 different cultural populations) for each of the 12 conditions defined by specific numbers of disciples.

The model then proceeded to iterate. We examined the extent to which the initially unpopular belief spread through the population, and the extent to which diffusion differed across different cultural populations. We did so by employing two analytic approaches similar to those employed in the "lone ideologue" analyses (described above).

The first approach focuses on the likelihood that the initially unpopular opinion eventually spread successfully to 50% of the population. Table 6 summarizes the key results from 12 separate binary logistic regression analyses, each of which analyzed results from a subset of 9000 simulations associated with a specific number of disciples (ranging from 1 to 12). For each of these 12 regression analyses, odd ratios reveal the effects of extraversion and conformity (and their interaction) on the likelihood that the 50% threshold was attained.

These results reveal three things. First, conformity exerted a substantial positive effect (indicated by odds ratios > 1) and this positive effect emerged regardless of the number of disciples. Second, extraversion exerted a negative effect (odds ratios < 1) and this negative effect also emerged regardless of the number of disciples. Third, there was no consistent interaction between mean extraversion and conformity. (In 7 of the 12 numbers-of-disciples conditions, the odds ratio associated with the interaction was greater than 1; in the other 5 conditions the odds ratio was less than 1. This pattern provides no basis for any confident inference about an interaction.) The two main effects (and the lack of a meaningful interaction) are graphically illustrated in Figure 6, which summarizes results obtained within the subsets of simulations in which the ideologue was accompanied by either 6 disciples or by 12 disciples. The initially unpopular belief was more likely to successfully spread to 50% of the population within cultures characterized by higher levels of conformity and lower levels of extraversion.

[INSERT TABLE 6 AND FIGURE 6 HERE]

The second analytic approach focused on temporal changes in the percentage of the population who hold the initially unpopular belief. We conducted a set of 12 separate regression analyses—each one corresponding to a specific numbers-of-disciples condition—on the percentage of the population holding the initially unpopular belief during each of the first 500 opportunities for influence. For each of these analyses, we regressed this percentage on mean levels of conformity, mean levels of extraversion, elapsed opportunities for influence, and the interactions between these variables. Of primary conceptual interest (just as in the "lone ideologue" context) were the main and interactive effects associated with extraversion and conformity. Table 7 summarizes the results associated with these three effects.

These results reveal three findings of primary interest, all three of which are inferentially consistent with the results of the preceding analyses. First, conformity exerted a positive effect, and this positive effect emerged regardless of the number of disciples. Second, extraversion exerted a negative effect, and this negative effect emerged regardless of the number of disciples. Third, there was no consistent interaction between mean levels of extraversion and conformity. These effects of conformity and extraversion are illustrated in Figure 7, which depict results obtained in the subsets of simulations in which the ideologue was accompanied by either 6 disciples or 12 disciples. As revealed in the figure, the initially unpopular opinion spread as opportunities for influence elapsed; and it spread more readily within cultural populations characterized by higher levels of conformity and lower levels of extraversion.

[INSERT TABLE 7 AND FIGURE 7 HERE]

Summary and Discussion

Just as mean levels of conformity and extraversion within simulated cultural populations had implications for the consolidation of existing majority opinions, so too did they had implications for the successful spread of initially unpopular beliefs. The effect of conformity emerged consistently across both the "lone ideologue" and "ideologue accompanied by disciples" contexts, and is perhaps somewhat counter-intuitive: Initially unpopular beliefs spread more successfully in cultural populations characterized by relatively high levels of conformity. Similarly, the effect of extraversion was somewhat weaker than that of conformity, but it also emerged consistently across both the "lone ideologue" and "ideologue accompanied by disciples" contexts. This effect too is also perhaps a bit counterintuitive: Initially unpopular beliefs spread more successfully in cultural populations characterized by relatively low levels of extraversion.

How is it that radical new beliefs—which were initially unpopular—spread more successfully in populations with relatively high numbers of conformists? The answer lies in the fact that social influence is governed primarily by *local* norms rather than global norms: When individuals conform, they tend to conform to whatever belief is held by the majority of people in their own personal social networks (regardless of whether or not the locally-popular belief is objectively popular in the broader population). This tendency to conform to local norms occurs more readily among individuals who are more dispositionally inclined toward conformity. Consequently, cultural populations characterized by high levels of conformity are more vulnerable to these local social influence outcomes. This principle applies under circumstances in which local norms match global norms (and so accounts for the faster consolidation of majority opinion); and it also applies under the rarer set of circumstances in which local norms deviate from global norms. It is because of the latter effect that unpopular beliefs can spread simply as a consequence of conformity processes—and spread more rapidly within more highly conformist populations.

The individuals most likely to perceive a globally unpopular belief to be popular among their acquaintances are those who have relatively few acquaintances. (The logic of sampling error is relevant here: Individuals who employ smaller samples to arrive at a subjective perception of majority opinion are more likely to perceive a majority opinion that varies from the objective majority within the entire population.) In other words, people are most likely to be influenced by a rebel espousing unpopular beliefs if they are acquainted with the rebel but are not acquainted with very many other people. This insight helps to explain why ideologues (with or without disciples) are more successful in spreading their initially unpopular beliefs within populations characterized by lower levels of extraversion. It is within those populations that well-connected ideologues are especially likely to find themselves in the position of being one of very few individuals within their acquaintances' social networks, and therefore able to exert a disproportionately large influence on the beliefs of those relatively lonely acquaintances.

General Discussion

Results of our computer simulations revealed that cross-cultural differences in individuals' dispositions may have long-term consequences for cultural stability and change. We focused on two empirically-documented cultural differences—differences in mean levels of conformity, and in mean levels of extraversion—and we investigated their implications for two population-level outcomes: (a) The speed with which existing opinion majorities consolidate into even bigger majorities, and (b) the extent to which initially unpopular beliefs successfully spread within a population. We found that higher mean levels of conformity facilitated the consolidation of majority opinion and also—perhaps counterintuitively—facilitated the spread of unpopular beliefs held initially by a well-connected ideologue (either alone or accompanied by a small number of disciples). Cultural differences in extraversion also had effects on these outcomes: Higher mean levels of extraversion facilitated the consolidation of majority opinion, but inhibited the spread of initially unpopular beliefs.

Although superficially very different, the two population-level consequences of conformity both reflect the same underlying process. One way to think about it is this: An individual's dispositional tendency to conform is equivalent to that individuals' likelihood of changing beliefs—of abandoning one belief in favor of another one (as long as it is held by the majority of that individuals' acquaintances). Therefore, populations characterized by higher mean levels of conformity are also characterized by relatively greater susceptibility to change. This greater susceptibility for change manifests in the greater likelihood that a small majority will consolidate into a super-majority, and also in the greater likelihood that an initially unpopular opinion will spread. Metaphorically, the mean level of conformity within a population functions like a lubricant: Under conditions in which there exists some potential for cultural change, that potential is facilitated by higher levels of conformity.

The effects of extraversion are somewhat subtler. An individual's dispositional tendency toward extraversion has consequences for the acquisition of acquaintances; this has further consequences for the number of people who are subject to that individuals' influence and for the number of influence sources that individuals are exposed to. It is the latter effect that appears to account for extraversion's positive effect on consolidation of majority beliefs and for its negative effect on diffusion of unpopular beliefs. Because extraverts are exposed to larger samples of people, their subjective perceptions of the majority belief are more diagnostic of the true population-wide majority belief. Therefore, when highly extraverted individuals abandon one belief in favor of the perceived majority belief, they are very likely adopting the true majority belief. By comparison, when highly introverted individuals abandon one belief in favor of the perceived majority belief, they are at greater risk of abandoning the true majority belief and adopting instead an objectively unpopular belief (which just happens to be locally popular among their relatively small number of acquaintances). Thus, in populations characterized by higher mean levels of extraversion, existing majorities become super-majorities more quickly, and radical new beliefs spread more slowly.

Of course, in addition to conformity processes modeled here, other considerations may also affect the consolidation of existing majorities and the diffusion of innovations. Some beliefs are more obviously accurate than others, and some radical new ideas—especially in the realm of technology—are more immediately useful, and so they spread more rapidly for these reasons instead. There may also be additional top-down pressures (e.g., authoritarian governmental policies) that facilitate the spread of some beliefs and inhibit the spread of others. To the extent that this is so, the conformity processes modeled here will be of relatively reduced importance. Therefore, our results probably apply primarily to subjective opinions and beliefs rather than to matters of verifiable fact, and also apply primarily to opinions and beliefs that are relatively unconstrained by laws or other institutional constraints. That still leaves a wide domain of application: These results apply to any idea, opinion, attitude, or behavioral decision that is subject to peer pressure.

Implications for Real-World Cultural Populations

Given the importance of the individualism / collectivism distinction in the description of actual human cultures, it is interesting to consider the implications that these simulation results have for predicting differences between individualistic and collectivistic cultures in the speed of cultural change. Prototypically individualistic cultures are characterized by relatively low levels of conformity and by relatively high levels of extraversion, whereas prototypically collectivistic cultures are characterized by high levels of conformity and by low levels of extraversion (Schaller & Murray, 2011).

Our simulation results showed that both conformity and extraversion positively predict the consolidation of small majorities into larger majorities, but also showed that the effect of conformity is substantially stronger than the effect of extraversion. One implication of this difference in effect sizes is that the consolidation of opinion majorities may occur more readily in individualistic cultures than in collectivistic cultures. An implied difference between individualistic and collectivistic cultures is even more evident when considering the speed with which radical beliefs and other innovations spread throughout a population. Our simulation results showed that radical ideas promoted by a single well-connected ideologue were least likely to spread widely within the population that was most prototypically individualistic and most likely to spread widely—and to eventually be held by the majority of people—within populations that were most prototypically collectivistic.

Considered in full, these results imply that individualistic and collectivistic cultural populations may be disposed toward different patterns of cultural change over time. Previous research on the non-linear dynamics of attitude change has suggested that population-level changes in popular opinion may sometimes be described by the mathematics of cusp catastrophes (Latané & Nowak, 1994; Tesser & Achee, 1994). The results of our simulations suggest that the likelihood of this kind of "catastrophic" change differs for individualistic and collectivistic cultural populations. In individualistic cultures (characterized by relatively low levels of conformity and high levels of extraversion), cultural change is predicted to occur slowly, incrementally. By contrast, in collectivistic cultures (characterized by relatively high levels of conformity and low levels of extraversion), majorities may more rapidly coalesce into monolithic super-majorities; but when this existing orthodoxy is punctuated by the spread of heterodox beliefs, this change is predicted to proceed at a pace that more closely fits the subjective perception of a "revolutionary" change.

Empirical Testability of the Hypotheses

The results of computer models are *not* empirical observations, of course; they are scientific hypotheses. They represent a set of analytically rigorous predictions about the effects that cultural differences in extraversion and conformity may have on the rate of change in public opinion and popular beliefs over time. Given that these hypotheses pertain to phenomena that pertain to entire populations and must be documented across potentially long stretches of time, they are not easily tested; but they are testable.

These hypotheses may be tested (if not immediately, then eventually) by conducting comparative longitudinal studies on attitudes assessed by survey instruments such as the World Values Survey, which are administered across multiple cultural populations and across multiple periods of time. It might also be possible to test these hypotheses on smaller, geographically-contained populations—such as those that exist in university dormitories or in sororities and fraternities—which can sometimes serve as proxies for larger cultural populations, and have been used previously in naturalistic studies of dynamic social influence and social contagion more generally (Bourgeois, 2002; Crandall, 1988; Cullum & Harton, 2007). It may even be possible to test these hypotheses in laboratory experiments on small groups. Previous research on the cumulative dynamics of social influence processes have attempted to create miniature proxy "cultures" in the form of small groups of individuals interacting over small periods of time, with some success (e.g. Baum, Richerson, Efferson, & Paciotti, 2004; Insko et al., 1980; Latané & Bourgeois, 1996; Mesoudi & Whiten, 2008). Similar methods might potentially be used to experimentally (rather than computationally) simulate the variables that define our models, and to test whether conceptually analogous group-level outcomes emerge.

Novel Features of Modeling Methods Employed Here

Of our primary results, only one (the effects of conformity on consolidation of majority opinion) is an intuitively straightforward consequence of individual-level social influence processes. The other results are less intuitive—in part because they emerge from the interplay between the complex geometry of social networks and from the dynamic manner in which interpersonal influence processes unfold over time within those networks.

These results highlight the value of rigorous computer models as a means for discovering non-obvious hypotheses about the population-level consequences of individual-level behavioral decisions (Kameda et al., 2003; Kenrick et al., 2003; Latané, 1996; Mason et al., 2007; Nowak, 2004; Pfau et al., 2013; Vallacher et al., 2002).

Computational methods are especially—and perhaps indispensably—useful as a means of identifying the long-term cumulative consequences of interpersonal influence processes. In addition to relevant work within the psychological sciences (e.g. Latané, 1996; Nowak et al., 1990), scholars from a wide-range of other scholarly backgrounds (including physics, economics, sociology, and anthropology) have attempted to model social influence processes in order to address a wide-range of topics, including the rise of political extremism (Weisbuch, Deffuant, & Amblard, 2005), changes in consumer preferences (Buenstorf & Cordes, 2008), and cultural evolution more generally (Boyd & Richerson, 1985; Henrich, 2004; Pfau et al., 2013). Our work here contributes in several novel ways to this scholarly tradition.

The central contribution follows from the fact that our models were designed to simulate individual differences in basic dispositional traits toward conformity and extraversion. Although there may be some general tendency for people to conform to opinion majorities, there is individual-level variability around this central tendency; by simulating this variability, one can model social influence outcomes more realistically. The same principle applies to extraversion. By simulating individual differences in extraversion, we were able to consequently simulate the emergence of social networks with geometric properties mimicking those of actual social networks, thus creating a realistic social ecology within which to examine the cumulative consequences of social influence outcomes. It is worth noting that extraversion has received very little attention in the psychological study of social influence—perhaps because effects of extraversion are not readily apparent on the short-term individual-level influence outcomes that are typically the object of psychological inquiry. But, as our results suggest, extraversion may have effects on the long-term population-level consequences of interpersonal influence.

By simulating individual differences in conformity and extraversion, we were also able to add another novel feature to our models: We simulated cultural differences in conformity and extraversion. This is important because, just as individuals vary around central tendencies toward conformity and extraversion, cultures vary in terms of the central tendencies themselves (Bond & Smith, 1996; McCrae et al., 2005). We simulated these cultural differences in a way that mimicked the magnitudes of actual cultural differences documented in the empirical literature. This has useful implications. The predictive utility of a model depends on the extent to which it realistically simulates the variables that are included. By using empirical results to inform our simulations of cultural differences, we can be more assured that the results of our simulations may be sensibly applied to predict outcomes in real human cultural populations.

Lacunae, Limitations, and Directions for Future Research

All models in the behavioral sciences—whether computational or not—represent intentional simplifications of reality. By necessity, these models must omit many of the countless variables that potentially influence individuals' thoughts, feelings, and behavioral decisions. This is not necessarily a limitation (Nowak, 2004). Still, it may be useful to draw attention to some of the specific ways in which our models—like other models of this sort—represent a simplified version of reality, and to consider the implications.

Consider Phase 1 of our models—the phase during which individuals acquired acquaintances and did so in a way that was computationally constrained by geographical proximity and extraversion. While both proximity and extraversion both do have important influences on the formation of social relationships (Asendorpf & Wilpers, 1998; Festinger et al., 1950; Harton & Bullock, 2007; Latané et al., 1995; Paulhus & Trapnell, 1998; Selfhout et al., 2010), other variables matter too. For instance, people are more likely to form relationships with others who have beliefs that are similar to their own (the so-called “similarity-attraction” effect; Byrne, 1971)—a tendency that varies in strength across individuals and across cultures (Heine, Foster, & Spina, 2009; Schug, Yuki, Horikawa, & Takemura, 2009). The omission of this variable (and of the many variables that can also affect individuals’ idiosyncratic decisions regarding who to befriend) did not undermine the objectives of Phase 1—as revealed by results showing that emergent social network structures realistically mimicked the geometric properties of actual social network structures, and also mimicked actual cross-cultural differences in these structural properties. Still, it may be worthwhile in future research to explicitly model both within- and between-population variability in this “similarity-attraction” effect, so as to explore the possible consequences that it too might have on the cumulative consequences of interpersonal influence.

Phase 2 of our models also omitted additional variables that have implications for social influence. In operationalizing the manner in which individuals assess majority opinion, we assumed that all acquaintances’ beliefs are treated equally. This is not always the case (in reality, individuals may accord greater weight to the opinions of their parents and siblings than to the opinions of their co-workers or Pilates instructors). More generally, the pool of opinions that really matter may be smaller than the full set of acquaintances that people have. Even if this is the case, however, it has negligible implications for the primary population-level outcomes we observed. The effects of individual differences in conformity are independent of the number of other people whose opinions subjectively matter; and so the effects of cultural differences in conformity will be obtained regardless. And as long as there is some non-zero relation between an individual’s level of extraversion and the number of other people that the individual may potentially influence (and be influenced by), then the effects of cultural differences in extraversion will occur as well.

Our simulation of social influence processes also assumed that individuals actually obtain veridical information about others' beliefs. In the real world, this is not always the case. People are sometimes reluctant to express their true beliefs—perhaps especially if they perceive that their beliefs are counter-normative. Indeed, for a variety of reasons bearing on the strategic psychology of social discourse, some beliefs are more likely than others to be the subject of conversations and other forms of interpersonal communication, and these differences in 'communicability' have implications for long-term stability and change in the popularity of these beliefs (Conway & Schaller, 2007; Schaller, Conway, & Tanchuk, 2002). The effects obtained from our simulations pertain primarily to attitudes and beliefs that are communicable in some meaningful way. To the extent that beliefs are less communicable, these effects would be expected to be less apparent.

For the subset of simulations that focused on the diffusion of an initially unpopular belief, we computationally ensured that the primary proponent of that belief was not only ideologically committed, but also highly extraverted. Had we not done so, the baseline likelihood of diffusion would have been substantially reduced, and the effects of both conformity and extraversion would have been reduced accordingly. When interpreting these effects on the spread of a radical new belief, it is important to keep in mind the fact that these effects are specific to conditions in which that radical new belief has some minimally realistic chances of spreading at all.

Across all simulations, we simulated a process in which individuals' are inclined (to varying degrees) to adopt whatever belief is held by a simple majority of their acquaintances. While this is indeed a common decision-rule guiding conformity (and decision-making more generally; Hastie & Kameda, 2005), it is by no means the only such decision-rule. Under different circumstances interpersonal influence may be contingent upon different thresholds of evidence, which may have additional consequences for long-term population-level outcomes (Boyd & Richerson, 1985; MacCoun, 2012). For instance, a more stringent standard of evidence (e.g., a 2/3 majority) would inhibit the speed with initially popular beliefs consolidated and initially unpopular beliefs diffused, and the observed effects of both conformity and extraversion would be somewhat reduced as well. In addition, in our simulations, we conservatively modeled an individuals' likelihood of conformity to be at or below the perceived size of the majority. In many circumstances, the likelihood of conforming exceeds the perceived size of the majority itself—a phenomenon that has been labeled "conformist transmission" (e.g., Efferson, Lalive, Richerson, McElreath, & Lubell, 2008; McElreath et al., 2005; Morgan, Rendell, Ehn, Hoppitt, & Laland, 2012). To the extent that the population-level outcomes of dynamic social influence processes are governed by the principles of conformist transmission, it would likely amplify the effects of we observed, for both conformity and extraversion.

Note too that our models were designed to simulate one specific form of social influence: Conformity. While conformity is certainly an important form of social influence (and is the form of influence that is typically simulated in models of consolidation, diffusion, changes in public opinion, and cultural evolution more generally), it is not the only form of social influence. In fact, for psychological reasons that are distinct from those underlying conformity, individuals are sometimes not only *not* motivated to conform, but may actually be motivated to *not* conform to perceived norms (identity signaling; Berger & Heath, 2007; Berger & Heath, 2008). More broadly, individuals' opinions, attitudes, and beliefs also change in response to persuasive messages—many of which are crafted with considerable cunning to take advantage of psychological processes that are independent of those that affect conformity, but which may still affect attitude change (Albarracín & Vargas, 2010). To the extent that these additional psychological processes also influence the consolidation of belief majorities and the diffusion of new beliefs, they represent phenomena that are conceptually independent of those examined by our models, and would need to be simulated separately in future models.

Finally, while our models are the first to rigorously examine the effects of dispositional variability (both within and between cultural populations) on dynamic social influence outcomes, we focused on just two of the many dispositional differences that may have implications for social influence processes. Other individual difference variables may matter too. For instance, within the psychological literature on persuasion processes, there is evidence that the influential impact of persuasive communications may be moderated by individual differences in needs for cognition and for cognitive closure (e.g., Cacioppo, Petty, Feinstein, & Jarvis, 1996; Kruglanski, Webster, & Klem, 1993). Not only do individuals vary in the extent to which they chronically experience these epistemic needs, there are cultural differences too (e.g. Chiu, Morris, Hong, & Menon, 2000). What implications might these individual and cultural differences have on the cumulative population-level consequences of interpersonal persuasion? We do not know. In order to sensibly speculate, it will be necessary to develop new models that, while conceptually distinct from our models (which focus on conformity rather than persuasion processes), incorporate analogous methodological innovations. For example: It may be possible to realistically simulate individual (and cultural) differences in need for cognitive closure, and also simulate the effects that these differences have on persuasion processes, and in doing so, computationally assess their long-term population-level consequences.

Broader Applications of These Modeling Methods

As the preceding paragraphs illustrate, the modeling methods that we have used are flexible, and can be amended to address additional interesting questions about effects of cultural differences on the population-level consequences of interpersonal influence. Our modeling methods may have a broader set of useful applications as well.

For example, the methods we used to simulate the emergence of realistic social network structures (in Phase 1 of our simulations) might be profitably amended to model the effects that other variables have on emergent social network structures, and to examine the consequences. Cultural populations are typically comprised of people defined by different demographic categories (gender, ethnicity, language, etc.); these differences affect the formation of relationships that, in turn, affect a wide range of outcomes of considerable psychological and societal importance—including prejudice and the acculturation of immigrants (Laar, Levin, Sinclair, & Sidanius, 2005). The processes can be formalized with the modeling methods that we employed, allowing for rigorous exploration of emergent population-level consequences of demographically constrained patterns of friendship formation (cf. Pfau et al., 2013).

These modeling methods might also have useful applications in the study of group decision-making. Although we have applied these methods to research questions bearing on large cultural populations, the methods can be easily amended to address research questions pertaining to smaller groups (Hastie & Kameda, 2005; Kerr & Tindale, 2004). For example, recent research shows that the effect of group size on the quality of group decisions depends on the extent to which group members make independent intellectual contributions to these decisions (Kao & Couzin, 2014). The independence of individuals' contributions is itself likely to depend, in part, on the group's social network structure—which, as we have shown, is influenced by the dispositional traits of group members. With minor amendments, our modeling methods might profitably be used as a means of identifying hypotheses about the effects that individual differences, and cultural differences, may have on group decision-making.

These methods may also have useful applications within the multi-disciplinary study of cultural evolution. Although there are many sophisticated models of cultural evolution (e.g., Boyd & Richerson, 1985; Henrich, 2004), it is rare for these models to explicitly simulate the geometric properties that define the social network structures of real human populations. For example, recent research reveals relationships between individual-level sociality and emergent cultural complexity (Muthukrishna, Shulman, Vasilescu, & Henrich, 2013); however, these results were based on models that—like most cultural evolutionary models—made simplifying assumptions about social network structure governing the interpersonal transmission of cultural information. By incorporating the methods employed in Phase 1 of our models, it may be possible to ask, and answer, questions about the realistic effects of social network structure on cultural transmission and cultural evolution.

Envoi

Since *Homo habilis* first banged two rocks together to make a chopping tool, specialized tools have allowed us to overcome the limitations of our bodies. (Hammers let you hit harder; trains let you travel further.) In modern societies, many tools are instrumental in overcoming the limitations of our mental faculties. (Computers let you calculate faster). Most hypotheses in the psychological sciences are generated without the need for any such specialized tools, because the typical objects of inquiry (unidirectional causal relations operating at a single level of analysis) are amenable to informal logical deduction. Things are different when addressing questions about phenomena defined by more complex causal relations that play out dynamically over time and produce emergent consequences that must be measured at a different level of analysis entirely. Specialized tools *are* needed. Computational models provide those tools.

There is a substantial body of computational modeling research identifying the population-level consequences of interpersonal influence outcomes as they accumulate dynamically across time (e.g., Axelrod, 1997; Mason et al., 2007; Nowak et al., 1990; Valente, 1995); but no prior research within this tradition had addressed questions about cultural differences on these influence outcomes. There is another substantial body of empirical research documenting effects of culture on social influence phenomena (e.g., Bond & Smith, 1996; Kim & Markus, 1999; Zou et al., 2009); but that research has focused almost exclusively on short-term individual-level outcomes. Our work represents a conceptual bridge between these two scholarly literatures. In doing so, it makes novel conceptual contributions to the psychological study of social influence and its cumulative consequences, and also to the study of cultural differences. Also, by showing how individuals' actions create specific kinds of ecological circumstances (e.g., social network structures governing patterns of interpersonal interaction), and showing how those ecological circumstances consequently affect individual- and population-level outcomes, this work also contributes to an emerging literature on socioecological psychology (Oishi, 2014). More broadly, it contributes both methodologically and conceptually to multi-disciplinary inquiry into the dynamic processes through which ideas spread, norms change, and cultures evolve.

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Table 1

Structural properties of the social networks that emerged in Phase 1 of the simulations, as a function of the population-wide mean level of extraversion within the population. Tabled values are means computed across 100 simulations for each of the three levels of extraversion (standard deviations around these means are in parentheses).

Population-Wide Level of Extraversion	Characteristic Path Length	Clustering Coefficient	Degree Distribution Skew
Low	3.82 (.04)	.13 (.005)	.56 (.07)
Medium	3.49 (.02)	.15 (.004)	.37 (.07)
High	3.23 (.02)	.16 (.003)	.25 (.08)

Table 2

Results of OLS regression analysis testing the effects that population-wide mean levels of extraversion and conformity had on the number of influence opportunities that elapsed before majority opinion reached a 2/3 super-majority threshold.

	β	*b*	SE	95% CI	*p*
Extraversion	-.10	-14.65	5.08	[-27.72, -1.58]	.002
Conformity	-.24	-35.76	5.08	[-48.83, -2.69]	<.001
Extraversion x Conformity	.01	1.82	6.23	[-14.83, 17.83]	.755
Intercept		151.91	4.15	[141.23, 62.57]	<.001

Note. R^2 = .07, F(3, 896) = 21.95, p < .001.

Table 3

Results of OLS regression analysis testing the effects that mean level of extraversion, mean level of conformity, and elapsed number of influence opportunities had on the size of majority opinion (across the first 500 influence opportunities).

	β	*b*	SE	95% CI	*p*
Extraversion	.03	0.513	0.02	[.471, .554]	<.001
Conformity	.12	1.983	0.02	[1.941, 2.024]	<.001
Influence Opportunities	.44	0.040	<.01	[.039, 0.040]	<.001
Extraversion x Conformity	<.01	0.074	.03	[.023, .126]	<.004
Extraversion x Influence Opportunities	.03	0.003	<.01	[.003, .003]	<.001
Conformity x Influence Opportunities	.02	0.003	<.01	[.002, .003]	<.001
Extraversion x Conformity x Influence Opportunities	.01	.001	<.01	[.001, .001]	<.001
Intercept		66.84	.02	[66.80, 66.87]	<.001

Note. $R^2 = .21$, $F(7, 450892) = 16920$, $p < .001$.

Table 4

Results of binary logistic regression analysis testing the effects that population-wide mean levels of extraversion and conformity had on the likelihood that a new belief—held initially by just one highly extraverted "lone ideologue"— spread to 50% of the entire population.

	Odds Ratio	*b*	SE	95% CI (Odds Ratio)	*p*
Extraversion	.81	-.21	.03	[.77, .86]	<.001
Conformity	1.65	.50	.03	[1.56, 1.74]	<.001
Extraversion x Conformity	1.02	.02	.03	[.95, 1.09]	.574
Intercept	.51	-.67	.02	[.49, .53]	<.001

Note. df = 8996.

Table 5

Results of OLS regression analysis testing the effects that mean level of extraversion, mean level of conformity, and elapsed number of influence opportunities had on the percent of population converted to a new belief held initially by just one highly extraverted "lone ideologue" (across the first 500 influence opportunities).

	β	*b*	SE	95% CI	*p*
Extraversion	-.05	-0.748	.006	[-.760, -.735]	<.001
Conformity	.18	2.662	.006	[2.650, 2.675]	<.001
Influence Opportunities	.24	0.020	<.001	[.020, .020]	<.001
Extraversion x Conformity	-.03	0.235	.008	[-.388, -.297]	<.001
Extraversion x Influence Opportunities	-.01	-0.003	<.001	[-.003, -.003]	<.001
Conformity x Influence Opportunities	.09	0.010	<.001	[.009, .010]	<.001
Extraversion x Conformity x Influence Opportunities	.01	0.001	<.001	[.002, .002]	<.001
Intercept		5.900	.005	[5.89, 5.91]	<.001

Note. R^2 = .11, F(7, 4508493) = 76360, p < .001.

Table 6

Results (odds ratios) of binary logistic regression analyses testing the effects that population-wide mean levels of extraversion and conformity had on the likelihood that a new belief—held initially by an ideologue along with disciples——spread to 50% of the entire population. Each row presents results associated with the subset of 9000 simulations associated with a specific number of disciples (varying from 1 to 12).

	Odds Ratio			
Number of Disciples	Main Effect of Extraversion	Main Effect of Conformity	Extraversion x Conformity Interaction	Intercept
1	.855	1.711	1.077	.801
2	.826	1.500	1.022	1.021
3	.810	1.569	1.072	1.398
4	.883	1.574	.915	1.710
5	.799	1.448	.961	1.866
6	.781	1.407	.958	2.072
7	.868	1.341	1.039	2.117
8	.842	1.393	.972	2.397
9	.779	1.408	1.003	2.681
10	.800	1.314	1.039	2.663
11	.794	1.397	.921	2.993
12	.828	1.363	1.040	3.126

Table 7

Results (raw regression coefficients) of OLS regression analyses on percent of population converted to a new belief— held initially by an ideologue along with disciples——across the first 500 influence opportunities. Each row presents results associated with the subset of 9000 simulations associated with a specific number of disciples (varying from 1 to 12).

	B			
Number of Disciples	Main Effect of Extraversion	Main Effect of Conformity	Extraversion x Conformity Interaction	Intercept
1	-0.748	2.662	-0.235	5.903
2	-0.528	3.240	0.109	7.492
3	-0.728	2.805	-0.123	8.541
4	-0.772	3.042	0.155	9.728
5	-0.437	3.188	-0.296	10.404
6	-0.577	3.013	-0.215	10.992
7	-0.798	2.880	-0.271	11.195
8	-0.601	2.720	0.004	11.274
9	-0.470	2.904	-0.172	11.609
10	-0.717	2.861	0.118	12.294
11	-0.672	2.559	-0.147	12.061
12	-0.634	3.164	-0.408	12.792

Figure 1. Three beta distributions from which values were randomly drawn to simulate individual differences and cultural differences in dispositional tendencies toward extraversion and conformity. The symmetrical distribution (long-dashed line) represents individual differences within cultural populations with a *moderate* mean level of the disposition (equal to the global mean). The right skewed distribution (short-dashed line) represents individual differences within cultures with a relatively *low* mean level of the disposition (approximately 0.5 standard deviations lower than the global mean). The left skewed distribution (solid line) represents individual differences within cultures with a relatively *high* mean level of the disposition (approximately 0.5 standard deviations higher than the global mean).

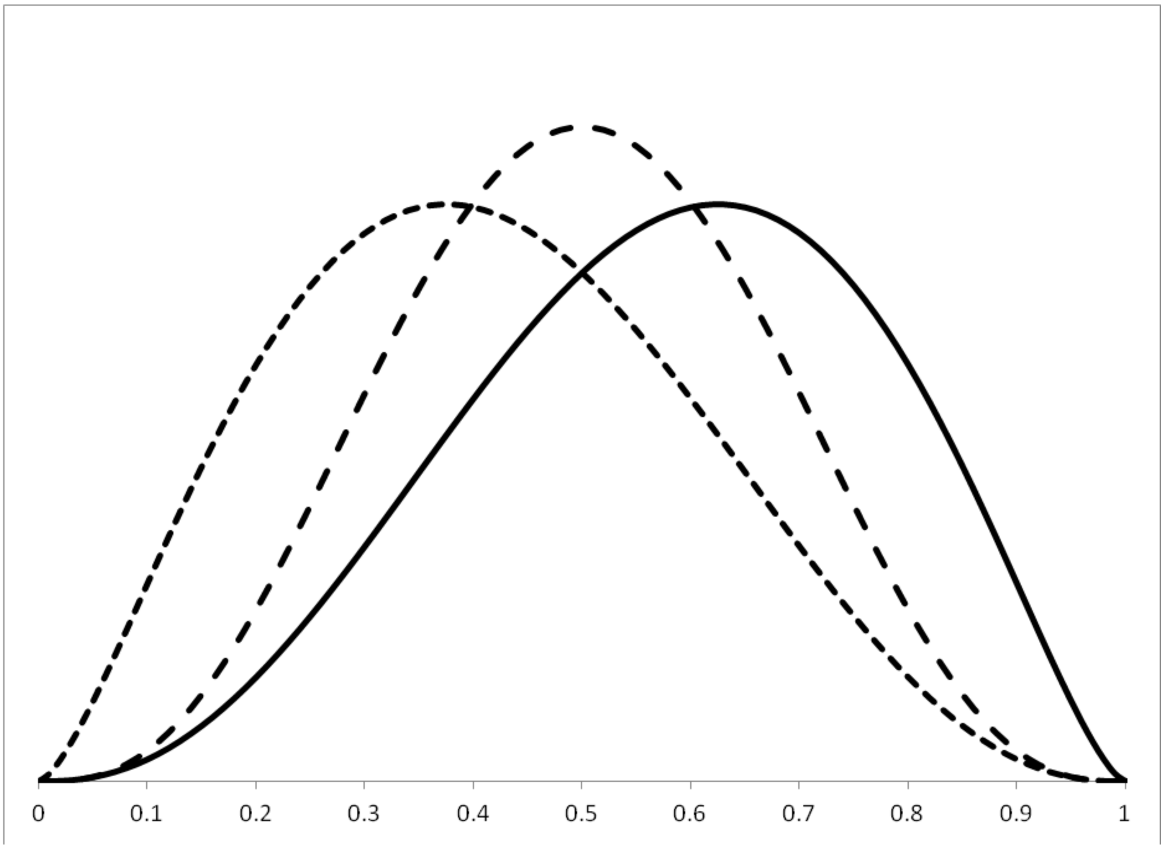


Figure 2. Mean number of opportunities for influence elapsed before majority opinion within a population reached a 2/3 super-majority threshold. (Means computed from 100 simulations for each of the 9 cultural populations. Error bars represent 95% confidence intervals).

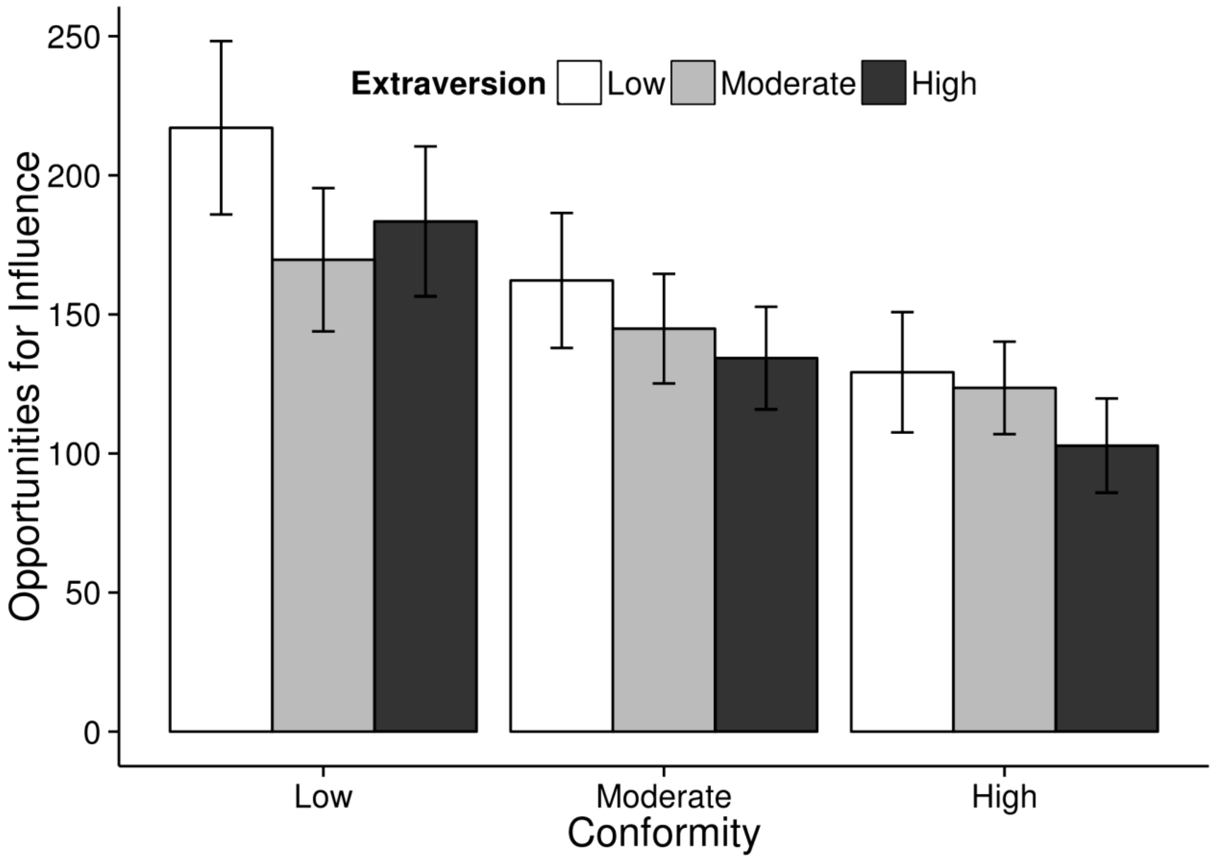
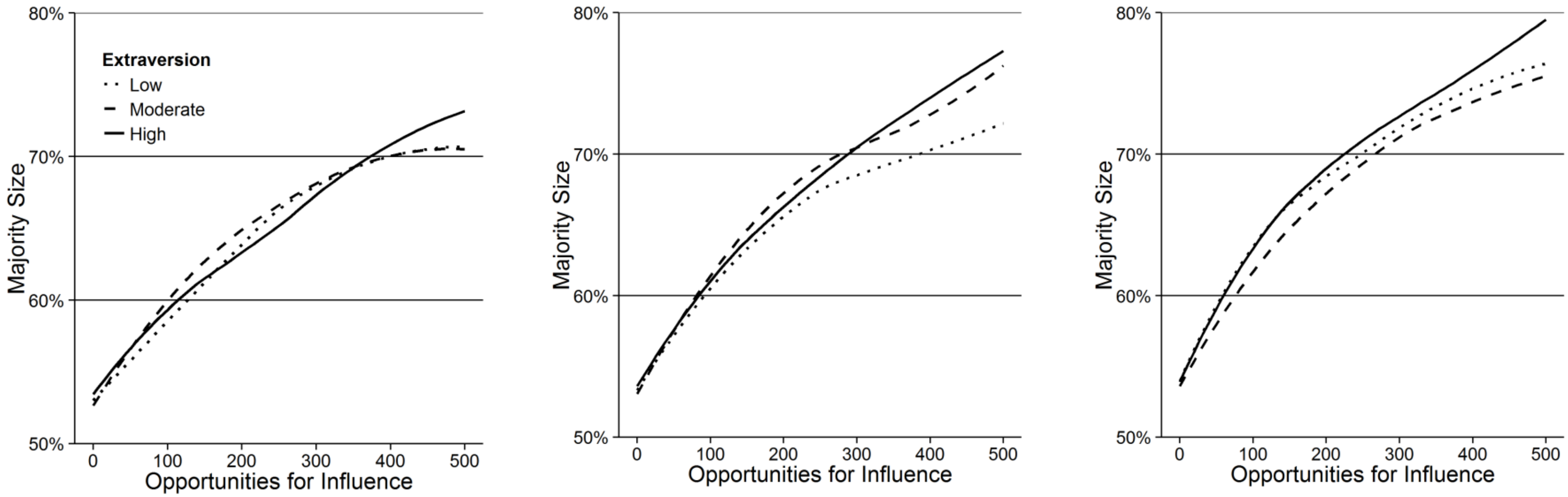


Figure 3. Percent of the population holding the majority opinion across each of the first 500 opportunities for influence. (Plotted values are mean percentage values computed from 100 simulations for each of the 9 cultural populations.)



Low Conformity **Moderate Conformity** **High Conformity**

Figure 4. Percent of simulations in which a new belief—held initially by just one highly extraverted “lone ideologue”—successfully spread to 50% of the entire population. (Percentage values based on 1000 simulations for each the 9 cultural populations.)

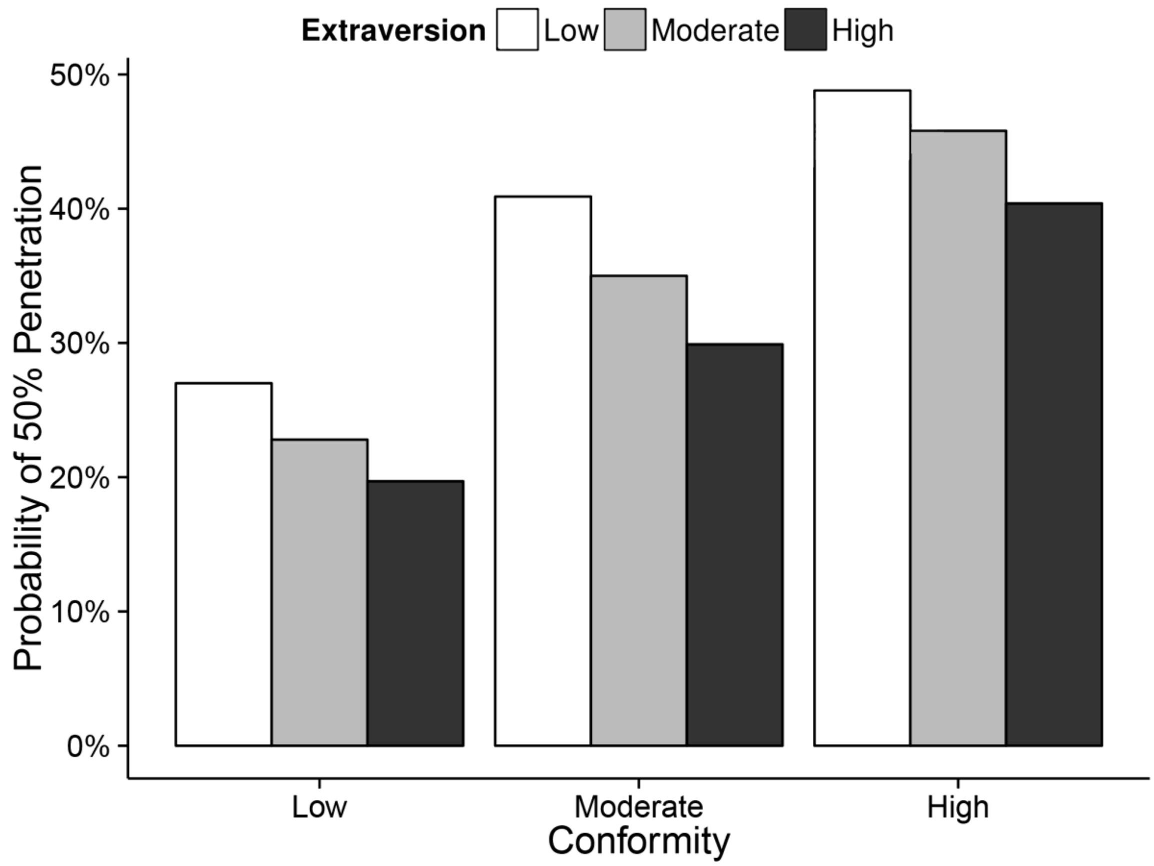


Figure 5. Percent of the population converted to a new belief—held initially by just one highly extraverted “lone ideologue”—across each of the first 500 opportunities for influence. (Plotted values are mean percentage values computed from 1000 simulations for each of the 9 cultural populations.)

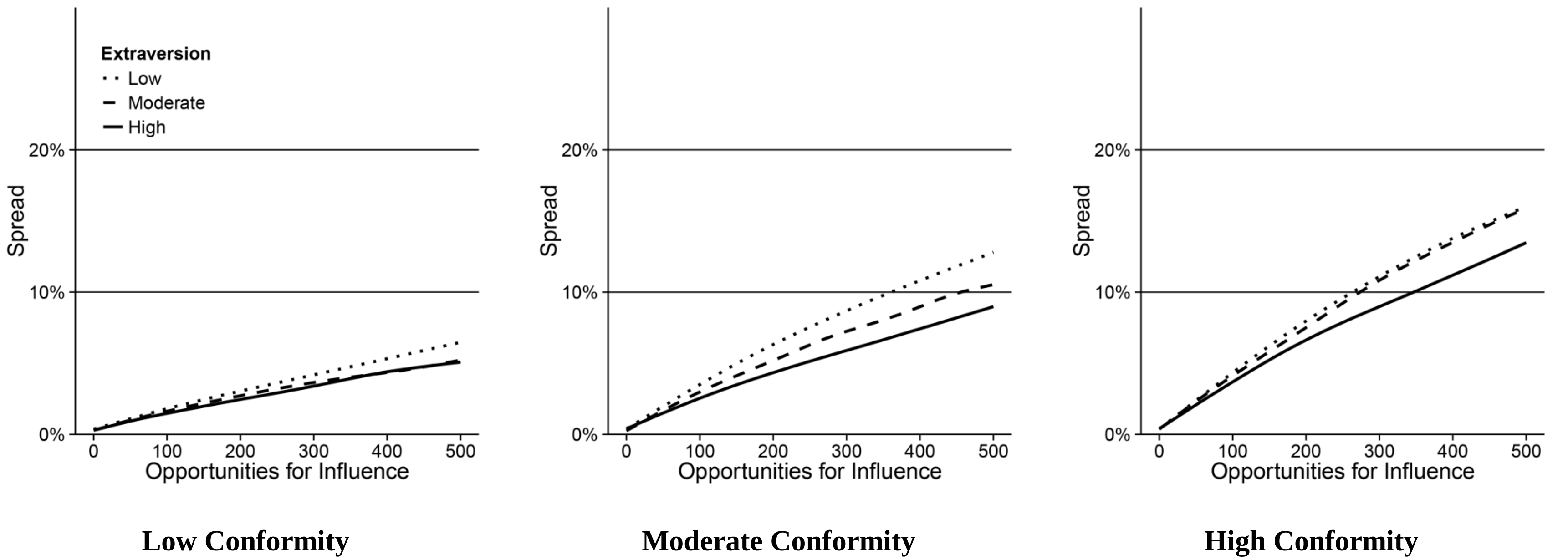
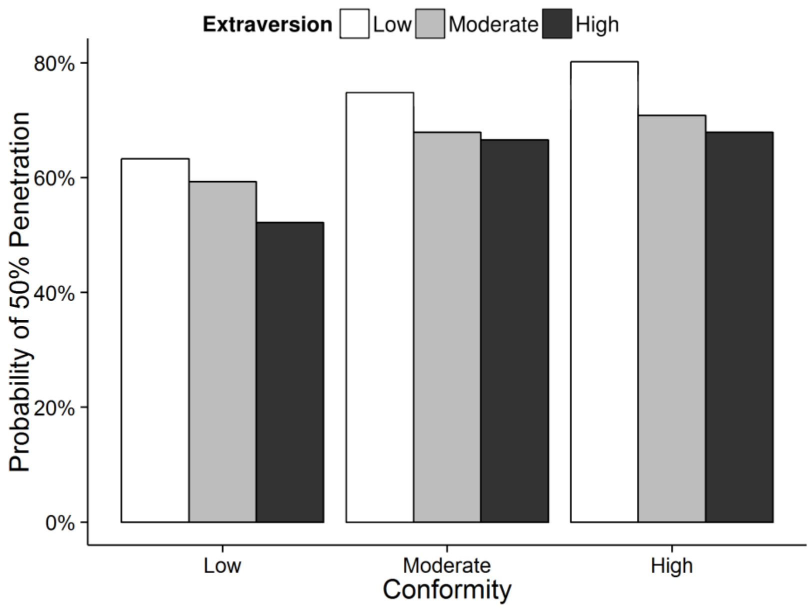
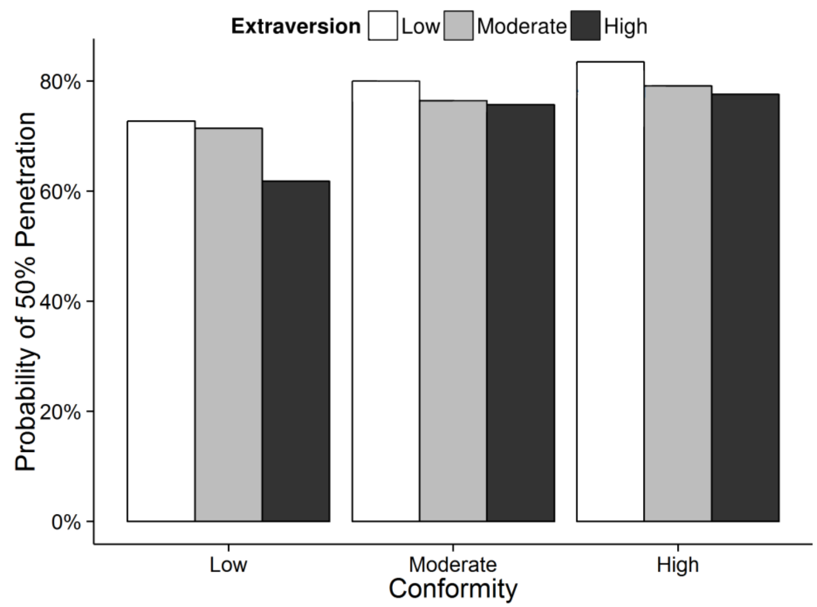


Figure 6. Percent of simulations in which a new belief—held initially by a highly extraverted ideologue along with either 6 disciples or 12 disciples—successfully spread to 50% of the entire population. (Percentage values based on 1000 simulations for each the 9 cultural populations.)

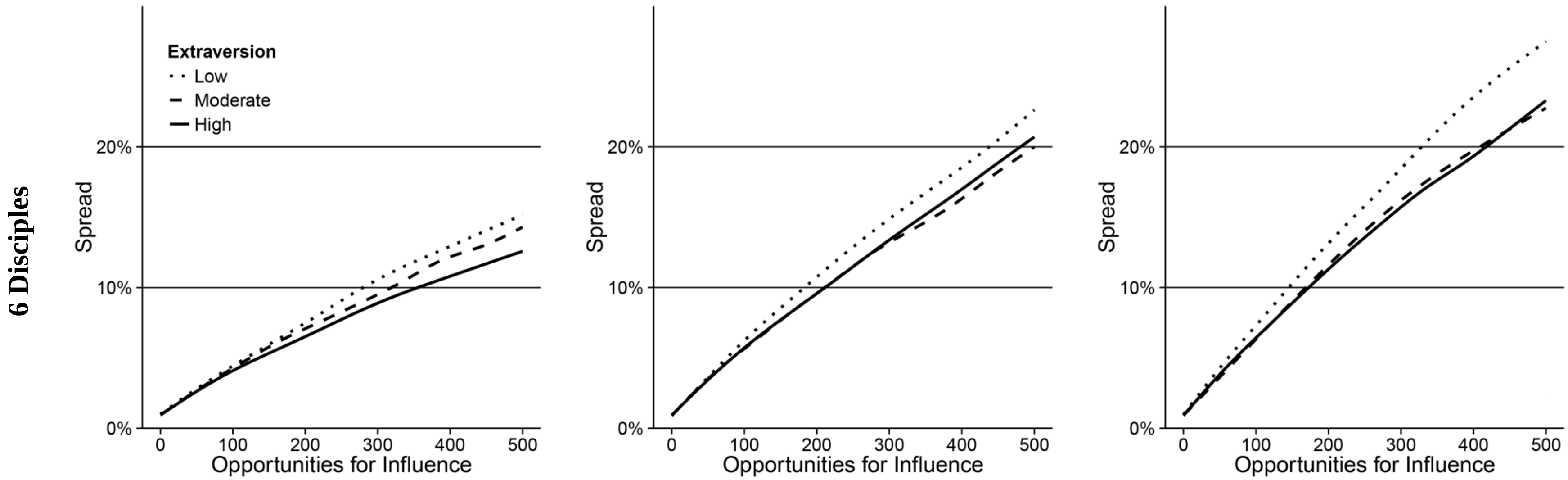


6 disciples

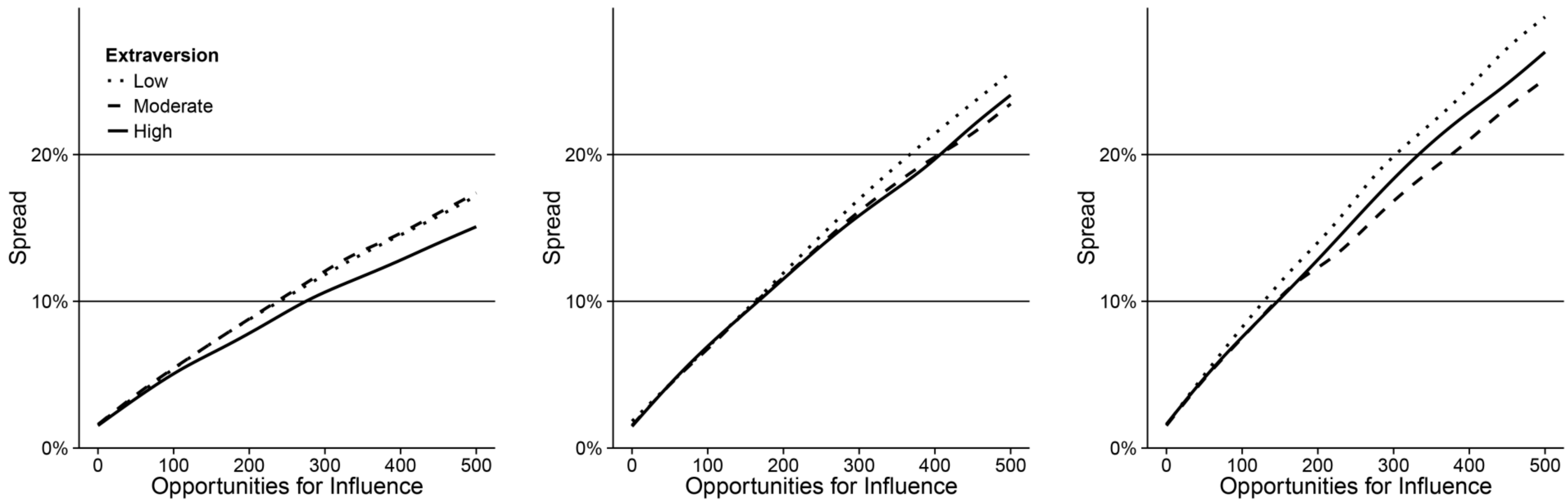


12 disciples

Figure 7. Percent of the population converted to a new belief—held initially by a highly extraverted ideologue along with either 6 disciples or 12 disciples—across each of the first 500 opportunities for influence. (Plotted values are mean percentage values computed from 1000 simulations for each of the 9 cultural populations.)



12 Disciples



Low Conformity **Moderate Conformity** **High Conformity**