**NOTICING HOW OUR SOCIAL NETWORKS ARE INTERCONNECTED**

**CAN INFLUENCE LANGUAGE CHANGE**

Shiri Lev-Ari, Bahara Haidari, Tathra Sayer, Vanessa Au & Fahima Nazihah

Royal Holloway, University of London

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Address correspondence to:

Shiri Lev-Ari

Royal Holloway, University of London

Egham Hill

Egham TW20 0EX

[shiri.lev-ari@rhul.ac.uk](mailto:shiri.lev-ari@rhul.ac.uk)

Abstract

Languages constantly change. This requires variants that are initially rare to become dominant. A prime question is how such changes come about. Here we propose that the inter-connectivity of people’s contacts, and people’s failure to take it into account leads them to over-weigh the informativity of repeated information. In Experiment 1 we find that that people do not sufficiently account for the independence of their sources, and that this neglect is stronger for linguistic terms than it is for opinions. In Experiment 2 we conduct simulations on real world networks and find that failure to account for source dependence promotes the spread of innovations. Together, these results show that language and opinions do not follow the same trajectory of change, and that the spread of innovations, and especially linguistic innovations, is facilitated by biases in the way we process information and community structure.

Introduction

Languages constantly change. A prime question for language researchers is how these changes come about. Such changes often require a form that is initially rare to become wide-spread and dominant which seems to be at odds with our common tendency to adopt the common forms around us. This paper tests the proposal that one reason that rare forms can spread is that people do not fully consider the identity of the speakers they hear and their relation to each other. Communities are dense, that is, many of one’s contacts also interact with each other. This allows the information that originates from one person to reach individuals multiple times, superficially from different sources. Prior research suggests that, at least with regards to opinions, individuals do not fully consider the lack of independence of the different sources, and thus perceive the information to be frequent and adopt it (Weaver, Garcia, Schwarz & Miller, 2007; Yousif, Aboody & Keil, 2019). Here we investigate whether the same tendency applies to linguistic variants. We further test the implications of this tendency for language change using computational simulations on real world networks. To preview our results, we find that individuals often neglect to account for the dependence of sources, and even more so when processing linguistic terms. We further find that this failure can promote language change.

*Change and its relation to community structure*

Languages change. In fact, change is such an inherent property of language that one can be certain that as long as the language is regularly used for every day interaction, it will change with time. New words will be invented or borrowed, and old words will change in meaning or disappear. Pronunciation also often changes with time, and during longer stretches of time, so might the morphology and grammar. Often, such changes do not fill a gap in the language, but instead come to replace previous forms. For example, the word *you* in its singular meaning came to replace the older *thou* (OED online), and the current Subject-Verb-Object word order in English replaced the Subject-Object-Verb order that existed in Old English (Pintzuk, 2014).

The mechanisms of linguistic changes are varied. Some changes are driven by language contact (e.g., Thomason & Kaufman, 1992), others are driven by errors of learning or misperception (e.g., Belvins, 2004), while others are due to functional benefits of the new forms (e.g., Cohen Priva, 2017; Wedel, Kaplan & Jackson, 2013) or other motivated or random changes. Importantly, while some changes might occur in parallel across many individuals, such as shortening of frequent words, many of the changes are introduced by a minority and would only lead to language change if they successfully propagate through the community[[1]](#footnote-2). The fact that such propagation occasionally succeeds poses a puzzle, as, initially, the new variants are rare, and a common assumption is that individuals adopt the common variants around them. This obstacle for propagation due to the tendency to not copy rare variants is called the threshold problem (Nettle, 1999). This paper focuses on conditions that can overcome the threshold problem and facilitate such propagation.

One factor that is argued to moderate the rate and success of language change is community structure. Such studies compare propagation in different types of networks. For example, Ke, Gong, and Wang (2008) found that scale-free structure, the structure most common in the world (Barabási & Albert, 1999; Barabasi, 2009), is among the structures in which innovations are less likely to spread. In contrast, work on contagion has shown that scale-free networks, unlike other network structures, allows a (computer) virus to spread without having to pass a certain threshold (Pastor-Satorras & Vespignani, 2001). It seems then that network structure can influence the likelihood of spread, though the direction is debated. Many of the tested networks in these studies have a structure that does not characterize human social networks[[2]](#footnote-3) (e.g., random, ring), leading their findings to potentially seem less applicable to language change. At the same time, one of the features that differentiate the different networks is community density, the degree to which individuals’ contacts are connected to each other, and this feature also varies within real world networks, even if to a lesser degree. A less explored but likely option then is that differences in community density within the same real world network structure can have an effect on the rate and likelihood of language change.

In addition to suggestive evidence described above that networks that vary in density also vary in rate of language change, network density can influence language change because it influences the degree to which sources are independent of each other. If the friends of an individual do not know each other, then the information that they provide is likely to have been obtained independently. If they do interact regularly, then the information that they provide might have been derived from the same source. Indeed, information tends to spread via weak ties, that is, less frequent and more superficial ties (e.g., Granovetter, 1973; Milroy & Milroy, 1992; Weimann, 1983), and this is argued to be due to the fact that strong ties, that is, close and meaningful contacts, all have access to the same information (Granovetter, 1973). This lack of independence also applies to the linguistic domain. Individuals adapt to each other’s speech patterns. When two people interact, they adjust their speech in the direction of their partners. Thus, they become more similar in the way they pronounce words, in the syntactic choices they make, in the words they choose, in their nonverbal behavior and so forth (e.g., Bock, 1986; Chartrand & Bargh, 1999; Giles, Coupland & Coupland, 1991; Pardo, 2006). This accommodation during interaction has been argued to lead to long term convergence (e.g., Pardo, Gibbons, Suppes & Krauss, 2012; Trudgill, 1972). Consequently, groups of people who interact with each other also tend to speak alike, so an individual might hear a new slang term from many of their friends, but these friends might have learned it from the same mutual friend.

*Susceptibility to repetition of information*

The fact that density reduces the independence of sources raises the question of whether individuals take that into account when they process information. Several theoretical and computational models in Economics suggest that they do not, and this failure to account for source dependence has been termed *Correlation Neglect* (Enke & Zimmermann, 2017; Ortoleva & Snowberg, 2015), or the *Persuasion Bias* (e.g., DeMarzo, Vayanos and Zwiebel, 2003) and individuals who fail to consider it have been referred to as *naïve learners, naïve herders* (Eyster & Rabin, 2010; Golub & Jackson, 2010) or *credulous Bayesians* (Glaeser & Sunstein, 2009). Experimental studies seem to support these models. For instance, Yousif et al. (2019) presented people with five articles about the Japanese economy. Four of them expressed the view that the Japanese economy would continue to grow, and one expressed the view that it would not continue to grow. Crucially, whereas in the true consensus condition each of the five articles relied on a different source, in the false consensus condition all four articles expressing a positive opinion relied on the same source. In the no consensus condition participants only read two articles, one expressing each view. When participants were asked to rate their view on the Japanese economy, participants in the false consensus condition showed equal optimism about the Japanese economy to those in the true consensus condition and significantly more than those in the no consensus condition, even though the four positive articles all relied on the same one primary source that was provided in the no consensus condition.

Such failure to account for source dependence at the individual level can be amplified at the community level where all individuals who are exposed to the same information are similarly influenced by it but perceive each other’s estimates as further independent support for the estimate. The individual failures to consider source dependence can thus cascade at the group level to the emergence of group polarization (Glaeser & Sunstein, 2009) or economic bubbles and crashes (Enke and Zimmermann, 2017).

The susceptibility to the influence of information provided by related sources might seem unsurprising considering people’s susceptibility to the influence of repeated information even from the same source. Dozens of studies in Psychology have demonstrated that repeating statements increases people’s perception of them as true (e.g., Begg, Anas & Farinacci, 1992; Brown & Nix, 1996; Dechene, Stahl, Hansen & Wanke, 2010; Fazio, Brashier, Payne & Marsh, 2015; Hasher, Goldstein & Toppino, 1977; Hawkins & Hoch, 1992). These findings are most often interpreted as due to fluency or familiarity. Direct tests of these mechanisms provide support for both claims. Manipulations of processing fluency by means other than repetition similarly affect truth judgments. For example, statements are rated as more likely to be true if they are written in a font that is easier to read (Parks & Toth, 2006), in a font color that has better color contrast with the background (Reber & Schwarz, 1999) or if they are uttered by native compared with foreign-accented speakers (Lev-Ari & Keysar, 2010). Manipulations of conceptual fluency, such as by providing a relevant vs irrelevant context also increase statements’ credibility (Parks & Toth, 2006). Many therefore assume that repetition influences truth judgment because repetition increases processing fluency (Jacoby & Dallas, 1981).

At the same time, others have argued that repetition increases familiarity, and familiarity increases belief not because it increases ease of processing but because the familiarity is interpreted as evidence that the information has been provided by multiple different people, and is therefore endorsed by multiple others. In line with this account, when participants are directly asked whether they have seen the experimental statements earlier, and if so where (in the lab vs outside of it), it is found that repeated statements are often judged to be familiar from before the experiment, and that such memory errors are associated with larger repetition effects (Arkes, Boehm & Xu, 1991; Law, Hawkins & Craik, 1998).

At the same time, there are two studies that found that participants do take into account the independence of sources. In particular, participants were more convinced by arguments in support of introducing senior comprehensive exams when each of the three arguments was provided by a different student than when all were provided by the same student, but this advantage of multiple sources disappeared when the three students were presented as members of one committee that was formed to discuss this issue (Harkins & Petty, 1987). Similarly, participants were more convinced by the three committee members if they had been told that committee members were elected to be dissimilar in their perspective rather than similar in their perspectives (Harkins & Petty, 1987). Such sensitivity to source dependence was also found in Whalen, Griffiths and Bauchsbaum (2018). They asked participants to estimate which urn others have drawn balls from based on their report. Each source stated clearly what their information is based on and whether they had access to others’ estimate or information. Participants showed sensitivity to source dependence by treating differently statements based on independent vs shared information.

*Current study*

As the review so far demonstrates, substantial evidence suggests that people believe information more, the more it is repeated. Additionally, while individuals seem to consider the independence of sources to some degree when it is highlighted (Harkins & Petty, 1987; Whalen et al, 2018), there is evidence that individuals sometimes neglect to account for that (Yousif et al., 2019). All the studies reviewed thus far, examined sensitivity to source dependence when processing opinions. To the best of our knowledge, no one has examined sensitivity to source dependence with linguistic stimuli, and the degree to which it resembles the pattern with opinions. Experiment 1 tests for the existence of failure to take sources’ dependence into account when processing linguistic terms and compares to the tendency to so with regards to opinions.

The design is similar to the one used in Yousif et al. (2019) with the addition of a contrast between language and opinions. While it is not typical of studies examining language change or language use, its similarity to prior paradigms examining attention to source dependence when processing opinions enables a direct comparison of performance with linguistic terms vs opinion while replicating prior studies. The experiment simulates a common real world case in which multiple news outlets report on the same event, but all rely on the same source. The experiment tests how likely participants are to adopt the linguistic term or opinion that is provided by the cited source in this case compared to a case when they read the cited source only once, and a case in which each of the media outlets cites a different source. Comparison of the rate of adoption of the information or the term when it is repeated by different outlets citing the same source to the rate of adoption in the other two cases would indicate the degree to which participants account for source dependence. If they fully fail to account for it, then adoption of the information or the term would be equal when all media outlets cite the same source and when each of the media outlets cites a different source. In contrast, if participants fully account for the source dependence, then their behavior should be similar to the case in which they read the cited source in only one media outlet.

In this experiment, each of the news outlets explicitly states the source of the information by providing the name of the source and directly quoting them. Therefore, this design highlights sources’ dependence and allows participants to detect and account for the lack of independence. This manner of presentation is even clearer than would often be in the real world. For example, when different friends repeat information that they heard from the same mutual contact, they are unlikely to repeat the information verbatim and might not always state from whom they learned the information. This test is thus conservative and failure to account for sources’ dependence in this design would provide strong evidence for the relevance of the failure in real life.

Following the report of Experiment 1, this paper will examine the implications of the results for language change using simulations with real world networks.

Experiment 1

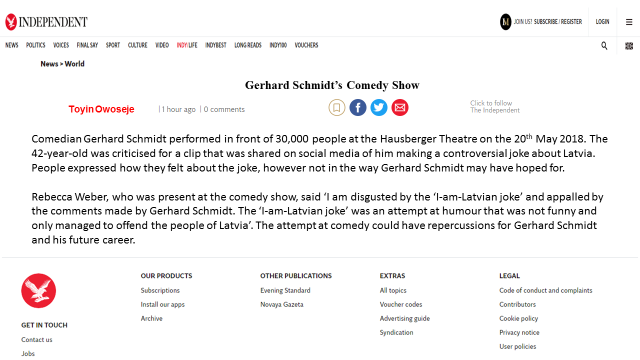
Experiment 1 tested whether individuals take into account the lack of independence of sources when processing linguistic terms, and whether the tendency to do so resembles or differs from the tendency to do so for opinions. To test that, we invented two events, a merger of a company, and an incident in which a comedian told a controversial joke. We wrote multiple short articles about those events. Articles differed in the term that they used to refer to the events (e.g., The ‘I-am-Latvian joke’ or the ‘Latvia joke’). Importantly, these terms only appeared within the quotation of the source (see Figures 1a and 1b for an example of articles citing the two terms).

In the target Repeated Source condition, each participant read 9 articles about each event. Each of the articles was from a different news outlet. Six of them used one term, and the other 3 used the alternative term. Crucially, the 6 articles that included a quotation with the same term all cited the same source using the same quote (see Fig 1a and 1c for an example). The remaining 3 articles, which used the alternative term, each relied on a quote from a different person. Thus, while there were six articles which included one term compared with only three articles that included the other, the latter term was used by more speakers than the former (3 vs 1). To test how participants treated the non-independent information, participants were asked to state which term is most commonly used to refer to the event.

If participants fail to account for the fact that the 6 articles all cite the same person, then participants should respond with the term that the repeatedly-quoted individual used, even though there were more individuals (3 vs 1) who used the alternative term. If participants completely fail to account for the repetition of source, then participants should be as convinced by the six repetitions as they would be by six independent sources. Therefore, to test whether participants account for the lack of independence of the six articles at all, performance in the target Repeated Source condition was compared to performance in the Multiple Sources condition. In that condition, the six news articles that quoted the same source in the Repeated Source condition were modified such that each of them cited a different source, rendering them independent. For example, while the Repeated Source condition included the articles in Figures 1a and 1c, which both cite Rebecca Weber, the article in Figure 1d replaced the article in Figure 1a in the Multiple Sources condition. Note that the articles 1a and 1d are identical except for the quote and the source of the quote. Difference between performance in the Repeated Source and Multiple Sources conditions would indicate that participants attend to the source and do not consider repeated information to be as informative and convincing as new information from a different source.

1a 

1b 

1c 

1d 

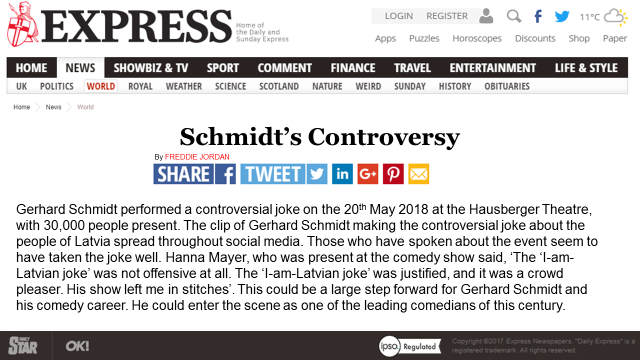
1e 

Figure 1. Examples of the articles participants read. Figures 1a and 1b provide examples of the two competing terms that were used to refer to the joke in the Language condition. Figure 1c shows how we created multiple articles relying on the same source for the Repeated Source condition – the article provides the same quotation by Rebecca Weber. Participants saw six such articles from six different news outlets all relying on the same quote from Rebecca Weber. In contrast, in the Multiple Sources condition, the articles were modified. Figure 1d provides an example of how article 1a was modified. The two are identical in their news outlet and the story frame but the quoted source is different (there is a quote of Arnold Schaffer instead of Rebecca Weber). Participants in this condition saw the same six news outlets and story frames as in the Repeated Source condition, but the quotes and sources were changed such that they were unique in each article. Figure 1e shows how articles were modified for the Opinion version. Unlike article 1b in the Language version which differed from the six articles in the term it used, in the Opinion version the article presented the same term but provided a different opinion (the joke was not offensive).

The comparison of the Repeated Source and Multiple Sources condition tests whether participants attend to source repetition at all. It could be, however, that participants attend to it and account for it, but only partially. That is, participants might be less influenced by six repetition of a single source compared with six different sources, but still perceive the term used by the repeated source to be more common than to they would have had they read the quote only once. Therefore, the experiment also included a Non-repeated Source condition. In this condition participants read only one of the six non-independent articles in the target Repeated Source condition, as well as the 3 articles that provided the alternative term. Any difference between performance on the Non-repeated Source condition and the Repeated Source condition would indicate that repetition increases persuasion.

To test whether attention to source dependence depends on the type of information (opinions vs language), an Opinions version of these three conditions: Repeated Source, Multiple Sources, and Non-repeated Source, was created. In this version the articles differed not in the terms that they used to refer to the events but in the position that they supported. That is, while in the Language version articles expressed the same opinion – the merger was successful and the joke was offensive – but used different terms to do so, in the Opinions version, all articles used the same terms (The ‘I-am-Latvian’ joke and MegaMerger) but differed in whether they described people as being offended by the joke, and for the merger event, in whether it was described as a success or a failure (e.g., Figure 1e replaced Figure 1b in the Opinion condition). See Table 1 and Method for a full break-down of the design. Each participant read about one event (merger or joke) in the Language version and the other event in the Opinions version.

Method

*Participants*. One-hundred-and-thirty-eight participants were recruited in two batches (age range: 18-70, M=25.4), resulting in 276 responses. The planned sample size was 100 participants (200 responses), but because some participants provided uncodable responses or failed attention checks, a second batch of participants was recruited to replace excluded responses. In total, 36 responses were excluded because at least 2 out of 3 attention check questions (see Stimuli) were responded to erroneously. Thirty-two additional responses were excluded because they were uncodable. For example, many answered the question regarding how the joke was referred to by saying ‘controversial’ or ‘offensive’ rather than responding with one of the intended names, the ‘I-am-Latvian joe’ or the ‘Latvia joke’. All analyses were therefore conducted on the remaining 208 responses. The initial batch of participants was recruited via social media websites, and participants were entered a raffle for an Amazon voucher. Participants in the second batch were recruited using Prolific website and were paid £1.50 for their participation.

*Stimuli*. Two events were invented, a merger of two cosmetic companies and an incident in which a comedian told a controversial joke about Latvia. For each event, multiple articles were created. All articles centered around a quote from an employee of the merged company or someone who attended the comedy show. The articles clearly stated the name and relevance of the source as well as provided a quote from them. These quotes were inserted inside a frame which consisted of a few introductory and concluding sentences. Articles were edited to look as if they originated from common UK news websites (see Figure 1a-1e). The articles were organized into 6 conditions representing all possible Content (Language, Opinion) x Sources (Multiple Sources, Repeated Source, Non-repeated Source) combinations. For all participants, each of the articles they read was from a different news outlet. Table 1 illustrates the design of the experiment and Supplementary Materials A provide all the articles in the joke event.

|  |  |  |
| --- | --- | --- |
| **Condition** | **Term used:**  **The ‘I-am-Latvian joke’ /**  **MegaMerger** | **Term used:**  **The ‘Latvia joke’ / Fantastic Fusion** |
| **Multiple Sources** | frame 1 + quote 1  frame 2 + quote 2  frame 3 + quote 3  frame 4 + quote 4  frame 5 + quote 5  frame 6 + quote 6 | frame 7 + quote 7  frame 8 + quote 8  frame 9 + quote 9 |
| **Repeated Source** | frame 1 + quote 1  frame 2 + quote 1  frame 3 + quote 1  frame 4 + quote 1  frame 5 + quote 1  frame 6 + quote 1 |
| **Non-repeated Source** | frame 1 + quote 1 |

Table 1. The experimental design focusing on the Language condition. The three source conditions were identical in the stimuli they used to present the alternative terms (e.g., the ‘Latvia joke’). They differed in the articles that presented the other terms. All articles were structured as a frame (introduction and ending) surrounding a quote with information about the quoted person. Frame number and quote number indicate whether they differed across articles and conditions. For example, the same six frames were used in the Multiple Sources and Repeated Source condition but the Multiple Sources condition used six different quotes whereas the Repeated Source condition included one quote. The Opinion conditions were similarly designed except that all articles used the same term but differed in the opinion that they supported.

The experimental questions were open-ended and tested which of the competing terms or opinions participants believed was most common. In the Language condition, the experimental question was “How is the joke most commonly referred to?” or “How is Nomo’s creation most often referred to?” (Nomo is the name of the merged company). Responses were coded as 1 if participants wrote ‘I-am-Latvian joke’ or ‘MegaMerger’, the names referred to by the 6 independent sources, the repeated source, and the single non-repeated source. Responses were coded as 0 if participants responded with ‘Latvia joke’ or ‘Fantastic Fusion’. In the Opinions condition the question was “Estimate the percentage of audience that consider the joke offensive” or “Estimate the percentage of employees that consider the merger a success”. Participants were provided with a slider scale. Responses were converted to a binary scale to render them comparable to the responses in the Language condition. Responses of 51% and higher were coded as 1, and responses of 0-50% were coded as 0.

To ensure that participants read the articles, participants answered 3 open-ended attention check questions about each event. The attention check questions referred to information that appeared in all articles about the event. For example, participants were asked to provide the name of the comedian in the joke event and the names of the merging companies in the merger event. Responses were marked leniently, that is, spelling errors and vague but correct responses (e.g., Schmidt instead of Gerhard Schmidt) were accepted. Data from participants who responded correctly to fewer than 2 out of 3 attention check questions were excluded.

*Procedure*. Participants were presented with articles, one at a time, and asked to read them. They were told that they will be asked questions about the articles later. Participants were randomly allocated into one of the six conditions per event (Language Multiple Sources, Opinion Multiple Sources, Language Repeated Source etc.) with the condition that if participants were allocated into a Language condition for one event, they were allocated to the Opinion condition for the other event and vice versa. The ordering of the joke vs merger events was randomized per participant. The order in which the event articles were presented was randomized per participant as well. The task was self-paced with the restriction that participants could not advance to the next article until at least 20 seconds have passed to prevent skipping articles without reading them. After participants read all articles about the event, they were presented with the attention check questions, and the experimental question. The entire experiment took about 10 minutes.

Results

To test whether participants accounted for the lack of independence of the different sources, a logistic regression was conducted with Content (Language, Opinion; Reference level: Language) and Repetition (Multiple Sources, Repeated Source, and Non-repeated Source; reference level: Repeated Source) and their interaction as predictors. Results revealed a difference between the Repeated Source and the Non-repeated Source in the Language condition (β=-2.44, SE=0.67, z=-3.67, p<0.001). As Figure 2 shows, participants were more likely to perceive the term as more common when it was repeated than when it was only mentioned once (70% vs 17%), and in fact perceived it to be more frequent than its alternative even though it was a single person who used the term compared with three sources who used the competing term. While the interaction between Content and Repetition did not reach conventional level of significance for the contrast between the Repeated and Non-repeated Source conditions (β=1.4, SE=0.82, z=1.7, p=0.089), the pattern suggests that the difference between Repeated and Non-repeated Source conditions was smaller in the Opinion condition, though it was still significant (β=-1.04, SE=0.48, z=-2.15, p<0.05; 49% vs 25%, respectively). Results did not reveal any difference between the Repeated Source and Multiple Sources conditions in the Language condition (70% vs 68%, respectively; z<|1|) indicating that not only did the repetition increase perception of prevalence, but it increased it to the same degree as receiving input from a difference source each time, suggesting that each encounter with the term was weighted equally regardless of whether the source was new or repeated. Results, however, also revealed an interaction between Content and the contrast between Multiple Sources and Repeated Source condition (β=1.5, SE=0.75, z=2, p=0.045). This interaction reflects the fact that in the Opinion condition, unlike the Language condition, participants gave more weight to 6 different sources than one repeated source (80% vs 49%; β=1.42, SE=0.5, z=2.81, p<0.01)[[3]](#footnote-4).

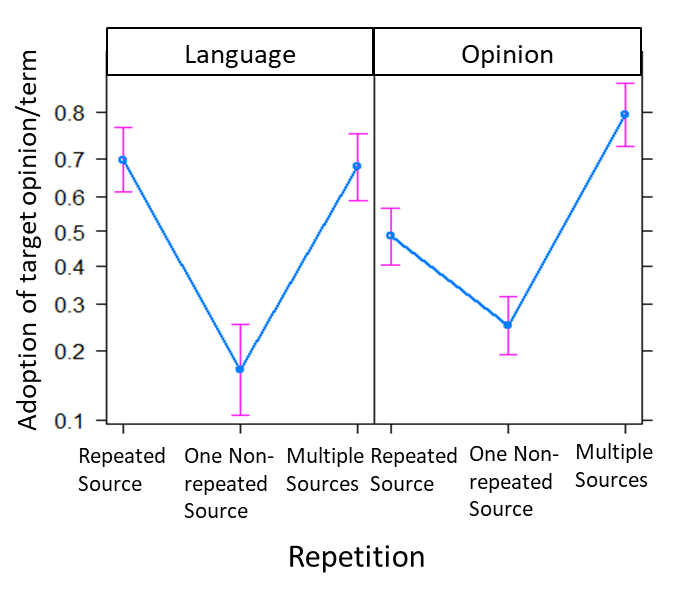


Figure 2. Likelihood of adopting the target opinion or term (the one supported by 6 independent sources, one repeated source, or one non-repeated source) as a function of Content and Repetition. Error bars show standard error.

Together, these results reveal not only that people do not fully account for source dependence when processing linguistic terms, but that this failure to account for source dependence is even larger than for processing opinions. Participants in this experiment did not exhibit any consideration for source repetition in the Language condition such that a term used by a single person who was quoted six times was perceived to be as common as a term used by six different individuals. Interestingly, when processing opinions, participants were more attentive to the source of the information, and therefore weighed information that is repeatedly delivered from the same source less than information provided by multiple sources. Considering that many models of language change, especially computational ones, treat language as information, these results are important and suggest that the content of the information that is processed could influence which details are encoded and how. Nonetheless, differences between the conditions were only in degree. Even when processing opinions, repetition boosts persuasion, as participants were more convinced by the information when it is delivered multiple times versus once.

These results have implications for language change. By showing that individuals do not fully account for the lack of independence of sources of linguistic terms, this study suggests a way by which rare linguistic variants can become dominant. While our paradigm might seem different from typical linguistic interaction, its rudimentary form is also its strength. In particular, the failure to fully account for source dependence in this study occurs even though participants were explicitly told that the information is provided by the same person, and the person’s words were repeated verbatim. In real life, individuals might not always know or keep in mind how their friends or associates are connected to each other. Furthermore, even when such awareness exists, speakers are unlikely to indicate where they have learned a term, or whose speech influenced them, and they do not repeat it verbatim, making it more difficult for individuals to discount the redundancy in the information they receive. Therefore, our results likely under-estimate the degree to which people fail to account for the lack of independence in their input.

One may wonder though whether our benchmarks are appropriate benchmarks. We argue that if individuals fully account for the lack of independence, they should perform similarly when receiving information from one source once vs 6 times. At the same time, one may argue that the fact that several different journalist conveyed the information from the same source might indicate that the source is of high importance, and should therefore be given higher weight than any other source which was cited only once. In other words, perhaps a difference in performance between the Non-repeated Source and the Repeated Source does not indicate failure to account for source dependence but an inference that the repeated speaker should be weighed more heavily. At the same time, the lack of any difference between the Repeated Source condition and the Multiple Sources conditions in Language condition show unambiguously that when it comes to linguistic terms, individuals do not account for the lack of independence of sources at all. These results thus suggest that one manner by which linguistic variants can spread is through this disproportional influence of repeated sources. Experiment 2 presents computational simulations that investigate the implications of these findings for language change.

Experiments 2a & 2b

Experiments 2a & 2b examine the implications of the findings in Experiment 1 for the spread of trends. Experiment 1 showed that people disregard source dependence, especially with regards to linguistic terms. Experiments 2a & 2b test how disregard for source dependence can influence the propagation of information, whether linguistic or not, in two real-life networks: a real-life network of highschool kids in Illinois (Coleman, 1964), and a network of a university Karate Club (Zachary, 1974), a network that is frequently used for network analysis purposes. These networks were selected as they represent complete sub-communities which are relatively dense. The simulations examined the likelihood that a new variant introduced by one, two, or three individuals (henceforth, innovators) could spread and become dominant across the entire community of 70 students or 34 Karate club members, and, in particular, how this likelihood depends on whether individuals account for the dependence of their sources.

Experiment 2a

*Method*

The simulations were agent-based models in which agents were connected to each other following the structure reported for the network of a highschool in Illinois was retrieved from Konect database (Kunegis, 2013), and is based on a study conducted in the late 1950s in Illinois (Coleman, 1964). In that study, 70 students were asked at two time points to name the friends they interact with most. The network dataset that we used collapsed over both time points, such that agents were connected if they were named at either or both time points. The network information was directed, as students sometimes named friends who did not name them. The direction information was implemented as weight, such that pairs of agents who both named each other were twice as likely to interact with each other than pairs of agents in which only one pair member named the other one. At the beginning of the simulation, all individuals other than the innovators used one variant. We manipulated the number of innovators, that is, individuals using a different variant, such that there was either one innovator, two innovators, or three innovators out of a total of 70 agents. We ran a total of 1800 simulations, 100 simulations for each combination of number of innovators (1, 2, 3) and weighting (0, 0.1, 0.2, 0.3, 0.4, 0.5; see below). All simulations ran for 1000 rounds.

In all conditions, in each round, each agent interacted with one of their contacts. During the interaction, each of the interacting agents produced a variant, and then updated their probability of using the variant in the future according to the variant that they heard their interlocutor produce. Probability of using a variant ranged from 0 to 1 and the probabilities of using the two variants always added up to 1. The main manipulation was how agents weighted the received variant when updating their representations. In the baseline condition, agents ignored the dependence of their sources (weight = 0). In this case, if agents interacted with someone with whom they have not interacted beforehand, they updated their probability of using the variant that the interlocutor has just produced, p(a), according to equation (1):

1. pt(a)=min(1,pt-1(a)+)

where *p(a)* represents the probability of producing the variant that the interlocutor has just produced, and *s* is the number of contacts that the agent has. That is, agents would increase their prior probability of producing the variant that their interlocutor has just produced by the inverse of their social network size (with the restriction of not surpassing 1, as probabilities cannot be higher than 1). For example, if an agent with 3 contacts has a probability of 0 of using the rare variant, and it then interacts with someone who uses the rare variant, the agent would update its probability of using the rare variant to 0.33 (and that of using the common variant to 0.67). The updating function was set to depend on the agent’s network size in line with previous findings that show an inverse relationship between the weight given to input and the size of one’s social network (Lev-Ari, 2017, 2018; Monster & Lev-Ari, 2018)[[4]](#footnote-5). If the agent had already interacted with the interlocutor beforehand and had received the same variant from them, the new input would be given only one tenth of its weight otherwise, namely:

(2) pt(a)=min(1,pt-1(a)+)

The updated probabilities predicted agents’ productions in their next interaction. That is, an agent with a probability of 0.33 has a 0.33 probability of producing the common variant, and 0.67 probability of producing the rare variant.

In the five other Weighting conditions, whenever agents received information from someone new, they took into account whether they had mutual contacts with that interlocutor, and whether the input received from the new interlocutor is the same as the input received from their mutual contact. Having a mutual contact that produced the same variant led to decreasing the weight given to that token by the parameter set for that Weighting condition (0.1-0.5) for every mutual contact, as is shown in equation (3):

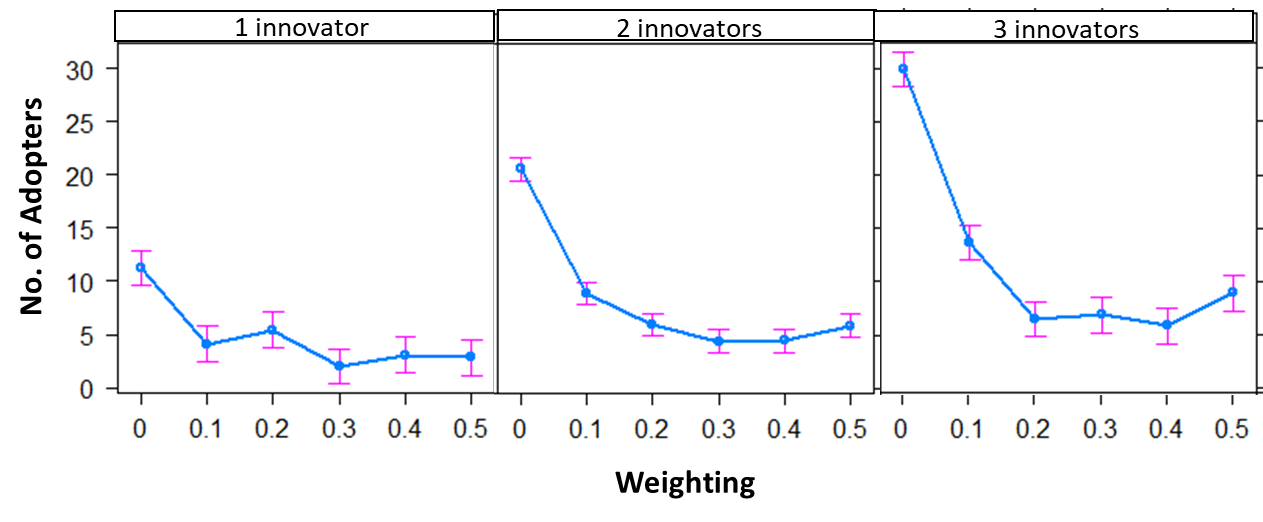
(3) pt(a)=min(1,pt-1(a)+)

where *m* represents the number of mutual contacts who produced the same variant and *weight* equals 0.1, 0.2, 0.3, 0.4, or 0.5, depending on condition. If the product of the number of mutual contacts who had produced the same variant times the condition’s weight was >1 (e.g., more than 3 mutual contacts in a condition with a weight of 0.3), the weight ascribed to the new input was set to be the same as a repetition of an old contact.

If the interlocutor produced a variant that was different from the variant that a mutual contact had previously produced, having a mutual contact did not reduce the weight ascribed to the input. Similarly, if an old interlocutor produced a variant different from the one that the interlocutor had previously produced, the input was given its full weight and not only a tenth of it.

Results

To test the influence of accounting for source dependence, a linear regression was run on the number of agents, other than the innovators, who had adopted the rare variant by the end of the simulations, that is, the number of agents whose likelihood of using the rare variant was higher than their likelihood of using the previously dominant variant. The model included No. of Innovators, Weighting, and their interaction as predictors. Number of Innovators was centered and Weighting was coded as an ordinal factor. Results showed an effect of Number of Innovators (β=3.56, SE=0.54, t=6.58, p<0.001) such that the more innovators there were, the more agents the innovation spread to. Crucially, results also showed linear (β=-10.57, SE=1.08, t=-9.75, p<0.001), quadratic (β=8.47, SE=1.08, t=7.82, p<0.001) and cubic (β=-2.72, SE=1.08, t=-2.51, p=0.012) effects of Weighting, as well as an interaction between number of Innovators and Weighting with a linear (β=-4.77, SE=1.33, t=-3.60, p<0.001) and quadratic (β=4.78, SE=1.33, t=3.60, p<0.001) component. As Figure 3 shows, the more weight agents gave sources’ lack of independence, the less the innovation spread. Importantly, increasing the penalty for each mutual contact had bigger effects for low levels of penalty. That is, the difference between completely ignoring a source’s mutual contacts and reducing the weight given to the input by 10% for each mutual contact is bigger than the difference between reducing the weight given to input by 30% vs 40% for each mutual contact. Furthermore, the interactions reflect the fact that the effect of Weighting was larger when there were more innovators, though this might be due to floor effect with low Number of Innovators. Additional analyses confirmed that for each Number of Innovators, there were linear and quadratic effects of Weighting (all *p*s<0.01) in the same direction as in the overall analysis. There was also a cubic effect when there were two innovators (β=-5.40, SE=1.83, t=-2.95, p<0.01) but this effect is harder to interpret and did not appear in the other conditions.

 Figure 3. Results of Exp. 2a. Number of Adopters of the rare variant at the end of the simulations as dependent on Number of Innovators and Weighting. Error bars are indicated in red. Maximal possible number of adopters is 69, 68, and 67 in the 1 Innovator, 2 Innovators, and 3 Innovators conditions, respectively.

The results of Experiment 2a then indicate that failing to account for sources’ connectivity can increase the likelihood of a variant to spread. To ensure that the effect is not specific to this network structure, Experiment 2b tested the same hypothesis on a different real world network, that of Zachary’s Karate Club (Zachary, 1977).

Experiment 2b

*Method*

Experiment 2b was identical to Experiment 2a except that the social network had the structure of Zachary’s Karate Club (Zachary, 1977) which is built-into the Networkx package in python. This network includes 34 members of a Karate Club. Edges are non-directed and indicate that the two members spend time together outside of the club activities. This network is characterized by having two clusters. It is frequently studied as these clusters predicted a later split in the group. Because this network is smaller than the network in Experiment 2a, simulations were only run for 200 rounds.

Results

Results were analyzed using the same linear regression as in experiment 2a. The predictors were Number of Innovators, Weighting, and their interaction and the dependent measure was the number of agents who were more likely to use the originally rare variant than the originally dominant variant by the end of the experiment. Number of Innovators was centered and Weighting was coded as an ordinal factor. The results paralleled those of Experiment 2a. There was an effect Number of innovators (β=3.42, SE=0.26, t=13.01, p<0.001) indicating that the rare variant spread to more agents the more innovators there were. Weighting also had an effect with both a linear (β=-4.23, SE=0.53, t=-8.04, p<0.001) and a quadratic (β=2.85, SE=0.536, t=5.43, p<0.001) component, reflecting the fact that penalizing more for mutual contacts hinders spread but that increased Weighting has a larger effect at low levels of weighting (e.g., a change from no weighting to small penalties for mutual contacts) than at higher ones. There was also a cubic effect of Weighting (β=-1.749, SE=0.53, t=-3.31, p<0.001). Additionally, as in Experiment 2a, the effect of Weighting was moderated by the Number of Innovators (linear: β=-2.62, SE=0.64, t=-4.07, p<0.001), reflecting the fact that Weighting had a larger effect the more innovators there were, potentially due to floor effects at low number of innovators.

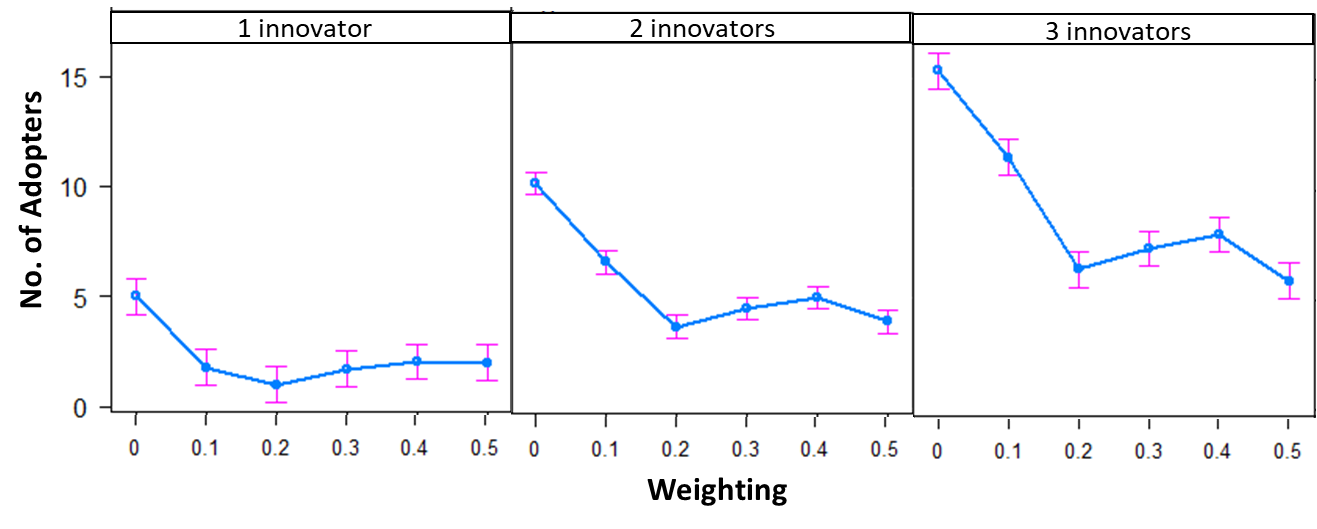


Figure 4. Results of Exp. 2b. Number of Adopters of the rare variant at the end of the simulations as dependent on Number of Innovators and Weighting. Maximal possible number of adopters is 33, 32, and 31 in the 1 Innovator, 2 Innovators, and 3 Innovators conditions, respectively.

*Discussion*

The results of Experiments 2a & 2b indicate that failure to account for sources’ independence can promote the spread of rare variants. They also revealed that the effect of accounting for sources’ independence is similar across two networks with quite different structures. In both networks, even partially accounting for sources’ dependence by reducing its influence by 10% has a large effect on reducing the likelihood of a variant to spread. The results thus support the proposal that one way by which rare variants manage to become dominant is through spread in dense networks where individuals fail to take the network’s inter-connectivity into account when assessing the informativity of the input they receive.

General Discussion

Our world is interconnected: social networks are dense, and media sources cite each other or rely on the same sources. Considering the ubiquity of source dependence in the input we receive from the world, our finding that people do not account for source dependence, especially when processing linguistic terms, and thus mis-estimate their prevalence, is striking. In Experiment 1 participants estimated that a term used by only one person is more frequent than another term used by three different people, because the information from the one person was repeated several times. Interestingly, results indicated that participants were more attentive to the source of the information when reading about opinions, yet even in that case, participants estimated the opinion that was only voiced by one person as more common than the opinion voiced by 3 people half of the time, significantly more than when it was not repeated.

Our study manipulated the lack of independence of sources by providing information from media outlets that explicitly stated their sources, as well as provided the same information verbatim. The task that participants performed was simpler than real world interaction, and its simplicity provides a stringent test. In the real world, the lack of independence of different sources can occur under different circumstances, and in many of them, the connection of the sources will not be made as explicitly. For example, people often do not state where they heard the information that they are passing, and they are likely to also rephrase it, decreasing its similarity. Furthermore, even when someone hears the same information from two contacts who are connected to each other, they might not know whether one of the contacts heard the information from the other or whether each heard it from someone else. Our study then is a strong test for individuals’ tendency to attend to source dependence under optimal conditions. In the real world, when the source of information is not explicitly acknowledged and its repetition is not verbatim, the failure to account for source dependence is likely to be even stronger.

Prior research has shown qualitatively similar findings with regards to opinions. For example, it has been shown that repeated statements are believed more than non-repeated statements (e.g., Begg et al., 1992; Brown & Nix, 1996; Dechene et al., 2010; Fazio et al., 2015; Hasher et al., 1977; Hawkins & Hock, 1992; Parks & Toth, 2006), and that people fail to account for source dependence (Yousif et al., 2019). At the same time, our finding that these effects extend to the processing of linguistic terms and is even stronger for these cases seems to contradict rich literature in Linguistics and Psycholinguistics that shows that people encode the social identity of a speaker together with their speech (e.g., Goldinger, 1998). For example, people process and interpret speech differently depending on speaker’s age, gender, or place of residence (e.g., Hay, Warren, & Drager, 2006; Johnson, Strand, & D’Imperio, 1999; Niedzielski, 1999). These effects are due to prior learning or stereotypes about how people with different social characteristics speak. According to the exemplar model account of language processing, people encode exemplars of the linguistic input they receive together with the social identity of their speakers. Later, during processing, people activate the exemplars they had stored according to both their linguistic and social similarity to the provided input. Exemplar models thus argue that people store and attend to the source of the linguistic information they receive, as well as rely on it during processing.

It should be noted that the comparison between the language and Opinion conditions is not as clean as would be ideal. For example, participants in the Language condition provided the common name in an open question format whereas in the Opinion condition they estimated the number of people who hold a certain opinion. That said, it is not immediately clear why an open question format would increase likelihood of neglecting source dependence compared with a closed question format. Another difference between the Language and Opinion conditions is that the phrasing in the Language condition might have been misinterpreted by some participants. That is, there might have been some participants who did not understand “most commonly referred to” as intended. Therefore, the difference between the Language and Opinion condition should be seen as suggestive, but further research is required. That said, the size of the effect in the Language condition is so large that it seems reasonable to conclude that there is neglect to account for source dependence, even if the size of this neglect might be smaller than found.

One way to reconcile the sociolinguistic and psycholinguistic findings with the results of Experiment 1 is to assume that source encoding varies along a continuum. That is, people might attend to and encode such information to different degrees depending on the situation. The effect of content type in Experiment 1 might reflect such situational differences. In the case of opinions, the sources differed with regards to the issue at focus, the opinion. Therefore, source information could have been seen as relevant for evaluating the information. In contrast, in the Language condition, the evaluated information was still the expressed opinions, and the sources were all in agreement, reducing the need to rely on source information to evaluate the opinion. Word choice was only a tool to refer to the event, not the focus of attention. In such a case, individuals might implicitly place lower importance on encoding source information. Such a situation, however, is representative of the difference between opinions and language, suggesting that source accounting will frequently be lower for linguistic terms. The difference between opinions and language might therefore be a special case of a general tendency to attend to source information more when it is perceived as more important for evaluating the information in focus.

Furthermore, a closer examination of the evidence regarding source encoding during language processing shows that listeners’ sensitivity to speaker identity during language processing reflects reliance on stereotypes that are sometimes at odds with real experience (Niedzielski, 1999), and therefore might not reflect regular encoding and reliance of source information. It therefore seems that while individuals sometimes encode the speaker’s social identity together with the information, they do not always do so. Additionally, it is possible that at least occasionally, individuals encode some relevant social characteristics of the speaker, such as their age or gender, but not their precise identity. Such a tendency would account for the effects of speaker identity in previous studies while predicting failure to account for dependence of sources when sources are not expected to differ in social characteristics, as the sources in our experiment. A recent study by Iacozza, Meyer and Lev-Ari (2019) provides initial support to these suggestions that source encoding might depend on the context as well as might be partial. In that study, participants encoded all source information for ingroup members, but only group membership for outgroup members. Future research should investigate whether the tendency to encode source information depends on the situation.

Another factor that might influence the degree to which listeners attend to the identity of the speakers who use a term is the connotation that the term has. In Experiment 1 neither term was stigmatized. Furthermore, as both competing terms were new, no term constituted a violation of existing norms. It might be the case that listeners would be more likely to encode the identity of speakers using terms that are perceived to violate a norm. This would consequently slow down the spread of the terms.

Individual differences might also play a role. For example, if fuller encoding requires resources, individuals with lower cognitive resources or in situations that are taxing might be less likely to encode source information. Individual differences in social stereotypes and preferences or personality, such as greater external locus of attention, might also influence the degree to which source information is encoded. Future research should investigate systematically how the interaction of contextual factors, content type, and individual differences influence source encoding.

Consideration of the dependence of sources has consequences for language change and the spread of information. The simulations in Experiments 2a & 2b indicate that failure to account for source dependence promotes the spread of rare variants. This study thus provides one manner by which rare variants can overcome the threshold problem and propagate throughout the community. The results of the studies suggest that language change might be more likely to occur in denser communities, where such source dependence is rampant, or in contexts where attending to the source is likely, such as when the new variants are not socially stigmatized and might not even be noticed explicitly.

In our studies, use of linguistic terms did not correlate with social characteristics or attitudes. In the real world, however, there is often such correlation, as change is introduced by younger generations or specific sub-groups. It would therefore be important to examine attention to source dependence in such cases and how these influence the propagation of the rare variants. Furthermore, the sources in our studies do not differ in their prestige, which might also influence attention to sources as prestigious sources might be better encoded. Thus, while our studies show how neglect of source dependence can influence spread, the inclusion of sociolinguistic factors would further indicate when and to what degree sources are neglected.

Lastly, throughout the paper we focused on the role of failure to account for source dependence on spread. Yet attention to source dependence has implications for synchronic processes, and not only diachronic processes, since assessing the prevalence of different variants is important for language processing. Language processing relies on prediction (e.g., Pickering & Garrod, 2004), and therefore wrong estimates of the prevalence of different linguistic terms or structures can slow us down or lead to miscommunication. Wrong estimates of the frequency of different terms can also lead us to be less effective communicators as we would not adjust optimally to our interlocutors, especially when they are unfamiliar. When the processed information is factual or attitudes, assessing its prevalence is important for assessing its reliability or predicting the future. For example, planning good policies require good assessment of the prevalence and distribution of dissatisfaction. Understanding our tendency to neglect source dependence could therefore have wide implications that go beyond those investigated in this paper.

To conclude, this paper shows that individuals do not always account for source dependence when processing information and that this failure to account for source dependence could influence language change. This paper thus opens the door to examining how attention and encoding interact with network dynamics in a manner that influences collective knowledge and behavior. The novel finding that linguistic and attitudinal information are treated differently also calls for re-thinking language change and further exploring how it differs from other cultural changes.

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Supplementary Materials B

These are the results of Experiment 1. Below is an explanation of each column in the dataset.

|  |  |
| --- | --- |
| Column name | Explanation |
| participant | Unique participant ID generated by Qualtrics |
| event | The event the participant responded to (comedy / merger). |
| attention1 | Participant’s response to the first attention check question. Correct response is: Gerhard Schmidt / Aurelia & Las |
| attention2 | Participant’s response to the first attention check question. Correct response is: Hausberger Theatre / Cosmetics |
| attention3 | Participant’s response to the first attention check question. Correct response is: 30,000 / South America |
| rawResponse | The response the participant provided, verbatim |
| response | The response converted into binary values. In the information condition: <=50% was coded as 0; >50% was coded as 1. In the Language condition: I-am-latvian / MegaMerger were coded as 1, Latvia joke / Fantastic Fusion were coded as 0 |
| include | Indicates whether the participant was included in the analysis. If the participant responded correctly to at least 2 out of the 3 attention check questions, they were included (‘y’). Otherwise, they were excluded (‘n’) |
| content | Content condition: language vs opinion |
| repetition | Repetition condition: multiple, repeated source, and non-repeated source |

The analysis was conducted using the lme4 package. Use of the commands below will reproduce the reported results:

#re-leveling the Repetition predictor to ensure the reference level is the same as reported:

spread$repetition=relevel(spread$repetition,ref="repeatedSource")

#logistic regression analysis:

Analysis=glm(response~repetition\*content, family=”binomial”,data=dataset[dataset$include==”y”,])

Supplementary Materials C

To ensure the robustness of our results, we ran simulations with some modifications to the assumptions and parameters to ensure that our reported results are not dependent on the specifications we selected but can generalize to other specifications.

Simulations with a flat updating function

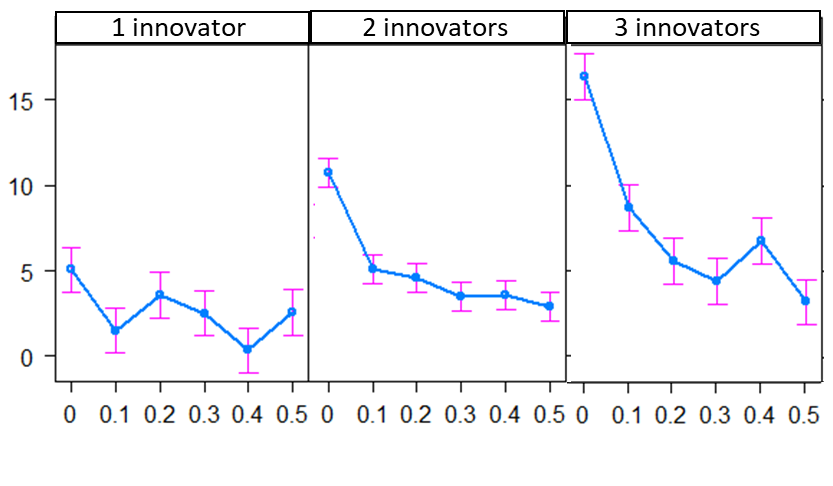
In the main simulations, the rate at which individuals updated their representations was inversely related to their network size, in line with prior findings that show that the smaller individuals’ network, the more they are vulnerable to the influence of others (Lev-Ari, 2017, 2018; Monster & Lev-Ari, 2018). To ensure that our results do not depend on this feature of the simulations experiments 2a and 2b were repeated with a flat updating rate. Equation 1 was modified such that *s* no longer represented the individual’s network size but the median network size in that community:

1. pt(a)=min(1,pt-1(a)+)

Thus, all individuals updated at the same rate, that of the individual with the median number of contacts in the original simulation.

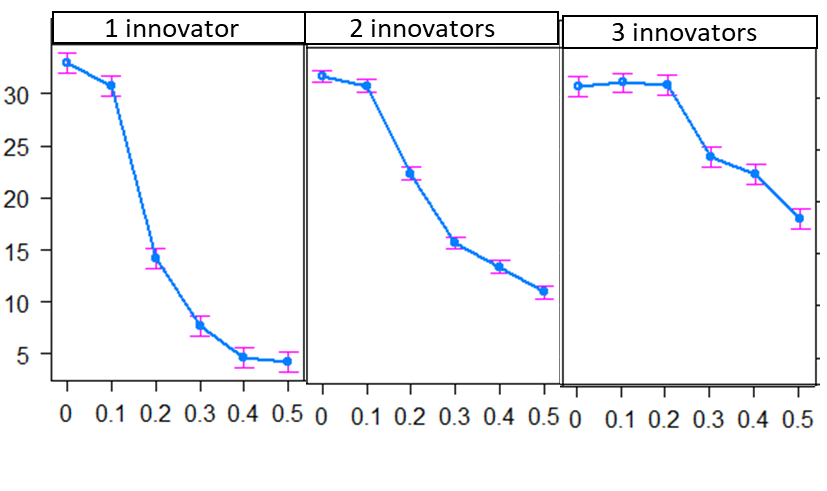
For the dataset in Experiment 2a, the results were very similar to the reported ones and replicated all the main findings. They are reported in the table and figure below. As in the main text, the number of innovators, the weighting, and their interaction were significant.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Predictor | Estimate | Std. Error | t value | p-value |
| (Intercept) | 5.0567 | 0.3520 | 14.364 | < 2e-16 \*\*\* |
| weighting.L | -5.3690 | 0.8623 | -6.226 | 5.94e-10 \*\*\* |
| weighting.Q | 2.9667 | 0.8623 | 3.440 | 0.000594 \*\*\* |
| weighting.C | -1.7568 | 0.8623 | -2.037 | 0.041768 \* |
| weighting^4 | 0.7049 | 0.8623 | 0.817 | 0.413782 |
| weighting^5 | -0.7150 | 0.8623 | -0.829 | 0.407139 |
| Number of Innovators | 2.4575 | 0.4312 | 5.700 | 1.40e-08 \*\*\* |
| weighting.L x Number of Innovators | -3.3425 | 1.0561 | -3.165 | 0.001578 \*\* |
| weighting.Q x Number of Innovators | 1.6726 | 1.0561 | 1.584 | 0.113428 |
| weighting.C: x Number of Innovators | -1.7695 | 1.0561 | -1.675 | 0.094023 . |
| weighting^4 x Number of Innovators | -1.9975 | 1.0561 | -1.891 | 0.058734 . |
| weighting^5 x Number of Innovators | -0.2469 | 1.0561 | -0.234 | 0.815156 |



Similarly, for the dataset used in Experiment 2b, the revised simulations showed effects of number of innovators, weighting, and an interaction between the two, though the nature of the interaction was more complex and had some differences from the main reported analyses.

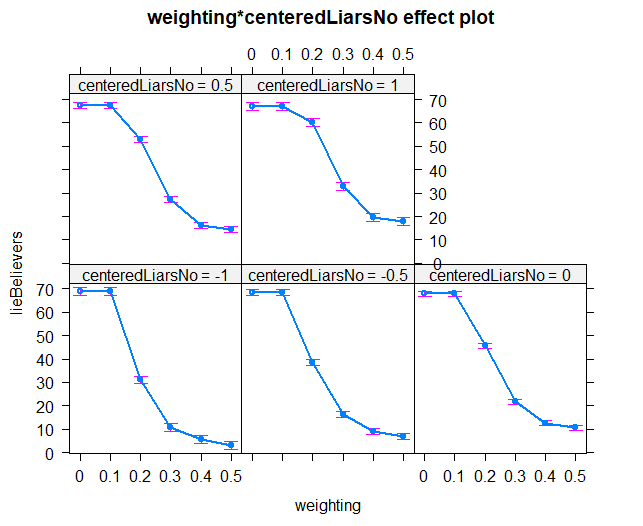
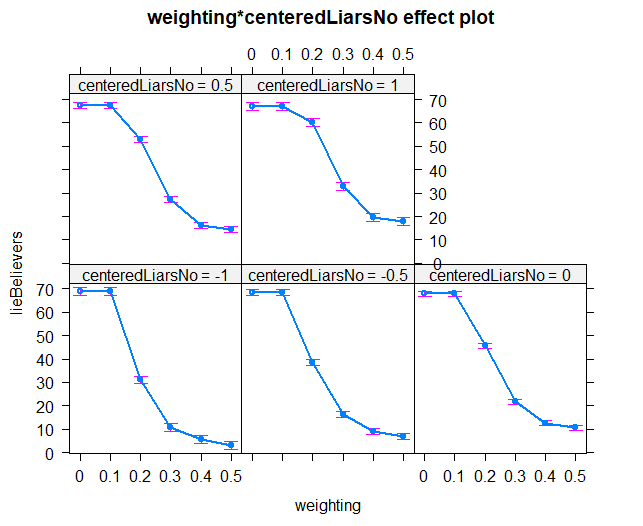
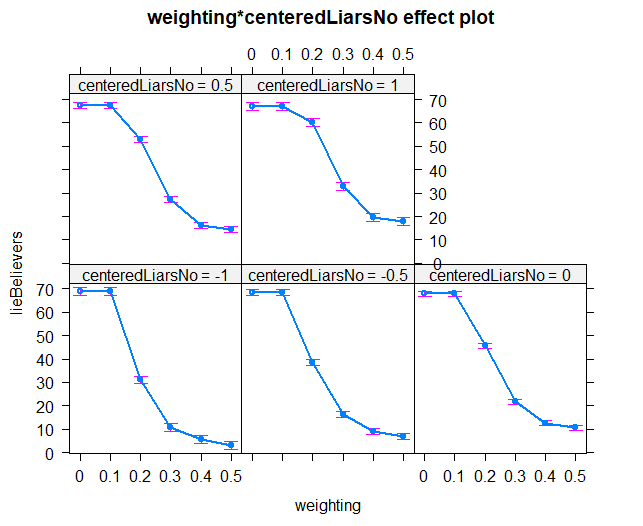
|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Predictor | Estimate | Std. Error | t value | p-value |
| (Intercept) | 21.09667 | 0.25482 | 82.791 | < 2e-16 \*\*\* |
| weighting.L | -19.44876 | 0.62418 | -31.159 | < 2e-16 \*\*\* |
| weighting.Q | 1.85594 | 0.62418 | 2.973 | 0.00298 \*\* |
| weighting.C | 3.34143 | 0.62418 | 5.353 | 9.75e-08 \*\*\* |
| weighting^4 | -2.57961 | 0.62418 | -4.133 | 3.75e-05 \*\*\* |
| weighting^5 | -0.01197 | 0.62418 | -0.019 | 0.98470 |
| Number of Innovators | 5.37833 | 0.31209 | 17.233 | < 2e-16 \*\*\* |
| weighting.L x Number of Innovators | 7.91002 | 0.76446 | 10.347 | < 2e-16 \*\*\* |
| weighting.Q x Number of Innovators | -5.07575 | 0.76446 | -6.640 | 4.16e-11 \*\*\* |
| weighting.C: x Number of Innovators | -1.48475 | 0.76446 | -1.942 | 0.05227 . |
| weighting^4 x Number of Innovators | 2.19975 | 0.76446 | 2.878 | 0.00406 \*\* |
| weighting^5 x Number of Innovators | -2.36228 | 0.76446 | -3.090 | 0.00203 \*\* |



Simulations with faster updating rate

We further tested whether the results generalize to other rates of updating. To do so, we re-ran the simulations with a rate of updating that is twice as fast (giving each input twice the weight as in the original simulation). The results with the data set of Experiment 2a are detailed in the table and figure below. We replicate all reported effects (with some additional effects at higher levels of polynomials).

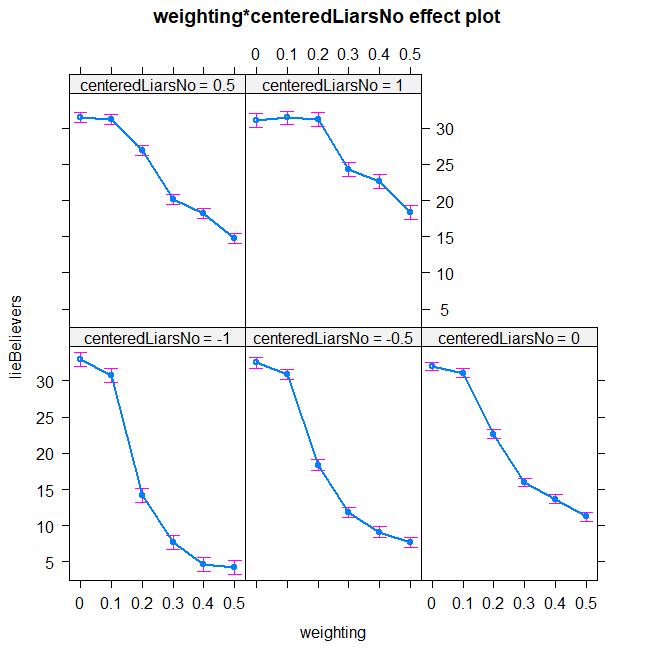
|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Predictor | Estimate | Std. Error | t value | p-value |
| (Intercept) | 37.7694 | 0.4476 | 84.391 | < 2e-16 \*\*\* |
| weighting.L | -57.0343 | 1.0963 | -52.025 | < 2e-16 \*\*\* |
| weighting.Q | 4.6331 | 1.0963 | 4.226 | 2.50e-05 \*\*\* |
| weighting.C | 14.6475 | 1.0963 | 13.361 | < 2e-16 \*\*\* |
| weighting^4 | -5.3022 | 1.0963 | -4.837 | 1.43e-06 \*\*\* |
| weighting^5 | -1.2584 | 1.0963 | 1.148 | 0.25117 |
| Number of Innovators | 6.3758 | 0.5481 | 11.632 | < 2e-16 \*\*\* |
| weighting.L x Number of Innovators | 7.4720 | 1.3427 | 5.565 | 3.02e-08 \*\*\* |
| weighting.Q x Number of Innovators | -8.3916 | 1.3427 | 6.250 | 5.12e-10 \*\*\* |
| weighting.C: x Number of Innovators | 0.0477 | 1.3427 | 0.036 | 0.97166 |
| weighting^4 x Number of Innovators | 7.5120 | 1.3427 \* | 5.595 | 2.55e-08 \*\*\* |
| weighting^5 x Number of Innovators | -4.2168 | 1.3427 | -3.141 | 0.00171 \*\* |



3 innovators

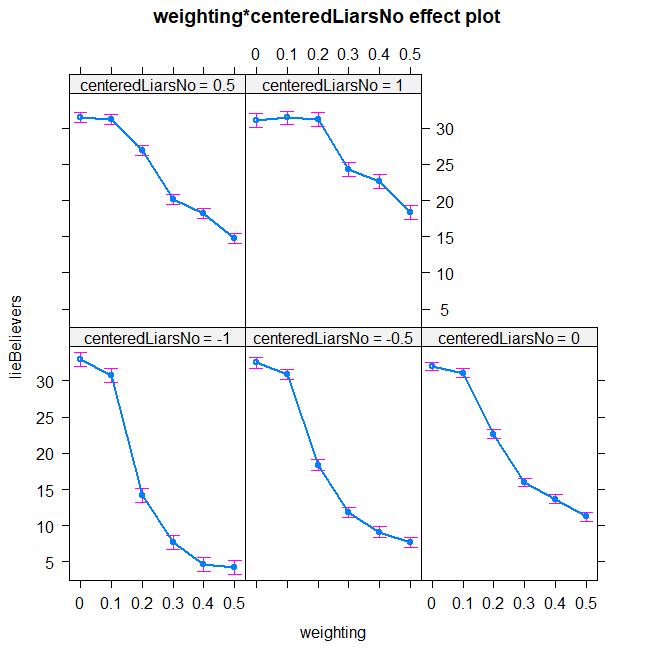
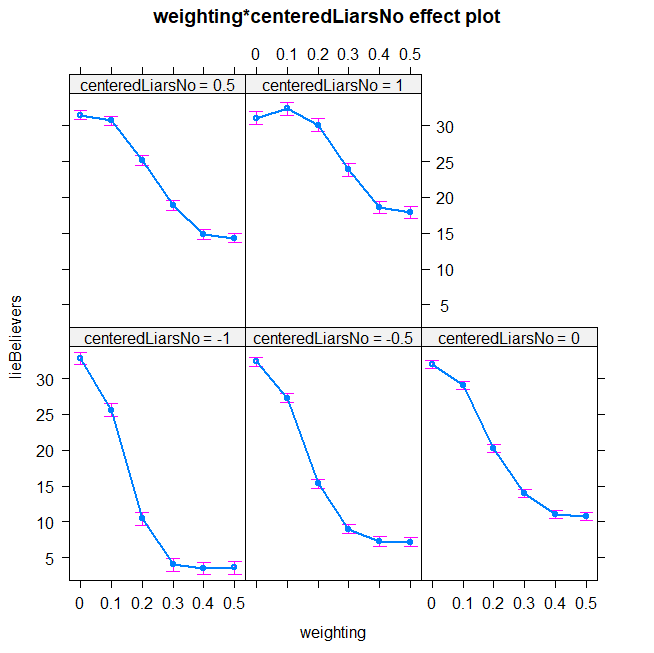
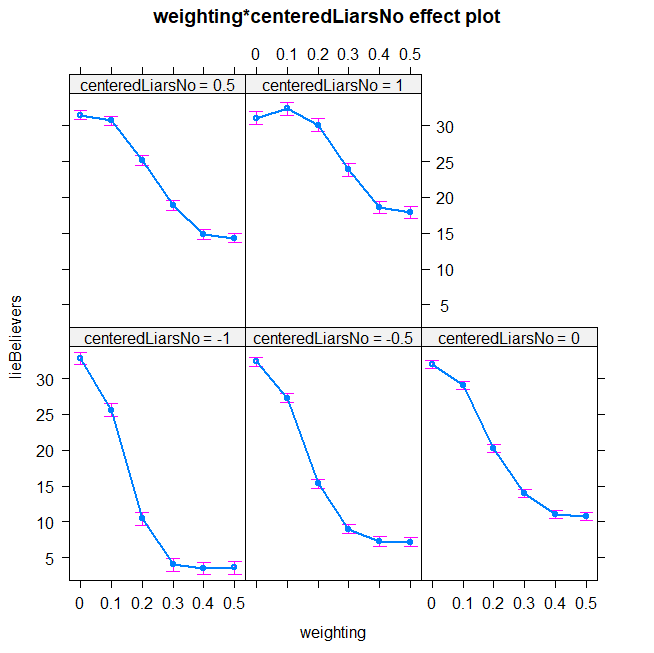
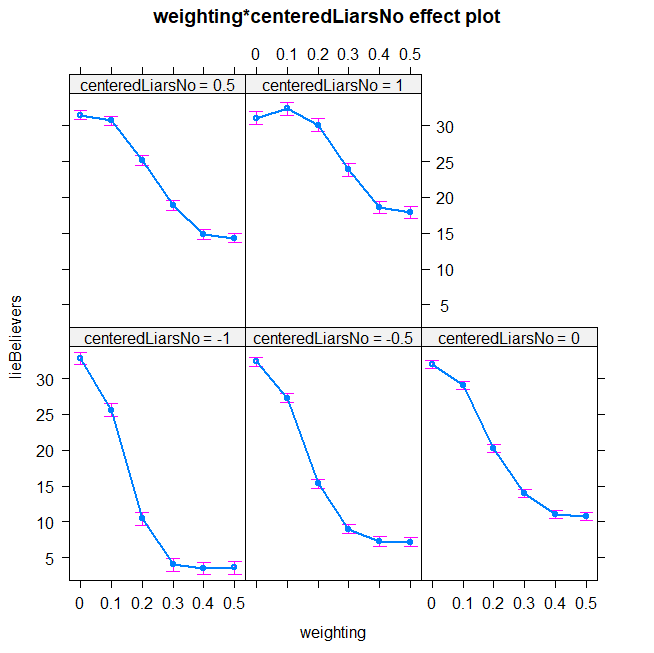
2 innovators

1 innovator



Similarly, below are the results for doubling the rate of updating for the simulations of Experiment 2b.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Predictor | Estimate | Std. Error | t value | p-value |
| (Intercept) | 19.4772 | 0.2338 | 83.323 | < 2e-16 \*\*\* |
| weighting.L | -19.8300 | 0.5726 | -34.633 | < 2e-16\*\*\* |
| weighting.Q | 3.9898 | 0.5726 | 6.968 | 4.50e-12\*\*\* |
| weighting.C | 3.3447 | 0.5726 | 5.841 | 6.14e-09 \*\*\* |
| weighting^4 | -1.7134 | 0.5726 | -2.992 | 0.002805 \*\* |
| weighting^5 | 0.3318 | 0.5726 | 0.579 | 0.562376 |
| Number of Innovators | 6.1608 | 0.2863 | 21.519 | < 2e-16 \*\*\* |
| weighting.L x Number of Innovators | 6.3018 | 0.7013 | 8.986 | < 2e-16 \*\*\* |
| weighting.Q x Number of Innovators | -6.3785 | 0.7013 | -9.096 | < 2e-16 \*\*\* |
| weighting.C: x Number of Innovators | 0.7975 | 0.7013 | 1.137 | 0.255579 |
| weighting^4 x Number of Innovators | 2.4549 | 0.7013 | 3.501 | 0.000476 \*\*\* |
| weighting^5 x Number of Innovators | -0.7666 | 0.7013 | -1.093 | 0.274447 |



3 innovators

2 innovators

1 innovator

As can be seen, the results with these faster updating rate replicate the main finding that neglecting to account for source dependence facilitates the spread of innovations. We should note that if the rate of updating is very low, innovations fail to spread.

1. Note that this issue is not constrained to horizontal transmission but also applies to vertical transmission, assuming that the variant that an individual uses does not influence their fitness and therefore the likelihood of having children. [↑](#footnote-ref-2)
2. Real world networks tend to have a scale-free structure (Barabasi, 2009). Among the notable characteristics of scale-free networks are having many members with few contacts and few members with many contacts (number of degrees follows a power law), and having short paths between each two members. [↑](#footnote-ref-3)
3. We coded the responses in the Opinion condition in a binary manner to enable a direct comparison to the Language condition in the same model. Results are similar if we examine participants’ raw estimates. The median percentage estimates for the percentage of audience/employees who support the opinion are: Non-repeated Source – 29.5%, Repeated Source – 50%, Multiple Sources – 66%. As in the main analysis, the Repeated Source condition falls in-between the other two conditions though the difference between it and the Multiple Sources condition is smaller than in the binary analysis, suggesting even greater failure to account for source dependence. [↑](#footnote-ref-4)
4. Supplementary Materials C provides alternative simulations including ones where the updating function is flat and does not depend on the individual’s network size. [↑](#footnote-ref-5)