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Original Article

Universal cognitive mechanisms explain the cultural success of bloodletting

Helena Miton [a], Nicolas Claidière [b], Hugo Mercier [c,*]

[a] Institut Jean Nicod, Paris, France, 29 rue d'Ulm, 75006 Paris, France
[b] Aix Marseille Université, CNRS, LPC UMR 7290, 13331, Marseille, France
[c] Cognitive Science Center, Université de Neuchâtel, Rue Pierre à Mazel 7, Neuchâtel 2000, Switzerland

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ABSTRACT

Bloodletting—the practice of letting blood out to cure a patient—was for centuries one of the main therapies in the west. We lay out three potential explanations for bloodletting's cultural success: that it was efficient, that it was defended by prestigious sources—in particular ancient physicians—, and that cognitive mechanisms made it a particularly attractive practice. To test these explanations, we first review the anthropological data available in eHRAF. These data reveal that bloodletting is practiced by many unrelated cultures worldwide, where it is performed for different indications and in different ways. This suggests that the success of bloodletting cannot only be explained by its medical efficiency or by the prestige of western physicians. Instead, some universal cognitive mechanisms likely make bloodletting an attractive form of therapy. We further test this hypothesis using the technique of transmission chains. Three experiments are conducted in the U.S., a culture that does not practice bloodletting. Studies 1 and 2 reveal that stories involving bloodletting survive longer than some other common therapies, and that the most successful variants in the experiments are also the most successful variants worldwide. Study 3 shows how a story about a mundane event—an accidental cut—can turn into a story about bloodletting. This research demonstrates the potential of combining different methodologies—review of anthropological data, experiments, and modeling—to investigate cultural phenomena.

George Washington died after losing half is blood. This massive blood loss was not due to a battle wound, but to the lancets of physicians (Cheatham, 2008; Morens, 1999). In this Washington was not exceptional: at least from the seventeenth to the mid-nineteenth century, bloodletting—cutting patients to let some blood flow out with a therapeutic aim—was one of the most popular forms of therapy in Europe and North America (Wootton, 2006). Why would people cut themselves—or, more commonly, ask others to cut them—to lose some blood when they are already weakened by disease?

A first explanation is that bloodletting is efficient in preventing or helping to cure some diseases. This is, however, unlikely. Phlebotomy, the modern instantiation of bloodletting, has very few indications (most of them rare diseases, see DePalma, Hayes, & Zacharski (2007). Still, it could be that bloodletting used to be efficient for indications that are now treated by more efficient means. In particular, it has been suggested that bloodletting causes iron deficiency, which can help prevent infections (Denic & Agarwal, 2007; see also Brain, 1986). While this hypothesis suggests that bloodletting might have some positive effects as a prophylactic, it says nothing about its value as a remedy when the infection is already in place. Bloodletting could have placebo effects, but it typically does not fulfill some of the conditions that make a placebo efficient, such as the patient being active (for a list of factors that increase the efficiency of placebo effects, see Trivers, 2011, p. 71).

More importantly, any positive effect bloodletting might have would be mitigated by its costs: bloodletting can endanger the patient's health through blood loss (potentially leading to dehydration and hypovolemia, see Morens, 1999), infection (the concept of aseptic operation was essentially unknown when bloodletting was commonly practiced in the west), or the danger of severing an artery (Brain, 1986). Finally, the reactions to blood loss—which can culminate in vasovagal syncope —tend to be unpleasant—they are for instance considered obstacles to blood donation (Bednall & Bove, 2011).

Another possibility to explain the spread and persistence of cultural practices, and in particular of maladaptive ones, is to use frequency based or model based biases such as the conformity and prestige biases (Boyd & Richerson, 1985; Richerson & Boyd, 2005). The conformity bias increases the likelihood that people adopt the most common behavior in their population (Henrich & Boyd, 1998), while the prestige bias favors the adoption of the most prestigious individuals' behavior (Henrich & Gil-White, 2001). The role of the prestige bias in the case of bloodletting relates to a common explanation: that bloodletting was practiced because it followed from the widely accepted humoral theory of disease (e.g. Arika, 2007; Wootton, 2006). Both bloodletting and the humoral theory had been part of the western cannon since Galen and the Hippocratic writers (Arika, 2007). The prestige of ancient

* Corresponding author.
E-mail address: hugo.mercier@gmail.com (H. Mercier).

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Fig. 1. A linear, prestige based history of bloodletting: the Egyptians adopt the practice of bloodletting, they influence the Hippocratic writers, who influence Galen, who influences the next two millennia of western medicine.

Roman and Greek thinkers—and of the physicians who relied on their theories—could therefore explain the success of bloodletting in western medicine (Fig. 1) (for examples of non-adaptive practices spreading through prestige bias, see, e.g., Mesoudi, 2008). Once bloodletting would have become a standard practice, it could be further sustained by the conformity bias.

A third possibility is that bloodletting is psychologically attractive. Cultural practices can spread and endure not because of who practices them, but because of how their content triggers cognitive mechanisms that make them more or less likely to be attended, memorized, and used (concept of guided variation in Boyd & Richerson, 1985; Sperber, 1996). The framework of cultural attraction provides conceptual tools and models linking cognitive mechanisms and cultural phenomena (Claidière & Sperber, 2007; Morin, 2013; Sperber, 1996). Attractors are defined as points or areas in the space of possible configuration towards which transformations tend to converge. They exist because factors of attraction affect the probability that individual variants of a cultural item depart from their models in one direction rather than another. These consistent biases cause the variants of a given item to gravitate towards, and then around the same point. Cultural attraction explains why some representations, practices and artifacts are more prevalent and robustly transmitted than others by looking at the micro-mechanisms involved in their transmission.

At the micro-level, transmission of information among humans is generally not a copying process and typically results in modifications of the information transmitted. To explain how macro cultural stability may nevertheless occur, cultural attraction stresses the importance of constructive factors in cultural transmission: the psychological mechanisms involved in imitation and in communication are partly preservative and partly constructive (Claidière & Sperber, 2007; Sperber, 1996). Learners use information provided by the teacher to construct their own version of the idea or the practice. If the modifications introduced by the learners were random many representations, practices, or artifacts could not remain sufficiently self-similar in the process of transmission for recognizable cultural items to become prevalent (Claidière & Sperber, 2007, 2010). If some items are culturally successful in these conditions, it is in large part due to psychological and ecological processes that bias the process of transmission in consistent directions (Claidière, Smith, Kirby, & Fagot, 2014). For instance, words can exhibit an extraordinary level of macro stability (Pagel, Atkinson, & Meade, 2007; for another example, see Howe et al., 2001). This stability comes at least in part from the fact that learners tend to bias the evolution of languages in the direction of greater learnability (Kirby, Cornish, & Smith, 2008). This could explain why we observe that the most frequent and most stable words are also the shortest (Pagel, Atkinson, Calude, & Meade, 2013).

In the case of medical treatments, general cognitive biases such as the confirmation bias have been used to explain the spread of inefficient therapies (de Barra, Eriksson, & Strimling, 2014; Hartman, 2009; Tanaka, Kendal, & Laland, 2009). These mechanisms might help explain why a medical practice, once established, persists for longer than warranted by its efficacy. However, these mechanisms cannot explain why a given practice spreads rather than another. In the case of bloodletting, the risks of the practice, and the existence of less risky alternatives, makes the need for other explanations even more acute. A successful explanation of bloodletting has to account not only for the origin, spread, and persistence of a practice but also for the particular form it takes. For instance, blood is known to elicit disgust in contemporary western populations (Tybur, Lieberman, & Griskevicius, 2009), and it has been previously shown that cultural items that elicit disgust—urban legends (Eriksson & Coultas, 2014; Heath, Bell, & Sternberg, 2001) or norms (Nichols, 2002)—tend to be more successful than variants that do not elicit disgust. Many other cognitive mechanisms could help explain why bloodletting became a common practice—in the conclusion, we discuss the potential roles of folk biology, folk physics, and folk psychology, along with more general memory mechanisms.

It is important to note that these three broad explanations are not mutually exclusive, and that they might all play a role in a complete explanation of bloodletting. For instance, some universal cognitive mechanisms might have favored the emergence of bloodletting, and the practice could then have spread and have be sustained by its efficiency (if it has any) and the prestige of its practitioners. Yet the different explanations make different predictions and the more one explanation proves to carry weight, the less necessary the others become. In particular, to the extent that universal cognitive mechanisms are able to account for the success of bloodletting, the standard explanation of bloodletting as chiefly being due to the prestige of some individuals would have to be revised.

The present research tests predictions derived from these explanations. If bloodletting is a historically situated tradition sustained chiefly by prestige and conformity, a practice that happened to be favored for idiosyncratic reasons by a few physicians who proved formidably influential, then one would expect bloodletting to be a common practice only within the sphere of influence of these early western physicians. By contrast, if universal cognitive mechanisms are largely responsible for the success of bloodletting, it should be found in various cultures that have not been influenced by early western physicians. Moreover, if bloodletting is a cultural attractor it should be attractive even in populations that do not practice it. Finally, we should also be able to discern differences in attractiveness between different variants of bloodletting—variants based on localization of the cut, on the status of the practitioner, on the theories invoked, etc.

In order to test these predictions, we use three different methodologies. The first is to analyze an anthropological database in order to gauge the extent of the practice in non-western cultures. If bloodletting is found to be practiced in many different cultures, it might also be possible to discern commonalities in the practice across these cultures. These commonalities could then help to infer the mechanisms that contribute to bloodletting's success. The second method is the use of experimental evidence. To ascertain the presence of mechanisms that make bloodletting intuitive, we rely on an indirect mean: transmission chains. This technique was developed by Bartlett (1932) to study the distortion repeated transmissions introduced in narratives and other representations; it has been found to be useful in the study of psychological mechanisms involved in cultural transmission in humans (e.g. Bangerter, 2000; Barrett & Nyhof, 2001; Kashima, 2000; Mesoudi &

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Fig. 2. Approximate localization of cultures practicing bloodletting referenced in eHRAF (©The Royal Society), with some examples of the way it is practiced (all pictures CC, except for top left, Royal Society Picture Library). Squares represent cultures from the PSF.

Whiten, 2004). If the cognitive mechanisms that make bloodletting an attractor are universal, they should influence the way participants remember the details of narratives involving bloodletting, even if the participants do not believe in its efficiency. Finally, we use models based on evolutionary causal matrices (Claidière, Scott-Phillips, & Sperber, 2014) to simulate the evolutionary consequences of repeated transmission to larger populations and longer time scales.

1. Anthropological data

We performed a search in the Human Relations Area Files anthropological database (eHRAF: World Cultures database) for the words 'bloodletting,' 'bleeding,' 'phlebotomy,' 'venesection,' and 'cupping.' This yielded 154 references (see ESM for the full list of references, available on the journal's Website at www.ehbonline.org). The first coding aimed at eliminating the instances of cupping that did not involve bloodletting. All instances of cupping that did not involve a cutting tool, incisions, or blood were removed (N = 14, see ESM for more details about this and the other codings, available on the journal's Website at www.ehbonline.org). Second, we removed all instances of bloodletting that did not explicitly have a therapeutic use, as determined by the eHRAF classification and information present in the extracts (N = 38).

All the remaining references (N = 102) were then coded on three dimensions: colocalization, practitioner, and explanation. These dimensions were chosen after an initial reading of the data had alerted us to potential patterns. The colocalization of the treatment was coded in two categories: colocalized (when the indication and the area bled coincide) and non-colocalized (when the indication and the area bled do not coincide). The practitioner of the treatment was coded as: the patient himself/herself (which turned out to be an empty category), third party with no special status (e.g. relative), or third party with special status (e.g. doctor). Finally, when enough information was available, the theory explaining the use of the therapy was coded as either involving the idea of 'bad blood' or not. A second coder, blind to the hypotheses, recoded 10% of the data, and we found a Cohen's Kappa of one on 64 items.

The 102 references to therapeutic uses of bloodletting covered 60 cultures/ethnic groups present in all continents (except for Antarctica, see Fig. 2). To exclude the possibility that the practice of bloodletting in these cultures descends from one or a few ancestral practices we used the probability sample files (PSF). The PSF offers a sample of unrelated cultures designed to control for pseudo replication linked to common ancestry. Fifteen out of the 60 cultures of the PSF have been reported to practice bloodletting, making it a cross-culturally recurrent practice (see Fig. 2 and ESM for maps of the different patterns which specify whether each culture belongs to the PSF, available on the journal's Website at www.ehbonline.org). All subsequent analyses are carried on the full sample of cultures (102 references representing 60 cultures). Given that the eHRAF is not exhaustive, either in the number of cultures it describes, or in its descriptions of the cultures (see, e.g. Hruschka, 2010), it is likely that further searches would likely have yielded more cases. However, the present results are sufficient to establish the worldwide recurrence of bloodletting and to allow for some limited generalizations.

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The anthropological data illustrate the high level of variability in the transmission of ideas and practices, highlighting by contrast the remarkable robustness of the core idea of bloodletting: intentionally letting someone's blood flow to achieve a therapeutic aim. For instance, a review of traditional methods of surgery in Alaska shows that while this core idea was present in many native Alaskan cultures, most associated representations varied widely: bloodletting was practiced for different indications, using different tools, on different body areas, by different people, and it was explained by different medical theories (Fortuine, 1985).

In spite of the wide variation in many representations associated with bloodletting, the anthropological data suggest some patterns. The first two patterns stem from the analysis of the explanations offered for bloodletting. The first of these two patterns is the dissociation between the practice of bloodletting and the explanation of specific ailments as supernaturally caused by human agents. In most cultures human agency, in the form of witchcraft and sorcery, can be blamed for ailments (Murdock, Wilson, & Frederick, 1978). By contrast, in none of the reports of bloodletting analyzed were human agents held responsible (information supporting other explanations was available in 14 cultures). The fact that bloodletting is not believed to be efficacious to cure illnesses caused by human agency is demonstrated by the Azande, who treat headaches (among other indications) with bloodletting by cupping. Strikingly, "[t]his wet cupping treatment is said to cure headache if it is not occasioned by witchcraft; for if this is the case it will continue in spite of cupping" (Evans-Pritchard, 1937 p.496).

The second of these patterns is the recurrence of the idea that 'bad blood' needs to be taken out as an explanation for the practice of bloodletting. The idea of 'bad blood,' or closely related concepts ('black blood,' 'foul blood'), is explicitly mentioned in 10 cultures. This is the only recurrent pattern among the 14 cultures for which we have enough information about the explanation for the practice, and it is the most common pattern in five out of six continents. Even when the medical theories are more sophisticated—as in the case of the humoral theory—we can often recognize the idea of letting a noxious element exit the body with the blood.

A third pattern is the frequency of 'colocalization' between the body part to be treated and the area being bled. The localizations of both the area in need of treatment and the area being bled were specified in 14 cultures. In 11 of these cases, the area in need of treatment and the area bled were at least sometimes the same, and in three they were specifically non-colocalized. Europe is the only continent with more instances of non-colocalized than colocalized bloodletting.

Finally, out of the 14 cultures in which the practitioner was mentioned, the practitioner was a third party with a status related to medicine (doctor, shaman, medicine man, etc.) in 13 cultures, and a third party with no status related to medicine in one culture. In all continents for which the relevant information was present, third parties with special status were the most common practitioners. The fact that each of these four patterns can be observed across the world suggests that they might be more robust than the small number of observations suggests.

The anthropological data show that bloodletting can be found in many cultures across the world, and thus that bloodletting cannot be chiefly explained by local factors such as the prestige of early western physicians. Moreover, no consistent pattern emerged in the ways bloodletting is practiced that would imply that medical efficacy is an important factor. Instead, the anthropological data suggest that some universal cognitive mechanisms make bloodletting relatively attractive as a therapy. The data also hint that some variants of bloodletting might be more universally attractive than others—in particular, those practiced by a third party in a colocalized fashion—while other aspects of the practice—such as the tool used—would depend more on local ecological constraints.

2. Experimental data

To further evaluate the role of universal cognitive mechanisms in the attractiveness of bloodletting, we conducted a series of experiments with U.S. participants. As mentioned above, phlebotomy is a rare practice in modern western medicine, and bloodletting is not common as an alternative form of therapy either, so that these participants belong to a population that can be considered not to practice bloodletting. In order to limit the impact of participants' explicit beliefs about the efficacy of bloodletting, we used the technique of transmission chains. This technique reveals what elements of a story participants are most likely to remember, as well as how they transform the elements of the story, two operations that need not involve explicit beliefs about the efficacy of bloodletting.

2.1. Study 1

Study 1 aimed at testing two hypotheses. The first was that bloodletting should prove more robust to repeated transmission than other forms of therapy. The second was that the traits of bloodletting that are most common worldwide should be more robust than other traits.

2.1.1. Methods

2.1.1.1. Participants. All the participants were recruited through the Amazon Mechanical Turk Website. They were paid $0.5 for their participation. All participants had to be in the U.S. at the time of the experiment. This applies to the three present studies. For Study 1, 301 participants were recruited (158 women, $M_{Age} = 33.5$, $SD = 16.4$). The Ns at the first generation were as follows: bloodletting seed, N = 27; ritual seed, N = 24; emetic plant seed, N = 27; emetic meat seed, N = 25.

2.1.1.2. Design. There were four conditions, one for each type of seed: bloodletting, ritual, emetic plant, emetic meat. We used a between subject design with each participant seeing only one story from one of the four conditions.

2.1.1.3. Procedure. Participants were told that they would be given a text to read attentively since they might have to answer questions about it afterwards. They were then provided with the input story—the seed in the first generation of each study; the story provided by a previous participant for later generations.

As a distraction task, the participants had to tackle a disjunctive reasoning problem, provide an argument for their answer, evaluate the argument given by another participant, and formulate a final answer (see ESM for more details, available on the journal's Website at www.ehbonline.org).

Finally, participants were invited to re-tell the story they had read at the beginning as well as they could, providing the output story. The stories were repeated at most for six generations, the chains being interrupted either when a participant failed to recall the therapeutic event or when the sixth generation was reached.

2.1.1.4. Materials. The seed of the bloodletting condition read as follows:

> In the Amazonian forest there are still tribes that have had little contact with modern technology. Yanobala was born in one of these tribes, the Yamotaba. Yanobala has mastered the art of archery, and he has become one of the best hunters of the tribe. In order to marry the chief's daughter, who is a very beautiful woman, he has to bring back a bird with magnificent feather that is very rare and hard to catch. He's eager to go hunting, but for several days he has suffered from an incapacitating headache. *Yanobala goes to see the medicine man, who uses a sharp stone to cut Yanobala's temple and let some blood flow*. [Italics added] The day after, Yanobala feels better and he goes looking for the special bird. After days of hunting, he finds one, manages to kill it and to bring it back: he will finally be able to marry the chief's daughter.

The seeds of the other stories were identical to this one except for the italicized sentence, which was modified in each condition. Table 1

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Table 1
Modified sentence from all the seeds used.

Study/Condition	Modified sentence
1/Bloodletting	Yanobala goes to see the medicine man, who uses a sharp stone to cut Yanobala's temple and let some blood flow.
1/Ritual	Yanobala goes to see the medicine man, who intones a ritual prayer addressed to the spirits while performing magical gestures.
1/Emetic plant	Yanobala goes to see the medicine man, who prepares a mix of plant to give Yanobala in order to make him throw up.
1/Emetic meat	Yanobala goes to see the medicine man, who prepares a piece of tainted meat to give Yanobala in order to make him throw up.
2/Not colocalised	Yanobala goes to see the medicine man, who uses a sharp stone to cut Yanobala's foot and let some blood flow.
3/Accidental	Yanobala takes his head in his hands and he accidentally cuts his temple with a sharp stone tool he's holding and some blood flows.
3/Intentional	Yanobala uses a sharp stone tool to cut his temple and let some blood flow.

provides the sentences used at the location of the italicized sentence in all three studies.

2.1.1.5. Coding. All the stories were coded for the presence of the following elements: therapeutic event (bloodletting, vomiting, one of the ritual acts); practiced by a third party; indication (headache); area bled (head—only in the bloodletting condition); tool used (stone—only in the bloodletting condition). A second coder, blind to the hypotheses, recoded 10% of the stories, and we found high inter-coder reliability (Cohen's kappa of 0.95 on 186 items).

2.1.1.6. Statistical analysis: survival analysis. We were first interested in the effect of different conditions on the probability that the stories are transmitted and persist across generations. To analyze these data we used survival analysis (also called event history analysis) which allowed us to construct survival functions for the different conditions. The survival function is the probability that a chain lasts for at least a certain number of generations. Knowing the survival functions, we can infer whether they significantly differ across conditions. The use of survival analysis is particularly apt here since the maximum number of generations a chain can last has been arbitrarily fixed; thus we do not always have the time at which some chains would have spontaneously stopped. This is known as 'right-censored' data, and survival analysis takes this into account. To analyze the data we used the R software (R Core Team, 2013) and the R package survival (Therneau, 2013). We conducted only planned analyses and used a limited number of tests comparing conditions two by two, and therefore we do not present corrected P-values.

2.1.2. Results

To evaluate the relative robustness of bloodletting, we compared the average chain lengths for the four seeds (see Fig. 3): bloodletting, mean = 3.0 generations (i.e. a bloodletting story survived on average three transmission events), SE = 0.43; ritual, mean = 0.4, SE = 0.16; emetic plant, mean = 1.7, SE = 0.37; emetic meat, mean = 2.4, SE = 0.46. Survival analyses show the length of the bloodletting chains to be significantly longer than that of the ritual chains ($\chi^2_{(1)} = 23.8$, $P < 0.001$) and the emetic plant chains ($\chi^2_{(1)} = 5$, $P = 0.026$), but not the emetic meat chains ($\chi^2_{(1)} = 0.5$, $P = 0.46$). These results suggest that even among participants who have no explicit belief in the efficiency of bloodletting, the representation of this practice proves robust during transmission compared to other forms of therapies. Since the bloodletting and emetic meat conditions involved the most disgust eliciting stimuli (see ESM for supporting data, available on the journal's Website at www.ehbonline.org), disgust is likely to have played a role in making these stories more robust to repeated transmission.

Focusing on the bloodletting seed, study 1 allowed comparing the relative robustness of representations associated with bloodletting: the fact that it was practiced by a third party, the tool used, and colocalization between indication and area bled. The fact that a medicine man performed the operation was better remembered (mean = 4.9; SE = 0.44) than the information regarding colocalization (mean = 3.1; SE = 0.40; $\chi^2_{(1)} = 7$, df = 1, $P = 0.008$) and tool use (mean = 1.3; SE = 0.12; $\chi^2_{(1)} = 40.3$, $P < 0.001$). The information regarding colocalization was also better remembered than the tool used ($\chi^2_{(1)} = 18.2$, $P = 0.001$).

To better understand the importance of colocalization, we calculated the chances that the therapeutic element (i.e. bloodletting), the area bled, or the indication would disappear as a function of the number of these elements in the input story. Simple memory loss would predict that when more elements are present, it is more likely that at least one element will be forgotten. However, if colocalized bloodletting forms an attractor, then this might counteract the effects of memory loss. Among the participants receiving a colocalized story as input, 24% (18 out of 74) failed to recall at least one element; among the participants receiving a story that was missing the area bled, the indication, or both, 36% (8 out of 22) failed to recall at least one element, even though they had fewer elements to recall (Fisher exact test, $P = .28$). This suggests that the attractiveness of colocalization can, to some extent, prevent memory loss.

These results match the anthropological data which suggest that bloodletting is generally practiced by specialized third parties, that it is often practiced in a colocalized manner, and that a wide variety of tools are used: the only element that was quickly forgotten by the participants—the tool—is the only one that shows no consistent cultural pattern worldwide.

2.2. Study 1: familiarity control study

The participants' potentially greater familiarity with bloodletting compared to the other therapies could affect the relative robustness of the different practices. The goal of the present study was to assess the familiarity of the participants with the different therapies used in study 1.

2.2.1. Methods

2.2.1.1. Participants. 80 participants were recruited on Amazon Mechanical Turk (50 women, $M_{Age} = 29.2$, $SD = 7.9$).

2.2.1.2. Design. We used a between participants design: each participant only answered the questions related to one of the seeds.

2.2.1.3. Procedure. Participants read one of the seeds from study 1 and then answered the three following questions in a randomized order:

Surprised by therapy: How surprised were you when you read about the mode of therapy [description of one of the three therapies] practiced by the medicine man? (1 to 7 scale, anchored with "not surprised at all" and "extremely surprised".)
Surprised by efficiency: How surprised were you when you read that after the therapy [description of one of the three therapies] Yanobala's headache was relieved? (1 to 7 scale, anchored with "not surprised at all" and "extremely surprised".)
Familiarity with therapy: Were you familiar with this mode of therapy [description of one of the three therapies] before? That doesn't mean that you have practiced it yourself or seen people practice it, but that you had maybe heard of it in stories for instance (1 to 7 scale, anchored with "not familiar at all" and "very familiar".)

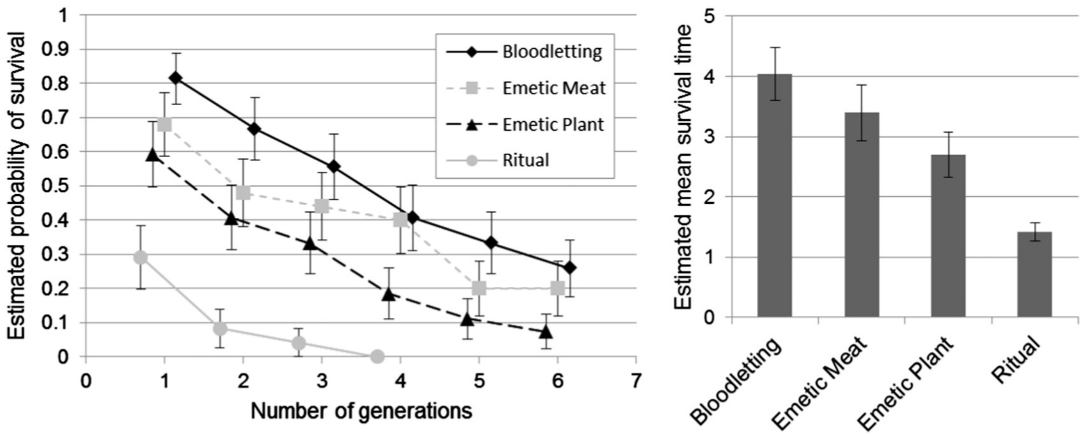

Fig. 3. Estimated survival curves for the bloodletting, emetic meat, emetic plant and ritual conditions of Study 1. We used the survival analysis described in the text to estimate the stories' probability of survival at every generation (left) and their average survival time (right). Error bars represent standard errors.

2.2.1.4. Analysis. We used multivariate regression (MANOVA function of the car package in R, Fox & Weisberg, 2010) to examine the effect of age, gender, education, and condition on the responses to the three questions.

2.2.2. Results

The median answers were as follows: surprised by therapy question: bloodletting 2; emetic plant 5; ritual 2; emetic meat 5. Surprised by efficiency question: bloodletting 5; emetic plant 5; ritual 4; emetic meat 5.5. Familiarity with therapy question: bloodletting 3; emetic plant 2; ritual 4.5; emetic meat 1. Only condition had a significant effect on the three responses (Pillai test, $F = 2.60$, $df = 9$, $P = .007$), whereas age, gender and education had no significant effect (all Ps > .05). Further analyses revealed that the emetic meat condition differed significantly from the bloodletting condition regarding surprised by therapy ($t(1) = 2.33$, $P = 0.022$) and familiarity with therapy ($t(1) = -2.80$, $P = 0.006$) but not surprised by efficiency ($t(1) = 0.77$, $P = 0.44$). The bloodletting condition did not differ from the emetic plant or the ritual condition on any of the three questions (all Ps > .05). Moreover, the medians for bloodletting were bracketed by those for emetic plant and ritual on each of the three questions suggesting that the bloodletting condition does not particularly stand out when compared to these two conditions. By contrast, the responses to the emetic meat condition were the most extreme on two questions.

These results suggest that the emetic plant, ritual, and bloodletting conditions are relatively closely matched in terms of familiarity, while the emetic meat condition is seen as more surprising. This fits with our reading of the anthropological literature, which suggests that tainted meat is not a commonly used emetic (we were unable to locate one such example in eHRAF with searches for "emetic," "vomiting," or "vomit" in conjunction with "meat"). By contrast, the use of plants as emetics, and of rituals as therapies, is much more common. As a result, it can be argued that the emetic plant and ritual conditions offer better controls for the robustness of bloodletting as a common form of therapy, while the emetic meat condition tests more specifically the role of disgust.

2.3. Study 2: Colocalization as an attractor

Study 1 suggested that the colocalized variant of bloodletting was a stronger attractor than the non-colocalized variant. The aim of study 2 was to test the hypothesis that a non-colocalized variant could spontaneously be transformed into a colocalized variant.

2.3.1. Methods

2.3.1.1. Participants. 59 participants were recruited on Amazon Mechanical Turk (25 women, $M_{Age} = 33.4$, $SD = 11.1$). There were 26 participants in the first generation.

2.3.1.2. Procedure. The procedure was identical to that of study 1 except that only one seed was used. The seed was identical to the bloodletting seed of study 1 but for the fact that the cut was practiced at the foot; the indication was still a headache (see Table 1). The chains were interrupted when a participant failed to recall the therapeutic event, transformed the indication or the area bled to create a colocalized variant, or at the third generation.

2.3.1.3. Coding. All the stories were coded for the presence of the following elements: therapeutic event (bloodletting); indication; area bled. In addition the cases in which the indication or the area bled were present in the output story but differed from the equivalent element in the input story were specifically recorded (these cases are reported below). A second coder, blind to the hypotheses, recoded 10% of the stories, and we found a Cohen's Kappa of one on 30 items.

2.3.2. Results

Out of the 59 transmission events, a non-colocalized variant was transformed into a colocalized variant twice: the colocalization emerged spontaneously as one participant wrote a story in which the pain was in the toe (while the cut remained at the foot), and one in which the protagonist was cut at the head (while the indication remained a headache). By contrast, the colocalized variant was never transformed into a variant that would specify both localization and indication but would not be colocalized; this was also true for study 1. Although there were only a small number of transformation events, this suggests that colocalized variants could be stronger attractors than non-colocalized variants.

2.4. Study 3: the emergence of bloodletting

One possible route for the emergence of bloodletting would be to start with an individual who witnesses someone else cutting herself accidentally and then recovering. This individual could tell this story to someone else, and the story could then be further repeated. In the process of transmission, the story might change so that it gets closer to the core representation of bloodletting; in particular, the cut might become intentional, and the recovery causally linked to the cut. In the end, a story fitting the core representation of bloodletting would spontaneously emerge from a relatively banal event: someone who is sick suffers an accidental cut and, later, recovers (see, Tanaka et al., 2009).

2.4.1. Methods

2.4.1.1. Participants. 190 participants were recruited on Amazon Mechanical Turk (89 women, $M_{Age} = 35.8$, $SD = 12.4$). In the first

Seed: …Yanobala takes his head in his hands and he accidentally cuts his temple with a sharp stone tool he's holding and some blood flows. The day after, Yanobala feels better and he goes looking for the special bird. … [See Methods for the complete seed]

Gen. 3: A tribesman wants to marry the chief's daughter, but needs to hunt a rare bird for fancy plumage before he can do so. He doesn't hunt because he has a headache. Later he cuts his head, the headache is gone. He hunts and gets permission to marry the daughter.

Gen. 5: A guy in the tribe has to catch a rare bird if he wants to marry the chief's daughter. But he has a headache and can't concentrate, so he can't catch the bird. Then he decides to cut himself and somehow that makes the headache go away. Hooray! He catches the bird and gets to marry his sweetie-pie!

Fig. 4. Partial chain from study 3.

generation there were 24 participants in the accidental condition and 24 in the intentional condition.

2.4.1.2. Procedure. The procedure was identical to that of study 1 except that only two seeds were used. In the first seed (accidental condition), the cut is accidental and not explicitly causally linked to the recovery (see Table 1). However, the series of transmission events leading to the core representation of bloodletting is likely to be relatively rare, and the experimental context makes it possible that most stories will fail to be recalled before the steps are completed. Consequently, we also used a second, intermediate seed in which the cut was intentional but not explicitly causally linked to the recovery (intentional seed). The chains were interrupted when participants failed to recall the therapeutic event or when they reached the sixth generation.

2.4.1.3. Coding. All the stories were coded for the presence of the following elements: bleeding event (defined as any mention of bleeding or cut); indication; area bled; accidental event (if the bleeding event is explicitly mentioned as being accidental); intentional event (if the bleeding event is explicitly mentioned as being intentional); causal link with recovery (if the bleeding event explicitly causes the recovery). A second coder, blind to the hypotheses, recoded 10% of the stories, and we found a Cohen's kappa of 0.97 on 80 cases.

2.4.2. Results

First, we look at the robustness to repeated transmission of the accidental and intentional variants. In the accidental condition, the average chain lengths was 2.5 generations (SE = 0.45); in the intentional condition, it was 4.1 generations (SE = 0.47; $\chi^2_{(1)} = 5$, $P = 0.025$). Starting with the accidental seed, the explicit mention that the cut was accidental survived on average for 0.8 generations (SE = 0.26); starting with the intentional seed, the explicit mention that the cut was intentional survived on average for 2.5 generations (SE = 0.40; $\chi^2_{(1)} = 10.4$, $P = 0.001$).

The intentional element was also introduced in five out of the 32 chains in which it was absent at least at one point, while the accidental element was not introduced in any of the 34 chains in which it was absent at least at one point (Fisher exact test, $P = .022$). The causal link with recovery was introduced in 15 out of the 48 chains (from which it was always initially absent).

The strong relation between intentionality of the action and causal efficacy is demonstrated by the increased likelihood of the introduction of the causal link with recovery in the intentional condition (11 introductions out of 24 chains) by comparison with the accidental condition (four introductions out of 24 chains) (Fisher exact test, $P = .059$). Moreover, in the accidental condition, two of the four introductions of a causal link with recovery were related to the introduction of an intentional event: in one case, the introduction of a causal link with recovery followed the introduction of an intentional event at the previous generation; in the other case, it was followed by the introduction of an intentional event at the next generation.

We observed twice the hypothesized transformation from stories in which the cut is accidental and not causally related to the recovery to stories in which it is intentional and causally related to the recovery—that is, standard versions of bloodletting (see Fig. 4 for an example). As in the previous study, the relevant transformations, although more likely to happen in the predicted direction than otherwise, were also relatively few in numbers.

3. Modeling

Experiments have constraints on the number of participants as well as the number of generations. As a result, some of the effects observed might seem too weak to have a significant effect on cultural evolution. However, even very small tendencies can be magnified over multiple transmission episodes and have large effects on cultural evolution (e.g. Kalish, Griffiths, & Lewandowsky, 2007). Modeling bypasses experimental limitations and provides a more accurate representation of the consequences of even weak biases on cultural evolution (Boyd & Richerson, 1985; Kalish et al., 2007; Kirby, Dowman, & Griffiths, 2007; Richerson & Boyd, 2005). We used evolutionary causal matrices to represent the transformations occurring during transmission and simulate the long term effects of these transformations (Claidière, Scott-Phillips, & Sperber, 2014). Other modeling tools could shed further light on the phenomena described here.

In the present experiments, knowing the story at a particular generation (e.g. G_4) is enough to predict the state of that story at any future generation (e.g. G_6) since the participants, and therefore the transformations that affect the stories, are independent. This process is 'memoryless' as the history of previous generations (G_{1-3}) does not affect the future (G_6) when one knows the present (G_4) and is similar to a Markov process (a discrete time Markov chain), while including the possibility of the termination of the chain (no recall). The process is characterized by a state space (the different forms the stories can take), a matrix describing the probabilities of transitions between states, and an initial state. We used multinomial logistic regression (R package nnet, Venables & Ripley, 2002) to estimate transition probabilities and their associated standard errors. Once the process is characterized, the evolution of the system under different conditions can be simulated straightforwardly with the estimated values.

In interpreting the results of the simulations detailed below, it is important to note that in the laboratory transmission chains inevitably lead to the loss of information (see, e.g., Bartlett, 1932). This loss can be explained by the fact that the participants are only exposed to the story once, and have only one chance to retell the story. In real life stories and practices can be stabilized in memory through repeated encounters and repeated productions. The simulations therefore assume that the total number of stories per generations remains constant—i.e. that there is no loss of information. They illustrate the evolutionary consequences of the transformations that happen between different story types.

3.1. Simulation 1: colocalisation

For this simulation, the data of studies 1 and 2 were used. Each story told by participants and indicating both an indication and an area bled was categorized as either colocalized (if indication and area bled matched) or non-colocalized (if they did not match). For each type of story, we used multinomial logistic regression to estimate the transition probabilities between the different states the story could take (colocalized, non-colocalized, no recall). Using these estimates we simulated the evolution of the proportion of the different story types. A simulation starting only with non-colocalized stories revealed that after 12 generations, bloodletting is colocalized in a majority of the stories, and that the colocalized stories completely dominate at equilibrium (see ESM, available on the journal's Website at www.ehbonline.org). This suggests that a colocalized variant of bloodletting is a stronger attractor than a non-colocalized one for the population studied. This is all the more remarkable since the most common depiction of bloodletting the participants would likely have been familiar with is non-colocalized: a cut at the arm irrespective of the indication is what was practiced in early modern Europe and North America.

3.2. Simulation 2: intentional vs. accidental bleeding

For this simulation, the data of study 3 were used; more specifically, the coding of each story as involving an explicitly intentional or explicitly accidental cut. On the basis of the transition matrix between the types of stories, it was possible to simulate what would happen if all the initial stories were accidental. After 6 generations the intentional variant becomes dominant (see ESM, available on the journal's Website at www.ehbonline.org), and at equilibrium it dominates the population, showing that the intentional version is a strong attractor.

4. Conclusion

Three explanations were put forward for the cultural success of bloodletting: medical efficiency, prestige and conformity bias, and attraction based on universal cognitive mechanisms. Regarding medical efficiency, the present data offer no support. Contrary to what one might expect if bloodletting was efficient to treat specific indications, we found it to be applied to a wide variety of indications. Moreover, there was no sign that bloodletting was most often practiced on the population that would benefit the most from iron deficiency—namely, young men (see Denic & Agarwal, 2007).

Regarding the prestige and conformity bias, the findings are mixed. On the one hand, bloodletting seems to be often practiced by a third party with special status. Moreover, it is entirely possible that bloodletting is typically a majority practice in the cultures that practice it. Thus both the prestige bias and the conformity bias can help explain the cultural success of bloodletting. On the other hand, we found bloodletting to be practiced in many unrelated cultures worldwide. This shows that the prestige of specific physicians such as Galen is not necessary for the practice to be culturally successful: bloodletting is not a mere personal fancy that happened to be the fancy of very prestigious sources. Another explanation is necessary to account for why bloodletting proved so successful, as opposed to any other form of therapy that could also be supported by the prestige and conformity bias.

Our findings provide strong support for the explanation in terms of universal cognitive mechanisms. The anthropological data show that bloodletting is practiced in many cultures which likely discovered it independently. They also suggest recurrent patterns in the way bloodletting is practiced: by a third party, at the diseased or painful area, in the hope of removing 'bad blood.' The experimental data show that even in a population that does not practice bloodletting, bloodletting is robust to repeated transmission compared to other common forms of therapy. Moreover, we observe a convergence between the most attractive variants observed experimentally and on the basis of the models, and the most common variants worldwide.

Contrary to other recurrent and robust cultural representations bloodletting cannot be easily accounted for by a well-known psychological mechanism. Self-injury is not an obvious mean to cure illness. Even though disgust likely plays a role in the attractiveness of bloodletting—as suggested by study 1—this role is not immediately clear. On its own, the psychology of disgust can maybe explain why stories about bloodletting are popular, or the prevalence of the idea of 'bad blood.' But disgust should also drive people to avoid this 'bad blood,' which means that they should avoid cutting themselves or others—a commonsensical prediction that makes bloodletting only more puzzling. However, in conjunction with another factor, the psychology of disgust might play a crucial role in making bloodletting a relatively intuitive form of therapy.

Animals recover from most of their illnesses, and most pains disappear rapidly. But contrary to other animals humans often look for explanations for significant events such as recovering from a disease or the cessation of pain. Events occurring between the onset of an illness and recovery can be interpreted as explanations for the recovery (see Tanaka et al., 2009). Some events trigger cognitive mechanisms that make them more intuitively plausible explanations. For instance, it has been argued that humans have, as part of an evolved moral sense, expectations of fair punishment and reward, and this might create a link between a benevolent gesture (giving money to charity) and recovery (a seemingly deserved reward) (Baumard & Chevallier, 2012). Moreover, folk psychology, which has a bias to treat behaviors as being intentional, could ease the transition from an accidental event to an intentional behavior (e.g., Rosset, 2008).

In the case of bloodletting, disgust and naïve biology could link blood loss with recovery. If an individual cuts herself accidentally between the onset of the illness and the recovery, disgust mechanisms might make her think that something like 'bad blood' came out.[1] Naïve biology, which includes the intuition that good and bad things going in and out of the body strongly affect health (Carey, 1985; Inagaki & Hatano, 2004; Keil, Levin, Richman, & Gutheil, 1999), would make the link between the bad thing that came out and recovery: if something bad came out, it makes intuitive sense that recovery should have been eased. If this explanation for recovery is accepted, one can be proactive the next time an illness occurs, and deliberately cut oneself or someone else in order to let the bad blood out in order to recover.

The intuition that letting bad blood out can make one feel better is evidenced even in cultures that do not practice bloodletting. For instance, clinicians have noted that patients who practice non-suicidal self injuries (NSSI) sometimes have the idea of "releasing 'bad blood'" (Favazza, 1996, p. 273). One patient explained why he cut himself in these words: "I cut secondarily for the pain, primarily for the blood… Watching the blood pour out makes me feel clean, purified" (Strong, 1999, p. 11) (see also Glenn & Klonsky, 2010).

The anthropological data are consistent with this hypothesis in that the most common explanation offered for the practice of bloodletting is that something bad—often referred to as 'bad blood'—is made to come out of the body. The anthropological data also suggest a factor that could make bloodletting especially appealing for some illnesses. Compared with other means to make 'bad things' come out of the

[1] An important caveat is that the evidence linking blood to disgust stems from contemporary western populations. One of the reviewers pointed out anecdotal evidence suggesting that traditional populations do not display the same reaction. Although we located some evidence that the link between blood and disgust is also present in non-western populations (India and possibly Burkina Faso, Curtis & Biran, 2001), we found no systematic study in traditional populations. Thus, although there is a seemingly sound evolutionary rationale for disgust towards blood (disease avoidance, see Curtis, Aunger, & Rabie, 2004; Rozin & Fallon, 1987), it is possible that this link is a peculiarity of contemporary, post medical-revolution populations. It should also be mentioned that most evidence linking blood to disgust bears on the blood of another individual. Thus, although we present the scenario here in the first person, it is at least as plausible from a third-party perspective (i.e. witnessing someone recovering after she cut herself, accidentally or intentionally).

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body—such as emetics and laxatives, two traditional remedies that are also very common (Coury, 1967)—bloodletting can be practiced close to where a pain is being felt. The fact that the loss of blood can be spatially contiguous to the disease area might trigger mechanisms of folk physics (e.g. Sperber, Premack, & Premack, 1995) and strengthen the intuitive causal link between bleeding and recovery. This fits with the prevalence of colocalization between pain and area bled in the anthropological literature.

Besides specific cognitive mechanisms such as disgust and naïve biology, more general mechanisms likely play a role in making different variants of bloodletting more or less attractive. For instance, the attractiveness of colocalization could partly be explained by general memory mechanisms that make it easier for people to remember the area bled if it matches the indication.

While the explanation was laid out here at the individual level, the different steps leading from an accidental cut to bloodletting can also be taken by separate individuals. Study 3 showed that biases in the process of transmission could follow the same steps as those hypothetically followed by a single individual.

In any case, we do not claim that the present data offer strong support for the involvement of the specific cognitive mechanisms highlighted above—disgust, need for explanation, naïve biology. Rather, this explanation appears to be consistent with the existing data, and it is offered as a hypothesis in need of further evaluation. In particular, experiments that involve direct experience with the act of bloodletting might reveal a different role for disgust mechanisms.

Bloodletting is a puzzling practice: in spite of likely being maladaptive, it has been a culturally successful practice in many cultures worldwide. It offers a good example of how cognitive mechanisms can render attractive and enable the spread of a maladaptive practice. The current research offers a plausible explanation for this puzzling practice. It also highlights the benefits of integrating different methodologies: this combination of anthropological data, experimental data, and modeling, brought together in the framework of cultural attraction, could yield valuable insight into many other cultural phenomena.

Supplementary materials

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.evolhumbehav.2015.01.003.

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