Cite this chapter: Lang, M., & Chvaja, R. 2023. Examining the possible adaptive value of ritualized behavior. In: Yair, L., & Lane, J. *The Routedge Handbook of Evolutionary Approaches to Religion*. Routledge: London and New York, pp. 164-184.

Examining the Possible Adaptive Value of Ritualized Behavior

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Introduction

The near-omnipresence of religious systems across the globe and throughout human history has led researchers to hypothesize that religious systems fulfill important adaptive functions in their specific niches (Lang & Kundt, 2020; Sosis, 2017, 2019).[1] Two functions have been of particular interest: promoting group coordination and cooperation and promoting positive effects on individual health and survival, while a third major function of religious systems, the promotion of reproduction, gradually gains attention (see Van Slyke, ch. 7 this volume; Shaver et al., 2020). Alongside beliefs in various superhuman agents and other components of religious systems, a major role in facilitating these functions appears to be played by ritual behavior, both in its individual and group forms (Purzycki & Arakchaa, 2013; Sosis, 2004; Xygalatas et al., 2019, 2013). In this chapter, we examine whether ritual behavior, in interaction with other evolved cognitive-behavioral systems, positively affects one of the three main outputs of religious systems—the promotion of individual health and survival—and speculate about ritual's tentative adaptive value.

The initial inspection of the relationship between rituals and health yields suggestive results: several population-level correlational studies show that ritual behavior consistently affects both psychological and physiological health-related variables (Chatters et al., 2008; Powell, Shahabi, & Thoresen, 2003) and lowers the mortality risk (Koenig et al., 1999; Li, Stampfer, Williams, & VanderWeele, 2016; Lutgendorf, Russell, Ullrich, Harris, & Wallace, 2004; McCullough, Hoyt, Larson, Koenig, & Thoresen, 2000). However, such correlational studies are often oblivious to the specific factors mediating the health improvements as well as toward the ritual mechanisms affecting the mediating factors; and while hinting at possible adaptive functions, the studies do not provide proper evolutionary analyses of selective pressures on health management. To remedy this theoretical gap, we examine whether ritual behavior promotes individual health and survival by facilitating anxiety management. We chose anxiety management as a mediating factor between rituals and individual health because anxiety significantly affects psychophysiological health and survival (see below), and there is substantial empirical research on the relationship between ritual behavior and anxiety management.[2] We first review studies documenting potential adverse effects of anxiety

on health and survival, then discuss mechanisms whereby rituals may affect anxiety management, and, finally, analyze whether the purported effects of rituals on anxiety management may be adaptive in a Darwinian sense, that is, maximizing biological fitness. To this end, we evaluate whether specific socio-ecological niches exert selective pressures for better anxiety management, which may positively impact psychophysiological health and, ultimately, reproductive success. Finally, we close the chapter with conjectures about the evolutionary pathways of ritual behavior.

Defining Anxiety

In order to submit anxiety to evolutionary analysis, we first need to establish anxiety as a trait with identifiable properties. Notwithstanding the popular use of the term, scientific definitions of anxiety are quite variable, often depending on a specific discipline and/or metric employed to study anxiety. Aiming to overcome these disparities, we introduce a general conceptualization of anxiety based on the assumption that it is a phylogenetically old trait with basic properties tractable across the mammalian phylogeny (Blanchard, 2017; Brosschot, Verkuil, & Thayer, 2015).[3] Here, we review the basic properties shared among humans and non-human mammals.

According to the *Dictionary of Psychology* published by the American Psychological Association, anxiety is "an emotion characterized by apprehension and somatic symptoms of tension in which an individual anticipates impending danger, catastrophe, or misfortune … Anxiety is considered a future-oriented, long-acting response broadly focused on a diffuse threat ..." (VandenBos, 2015, p. 66). This definition highlights several important characteristics of anxiety that help to distinguish anxiety from related concepts such as fear or stress. The main distinctive feature of anxiety is its projection onto possible future threats. Whereas fear and stress are often activated with imminent manifest threats, anxiety may be activated even in safe environments by prospective hazards (Craske & Stein, 2016). The set of prospective threats that elicit anxiety is likely evolutionary old, including threats such as predation, resource scarcity, reproductive risks, or social harm (Boyer & Liénard, 2006). In mammals, anxiety from prospective hazards might be elicited by ambivalent sensory inputs that, for instance, indicate a possible presence of a predator or stimulated internally without a triggering sensory input (this will be mostly specific to humans; Bulley, Henry, & Suddendorf, 2017).

Essential aspects of prospective threats are their unpredictability and uncertainty (Grupe & Nitschke, 2013). Regarding the former, the probability of the threat occurring is often unclear. In this sense, anxiety can be understood as a risk assessment strategy (Blanchard, Griebel, Pobbe, & Blanchard, 2011; Maximino, de Brito, & Gouveia, 2010), weighing the possibilities of whether the prospective threat will occur or not. Supporting this characterization of anxiety, laboratory experiments often use an "NPU" paradigm (neutral, predictable, and unpredictable stimuli), expecting that only unpredictable stimuli will elicit anxiety. For instance, Herry and colleagues (2007) subjected both rats and human subjects to the NPU paradigm and found that in comparison to neutral and predictable sound stimuli, the unpredictable stimulus elicited more anxiety-like behavior in both species. Compared to unpredictability, uncertainty can relate to more parameters of the threatening stimulus than just the probability of its occurrence. For instance, while a person might be rather sure that a threat exists, they may not be certain about its form, onset, geographical distance, or proper management (Carleton, 2016). Importantly, the role of unpredictability and uncertainty of future hazards in generating anxiety is supported by both rodent and human studies where anxiolytic drugs alter responsiveness specifically to

uncertain threats but do not affect defensive behaviors during threat manifestation (Blanchard, Griebel, & Blanchard, 2003; Perkins et al., 2009).

Apart from predatory threats, similar effects of unpredictability and uncertainty of prospective hazards were observed in other anxiogenic contexts such as the context of social harm. Primate models of social anxiety show that anxiety is often elicited by the instability of social hierarchy and the uncertain position that an individual has within that hierarchy rather than by threats from dominant individuals or social rejection (Brosnan, Tone, & Williams, 2017). Furthermore, in a study with human subjects (Knight & Mehta, 2017), high-status participants had lower cortisol levels, reported lower anxiety, and performed better during a stress-inducing cognitive task compared to low-status participants. However, this result was found only in a stable-hierarchy condition. In an unstable-hierarchy condition where performance in the cognitive task impacted status change, high-status participants felt more anxious, had higher cortisol levels, and performed worse in the task compared to low-status participants.

In summary, anxiety can be viewed as an affective state that stems from the unpredictability and uncertainty of future prospective hazards. These hazards are usually limited to salient threats to fitness shared among mammals, and anxiety appears to be a generally shared response to such threats. In the next section, we investigate whether anxiety is adaptive, and under which conditions it may malfunction.

The Adaptive Value of Anxiety

To ask about the adaptive value of anxiety, we need to isolate anxiety as a subsystem of the human cognitive architecture that is sustained by specific neural and neurohormonal structures and is (at least partially) genetically inherited. Since anxiety has received much attention in the past 50 years, there are multiple models of the anxiety subsystem. Here, we will draw a general conclusion from three models that are most relevant: the Security Motivation System proposed by Szechtman and Woody (2004), the Hazard-Precaution System proposed by Boyer and Liénard (2006), and the Uncertainty and Anticipation Model of Anxiety proposed by Grupe and Nitschke (2013). Generally, these models present the anxiety subsystem as a feedback loop mechanism that comprises distinct processing steps. First, the subsystem is triggered by an external or internal stimulus related to a potential threat from a confined set of fitness-related threats. The probability of the threat's occurrence is estimated, and vigilance behaviors are employed to sharpen the estimation. If the probability of occurrence is high, a physiological stress response is activated (sweating, transporting blood to muscles) to motivate and facilitate specific precautionary or avoidant behavioral patterns. The stress response is active until the probability of threat occurrence is diminished and the individual feels safe again, ceasing the subsystem's activity.

The neural structures that carry individual processes of this anxiety subsystem are also well described in the literature. For example, the Security Motivation System (Woody & Szechtman, 2013) was identified as being carried by a specific cascade of cortico-striato-pallido-thalamo-cortical connections with the ability to regulate the physiological stress response, which is promoted by the hypothalamic-pituitary-adrenocortical axis, by a direct pathway to the brainstem (c.f., Boyer & Liénard, 2006; Grupe & Nitschke, 2013). Further support for the specific neural underpinnings of the anxiety subsystem is provided by various anxiety disorders in which the individual feedback loops between the neural parts of the anxiety subsystem are dysfunctional. For instance, in the obsessive-compulsive disorder, the specific malfunction of the feedback loop that is responsible for signaling safety and ceasing the precautionary

activity causes the patients to repetitively and obsessively engage in such behaviors even after the prospective threat is no longer probable (Boyer & Liénard, 2008; Eilam, Zor, Fineberg, & Hermesh, 2012; Woody & Szechtman, 2013).

The sensitivity and response magnitude of the anxiety subsystem also differ across individuals and populations (Baxter, Scott, Vos, & Whiteford, 2013). While the immediate anxiety response reflects a particular state of the system (that we call *state anxiety*), the proneness of the anxiety subsystem for activation is commonly conceptualized as trait anxiety (Spielberger, Gorsuch, & Lushene, 1970). *Trait anxiety* is an individual predisposition to react to potential threats and affects both the frequency of anxious responses and the magnitude of the responses. Importantly, trait anxiety (compared to state anxiety) has a substantial genetic component whereby around 31 percent of the variation in trait anxiety is estimated to be moderated by genetic effects (Lau, Eley, & Stevenson, 2006). This genetic component is further moderated by individual early experiences during ontogeny, as predicted by Tinbergen's levels of evolutionary analysis (Tinbergen, 1963); specifically, early experiences of uncontrollability promote exaggerated anxiety responses to prospective threats in adulthood (Barlow, 2000).

Showing that there is an identifiable anxiety subsystem with underlying neural structures, inter-individual variation, and a genetic component, we can now ask about the adaptive value of such a subsystem.[4] As should be apparent by now, the prime function of the anxiety subsystem is protection from hazards of injury, pathogen contamination, and death. By increasing vigilance and triggering precautionary and avoidant behavioral patterns, anxiety serves to limit the potential danger to a minimum. However, while such protection appears extremely useful at first sight, it is necessary to also analyze the costs that potential over-protection carries. As with other evolved traits, there are significant trade-offs that individuals face. For instance, organisms usually face a trade-off between feeding and vigilance—if they would only feed without scanning the environment for predators, they would be easy prey; if they would only scan the environment, they would become malnourished (Maximino et al., 2010). Thus, each individual faces a trade-off of how much time to dedicate to feeding and how much time to dedicate to vigilance (motivated by the anxiety subsystem).[5] Translating this example specifically to the human context, a hunter might benefit from exploring new territories that are potentially full of game but also dangerous predators. If the anxiety subsystem motivates the hunter to move only within their usual predictable environment, they would potentially miss a significant caloric opportunity; but a low-functioning anxiety subsystem might lead to fatal risks, despite the short-term caloric advantage.

Since there are significant trade-offs between safety and lower gains on the one hand and vulnerability to threats and higher gains on the other hand, everyone faces a fundamental dilemma whether and how much to react to a potential threat. This dilemma is well described by the signal detection theory and specifically by the smoke detector example provided by Randolph Nesse (2001). Ideally, the smoke detector should only signal actual fire hazards and not react to a slightly burned pie in the kitchen, but such precision is very rare. Instead smoke detectors work on the principle "better safe than sorry," whereby the system emphasizes signal's sensitivity over specificity. Translated to the context of anxiety, it is better for the individual to feel excessive anxiety from non-existent threats rather than fail to detect a predator even once, which can have lethal consequences.[6]

Two important insights can be derived from the smoke detector principle: first, there should be a mix of strategies tackling the anxiety trade-off in the population expressed as varying sensitivity thresholds (risky vs. risk-averse strategies—in accordance with inter-individual variation in trait anxiety); second, the benefits that such strategies confer should be estimated based on hazard unpredictability and uncertainty regarding the magnitude of the hazard. These insights

are formalized in the mathematical model of threshold optimization provided by Bateson, Brilot, and Nettle (2011) where the optimal threshold for activating the anxiety subsystem is based on the threat probability ratio (the probability of no threat divided by the probability of threat) multiplied by individual vulnerability (the cost of false alarm divided by the cost of missed alarms). The higher the threat probability ratio and individual vulnerability (e.g., death from predation), the more sensitive the anxiety subsystem should be. However, if the environment is relatively safe with low threat probability and/or the cost of potential miss is not too high (e.g., mild injury), then the anxiety subsystem should be only rarely activated (think of a walk through an uncharted Amazon jungle vs. a nearby forest).

For the anxiety subsystem to be adaptive, we should expect that the subsystem's triggering threshold would be optimized to maximize fitness. The exact fitness maximizing threshold will depend on A) an individual's trait anxiety, which results from the interaction between the genetic and ontogenetic components; B) current health and energy resources; and C) threat unpredictability and uncertainty. However, while realistic, this optimization model presents a challenge when fitted to the available data on mortality and reproductive success that could speak to the adaptive value of the anxiety subsystem in the human population. The problem lies in the insufficient individual-level indicators of threat unpredictability and uncertainty that could adjust the models for factors such as the threat probability for each subject (illness, homicide, social-hierarchy threats) and the cost of not detecting these threats. Thus, for simplicity, we will assume that the mean anxiety level in a population is calibrated to the environment and average individual vulnerability (constant threat probability and the cost of missed threat detection). With the implementation of this simplification, we can now predict that scoring further away from the average population-level of anxiety should be associated with decreasing fitness, and both the extreme ends of the anxiety continuum (too sensitive and insensitive thresholds) should be maladaptive in terms of increased mortality and reduced reproductive success.[7]

Focusing on the association between anxiety, individual health, and mortality risk, two longitudinal studies provide supportive evidence. First, a study of 4,000 individuals from the 1946 UK birth cohort (Lee, Wadsworth, & Hotopf, 2006) used teachers' assessment of participants' anxiety in school when they were 13–15 years old to predict accidental and non-accidental mortality in later ages. The results showed that compared to the "somewhat anxious" subjects, the "low anxious" subjects (as rated by teachers) had higher accidental mor- tality and a higher number of self-reported non-fatal accidents between their 16th and 25th birthdays. After the 25th birthday, the hazard ratio of accidental deaths equalized between the two groups. However, during their thirties, the "somewhat anxious" subjects started to have higher hazard ratios of non-accidental deaths, a trend that was most prominent at their 50th birthday. Second, Mykletun and colleagues (2009) analyzed mortality in approximately 60,000 Norwegian participants during the four years that followed initial anxiety assessment via the Hospital Anxiety and Depression Scale. The results showed a U-shaped association between anxiety and mortality, with the extreme ends (low and high anxiety) having substantially higher mortality rates. Together, these studies show that anxiety is adaptive in the middle range of the spectrum: whereas low anxiety is associated with increased mortality from accidents during maturation, high anxiety, while initially protective, may take its toll later in life through various chronic diseases.

The evidence for the association between anxiety and reproductive success is less straightforward. First, indirect evidence is provided by data from infertility clinics that assess anxiety. Prospective parents at these clinics have higher anxiety rates compared to the general population (Zorn, Auger, Velikonja, Kolbezen, & Meden-Vrtovec, 2008), and chronic anxiety is

correlated with psychological causes of infertility (Fassino, Piero, Boggio, Piccioni, & Garzaro, 2002). Moreover, state anxiety in infertile males is negatively correlated with sperm number and quality (Clarke, 1999), suggesting that high anxiety may negatively impact reproduction. However, these correlational studies often do not allow to disentangle the complex causal chain of infertility (infertility diagnosis likely increases anxiety). A more direct study of reproduction success was reported by Jacobson and Roche (2018) who analyzed the association between the Hopkins Symptom Checklist anxiety scale and the number of children in a three-generational sample of approximately 2,700 US participants. Unexpectedly, they found a reversed U-relationship between anxiety and reproduction that predicted higher fertility for the extreme ends of the anxiety scale. While we are suspicious about this result,[8] it can be partially explained by different life-history strategies: as the authors suggest and other works have shown (Jacobson, 2016), highly anxious people chose earlier reproduction due to the perceived unpredictability of their environment.

Apart from studying the effects of natural variation in trait anxiety, further supportive evidence for the adaptiveness of the middle range of the anxiety spectrum is offered by examining the prevalence of anxiety disorders. Patients with anxiety disorders represent the upper quartile of the anxiety spectrum because they suffer from overactive processes within the anxiety subsystem (Baxter et al., 2013; Wittchen, 2002); therefore, we should expect that such overactivation of the anxiety subsystem would be maladaptive. Indeed, due to hyperactive anxiety, the prospective hazard is rarely confronted by people with anxiety disorders and, thus, the safety signal cannot be generated, leading to chronic activation of the anxiety subsystem (Meacham & Bergstrom, 2016). Such hyperactive processes and chronic activation impede the quality of life and can be severely debilitating for patients with anxiety disorders (Olatunji, Cisler, & Tolin, 2007), including an increased risk of suicide (Khan, Leventhal, Khan, & Brown, 2002).

In summary, we can conclude that a hypersensitive (setting the anxiety threshold too low) and hyperactive (excessive magnitude of the response) anxiety subsystem negatively affects several proxies of biological fitness, making the hyperfunctioning anxiety subsystem maladaptive. On the other hand, the chronically low levels of activation also increase mortality risk due to an increased accident likelihood, although we do not know much about the well-being of people with such low anxiety because they usually do not seek clinical help. Both results nonetheless suggest the existence of an optimal threshold for activating the anxiety subsystem rather than supporting the hypothesis that increasing anxiety levels positively affect fitness. However, while promising, this evidence is very preliminary, and much work needs to be done to systematize the available data.[9]

Ritual Effects on Anxiety

To stimulate precautionary activity, anxiety is experienced as a negative affect that, through a stress response, motivates people to act (resolve potential threats) to terminate such unpleasant feelings. However, the negative-affect motivation is potentially hazardous (leading to psychosomatic disorders in chronic stress responses) given that many prospective threats are either imagined or beyond individual control, thus lacking any specific action to resolve the prospective hazard. While taking precautionary measures when a predator's scent is detected may be adaptive, constantly worrying about possible adverse situations such as natural disasters or a family member dying in a car crash may have long-term negative health impacts. Of course, one can take some precautionary measures in both scenarios (e.g., fortifying a house/building a shelter; reminding others to drive safely), but these measures do not directly influence the

looming threat. To cease the workings of the anxiety subsystem in such situations, people often engage in substitute actions that should provide the feeling of safety and/or control over the prospective threat. As recognized by Bronislaw Malinowski (1948), it is exactly in such situations that we encounter magico-religious rituals.

Malinowski observed that in anxiogenic situations which lack a clear action to avoid the potential threat (a family member driving on a dangerous road), anxiety still motivates people to engage in precautious action. Thus, people often perform surrogate activities that should instill a sense of control over the threat and terminate the unpleasant anxiety. According to Malinowski, rituals are such a surrogate activity (1948, p. 79). During his fieldwork in Melanesia, Malinowski described Melanesians as very skilled gardeners and canoe builders. Yet, when it came to potentially threatening events that endangered their crops or lives on an open sea and were beyond control (such as draughts or monsoons), Melanesians would perform magical rituals to safeguard themselves against these dangers and, as pointed out by Malinowski, to decrease their anxiety. From such observations, Malinowski (1948) extrapolated a core hypothesis regarding the relationship between anxiety and rituals, which can be paraphrased as two basic predictions: A) in anxiogenic situations where people lack control over the potential threat or means to avoid it, they will engage in substitute protective activity (magical rituals); and B) this substitute activity will instill an illusion of control and, in turn, decrease anxiety.

Following Malinowski, this hypothesis was embraced by other ethnographic observations and later by experimental studies. For instance, New England fishermen who regularly embarked on long fishing trips knew more prospective sayings associated with ritual avoidance of danger compared to coastal fishermen (Poggie, Pollnac, & Gersuny, 1976). Similarly, Ulithi sea voyagers were observed to engage in extensive magical rituals before a long sea voyage whereas no rituals were associated with one-day voyages (Lessa, 1966). In a war context, Israelites living in cities exposed to missile attacks during the Gulf War encouraged the usage of magical protective rituals to a higher degree compared to the inhabitants of cities not targeted by the attacks (Keinan, 1994), and war exposure increased ritual participation in Uganda and Tajikistan years after the ceasefire (Henrich, Bauer, Cassar, Chytilová, & Purzycki, 2019).[10] Furthermore, college students reported using magical/religious rituals like knocking on wood, crossing fingers, and praying before various challenging scenarios (like test taking or athletic events), and the likelihood of using these rituals correlated with the difficulty of the challenging task (Rudski & Edwards, 2007). Similar results were also obtained in professional sportsmen (Burger & Lynn, 2005; Gmelch, 1971). Finally, confronting stressed participants with scenarios involving potential threats (illness, accidents) increased the likelihood of using the knocking on wood behavior as a magical protective ritual (Keinan, 2002).

Showing that anxiogenic contexts increase the probability of using magico-religious rituals to protect oneself, another set of studies support Malinowski's second prediction, namely that such rituals decrease anxiety. Similar to Keinan's (1994) design, Sosis surveyed Israeli women on experienced anxiety and the practice of psalm recitation during the 2006 Lebanon War (Sosis, 2007; Sosis & Handwerker, 2011) and found that psalm recitation was correlated with reduced anxiety only in women who lived in areas threatened by missile attacks. That is, psalm recitation was effective in perceived anxiety decrease only in anxiogenic environments high on unpredictable threats. Likewise, participation in the Holi and Navratri rituals in a Hindu refugee community living in uncertain conditions decreased both perceived anxiety and physiological stress responses indicated by cortisol measurements (Snodgrass, Most, & Upadhyay, 2017).[11] On a small sample of Catholic college students, Anastasi and Newberg (2008) showed that reciting the Rosary affected perceived anxiety more compared to watching a religious video; and Brooks and colleagues (2016) showed that performing

actions identified as rituals decreased self-reported and physiological anxiety evoked by social performance and a challenging cognitive task. Finally, Lang, Krátký, and Xygalatas (2020) used a public speaking paradigm to elicit anxiety in women from the Marathi community in Mauritius and subsequently asked them to either sit in silence or perform their usual ritual in the local temple. The results showed that women who prayed in the temple self-reported lower anxiety and displayed lower physiological anxiety after prayer compared to women who just sat in silence.

While providing initial support for the hypothesis that rituals help decrease anxiety stemming from uncertain prospective threats, these studies exhibit substantial variation in the definition of ritual behavior, which prohibits us from identifying a specific behavioral pattern that responds to anxiety. Indeed, the described magical rituals include an array of magical practices like superstitious and magical thinking manifested in taboos and the use of good luck charms; the use of simple behavioral gestures like crossing fingers or knocking on wood; prayers such as the Rosary or psalm recitation; and over to complex behavioral patterns like ritual festivals in India. Within this variety, multiple cognitive and behavioral mechanisms likely have anxiolytic effects (Hobson, Schroeder, Risen, Xygalatas, & Inzlicht, 2018).[12]

For instance, superstitious/magical thinking is most likely facilitated by the human cognitive system that assesses causality. If a threat resolution has a complex causal link, assessing the true causes of danger elimination may be extremely difficult, and the human mind might be susceptible to generating ample spurious associations that connect various environmental elements and behaviors with a successful threat elimination (Fessler, 2006). Engaging in protective actions, which are generated by such spurious associations and deemed effective in resolving the threat, may instill the illusion of control and facilitate anxiety alleviation. Another mechanism may relate to belief in various superhuman agents and their possible protective powers. Asking supernatural agents for protection through prayers or offerings may outsource the control-regaining activity to the worshipped deities, effectively deactivating the anxiety subsystem (Kay, Whitson, Gaucher, & Galinsky, 2009).

However, while these additional mechanisms are relevant to the general question about the anxiety-management function of religious systems, in this chapter, we are interested in people engage in culturally prescribed ritual behaviors (such as reciting prayers or formalized hand movements) when overwhelmed with anxiety. That is, the mechanisms of spurious associations and belief in superhuman agents may provide additional anxiolytic effects. However, here, we focus specifically on the performative aspect of ritual behavior that seems to recur across cultures in anxiogenic contexts and is probably evolutionary older than magico-religious beliefs (Lang, 2019; Sosis & Alcorta, 2003; Tonna, Marchesi, & Parmigiani, 2019). It is the possible anxiolytic function of this performative aspect of ritual that we aim to examine.

The idea that the performance of ritual behavior has a cross-culturally recognizable form that may channel important functions was elaborated and promoted by Roy Rappaport (1979, 1999), who defined rituals as "the performance of more or less invariant sequences of formal acts and utterances not entirely coded by the performers" (1999, p. 24). While this definition serves mostly to describe the communicative/signaling function of ritual behavior, which we cannot unpack here (but will return to it shortly in the final section),[13] Rappaport's insights are also important for understanding ritual's purported anxiolytic function. He recognized that ritual performance is often not instrumentally connected to the goal it is supposed to achieve and that the performance is usually very formalized (executed in a rigid set of steps) and repetitive.

Building upon these insights, Boyer and Liénard (Boyer & Liénard, 2006; Liénard & Boyer, 2006) proposed a general model of ritualized behavior (as they call ritual's formalized aspects), which explains the specific form of ritual behavior that can be found in anxiogenic contexts. This model predicts that evolutionary salient threats trigger the Hazard-Precaution System, which in turn motivates people to engage in some protective action. Since the potential threats are often vague and unspecific, instrumental action may not be available, and goal demoted ritualized behavior is employed instead. Ritualized behavior, in accord with Rappaport's definition, is characterized by a repetitive and rigid set of steps that are defined on the low levels of action flow (e.g., gestures). Because it is impossible to intuit the correct course of ritual action (the specific steps must be learned) and the action often plays out on a very detailed gestural level, the performers must dedicate their focus to the repetitive performance of specific sequences of ritualized action, which effectively swamps their working memory. Swamped working memory cannot hold threat-related thoughts anymore, and relieving worrisome thoughts results in a temporal anxiety decrease (Van Dillen & Koole, 2007). Nevertheless, while providing a temporal relief, this system has, according to Boyer and Liénard (2008), an ironic outcome. Since rituals are performed regularly, they might increase the salience of particular threats in the long-term (along with anxiety triggered by these threats), which again motivates ritualized performance, thereby imprisoning ritual performers in this "vicious circle" (in analogy with the rituals of patients with the obsessive-compulsive disorder). In this respect, ritual performance in anxiogenic contexts may be maladaptive.

Inspired by Boyer and Liénard's model, Lang and colleagues suggested an alternative submechanism facilitating the purported anxiolytic effects of ritualized behavior (Lang, Krátký, Shaver, Jerotijević, & Xygalatas, 2015; Lang, Krátký, Shaver, Jerotijević, & Xygalatas, 2019): rather than swamping working memory, the repetitive and rigid nature of ritualized behavior functions to increase the interoceptive predictive success. This predictive success regulates the sense of control and may thus decrease perceived anxiety. This submechanism is based on the predictive coding paradigm that explains general brain processing (Clark, 2013; Friston, 2009). According to this paradigm, brains actively predict sensory inputs and code only prediction errors, which signal that the actual inputs did not match the predicted ones. In uncertain and unpredictable situations, the state-space of possible environments is amplified, and prediction errors exponentially grow, causing an increase in internal entropy, which the human cognitive-behavioral system experiences as anxiety (Hirsh, Mar, & Peterson, 2012). In such situations, engaging in ritualized behavior—characterized by repetitiveness and rigidity, that is, high predictability—may increase interoceptive predictive success and help the cognitive system return to low-entropy states, effectively decreasing anxiety (Lang et al., 2015).[14]

Experimental evidence that would support these models is sparse but encouraging. In one study, Lang and colleagues (2015) tested the first Malinowski's prediction in regard to ritualized behavior, which states that anxiogenic contexts should lead to an increased frequency of ritualized behavior. The authors recruited university students and employed the public speaking paradigm to elicit anxiety in the experimental condition. While anxious, participants were asked to clean an object, and Lang et al. measured the amount of spontaneous ritualized behavior manifested in participants' hand movements. They found that compared to a control group, anxious participants exhibited more repetitive and rigid behavioral patterns, consistent with the prediction that anxiogenic contexts trigger ritualized behavior. A subsequent study by Karl and Fischer (2018) bolstered this result by providing an indirect replication of the same effect. Furthermore, the study by Karl and Fischer (2018) also attempted a direct comparison of the Boyer-Liénard and Lang et al.'s models by subjecting participants to an anxiety treatment and compared the anxiolytic effects of cognitive load with spontaneous ritualization. They

found that cognitive load did not affect anxiety reduction on either psychological or physiological levels (c.f., Vytal, Cornwell, Letkiewicz, Arkin, & Grillon, 2013), but spontaneous movement ritualization (measured as repetitiveness) positively affected physiological anxiety reduction.

Together, these two studies suggest that the specific ritual form, labeled as ritualized behavior, may play a role in anxiety management. However, whether the submechanism facilitating this effect pertains to the swamping of working memory, a return to predictable low-entropy states, or both is still uncertain, and more evidence is needed (Krátký, Lang, Shaver, Jerotijević, & Xygalatas, 2016; Lang et al., 2020). Using this preliminary evidence, we next discuss whether ritualized behavior might be an evolved adaptive response to the hyperactive anxiety subsystem.

Is the Ritual Management of Anxiety Adaptive?

As shown in the section on the adaptive value of anxiety, excessively high activity of the anxiety subsystem might be detrimental to the individual. This is especially true for prolonged overactivation of the anxiety subsystem, which is accompanied by chronic stress response and hypervigilance. Given that the anxiety subsystem reacts to prospective/imagined threats rather than to detected stressors that require an immediate reaction, there is immense potential for maladaptive overactivation in safe environments, as documented by the various anxiety disorders. Furthermore, in the previous section on rituals, we provided preliminary evidence that various aspects of magico-religious behaviors might decrease anxiety (presumably by increasing the sense of control over uncertain threats). Focusing on the specific case of ritualized behavior, we argued that this cross-culturally recurring behavioral pattern helps to decrease anxiety because the repetitive and rigid nature of ritualized behavior makes the behavior well-predictable and increases the interoceptive predictive success. While the data supporting both conjectures are still preliminary and in much need of further refinement, they suggest that the ritual management of anxiety should positively affect proxies of biological fitness, especially in individuals high on trait anxiety who live in relatively safe environments. However, this preliminary conclusion requires detailed scrutiny.

Let us first return back to Bateson et al.'s (2011) optimality model of anxiety threshold described in the section on the adaptiveness of anxiety (Eq. 13.1).

$$(13.1)\quad \lambda = \frac{pnt}{pt} \times \frac{wfa}{wmiss}$$

In this simplified equation, the anxiety threshold (λ) increases with the decreasing threat probability ratio, which is calculated as the probability of there being no threat (***p****nt*) divided by the probability of there being a threat (***pt***). The effect of this probability ratio is regulated by the cost ratio given by the cost of a false alarm (***wfa***) divided by the cost of a threat that was real but not perceived (***w****miss*). For example, in contexts with high threat probability and high cost of not detecting the threat, the anxiety threshold would be very low, and the anxiety subsystem would be frequently activated. In relatively safe environments, the probability ratio of threat would be high and increase the anxiety threshold such that the system would be rarely activated.

However, while serving as a useful starting point, the model by Bateson et al. (2011) in Eq. 13.1 does not consider the individual perception of threat probability. As discussed in the previous section of this chapter, the individual perception varies within the population (trait anxiety) and that contribute to long-term adverse effects of anxiety on health in individuals with high trait anxiety. That is, anxiety is triggered by perceived threat probability (***Pp***), which can

be markedly different from the actual probability. To assess the benefit of ritualized behavior (R) in increasing the anxiety threshold (λ), which triggers and keeps running the anxiety subsystem, we need to assess the difference between the two probability ratios, moderated by the cost ratio (Eq. 13.2).

$$R = \left(\frac{pnt}{pt} - \frac{Ppnt}{Ppt}\right) \times \left(\frac{wfa}{wmiss}\right) - K \quad (13.2)$$

The second equation states that the benefit of anxiety management through ritualized behavior would be increased when the actual probability ratio of threat occurrence (***p****nt*/***p****t*) is larger than the perceived probability ratio of threat (***Pp****nt*/***Pp****t*). That is, when people overestimate the threat's presence, the ritual increase of anxiety threshold would be beneficial. This benefit would be further amplified by decreasing the cost of a missed threat (***w****miss*) or increasing the cost of false alarms (***wf****a*), which may be understood not only in terms of somatic costs but also in terms of missed opportunities. Finally, the energy expended during a ritual is captured by a constant value (K). If people were able to estimate threat probability precisely, rituals would have negative effects due to wasted energy (assuming, unrealistically, that there would be no additional benefits of performing the ritual). However, per the smoke detector principle (Nesse, 2001), we should expect that on average ***Pp****t* > ***p****t*; and when (***p****nt*/***p****t*)–(***Pp****nt*/***Pp****t*) > K, the hypothetical benefit of ritualized behavior should be increasing.[15]

How could this model be translated into real-world scenarios? For example, using the context of the Israel-Lebanon 2006 war where the study by Sosis & Handwerker (2011) took place, overestimating the probability of Hezbollah missile attacks (***Pp****t*) would decrease the anxiety triggering threshold (λ) and lead to a pro-longed anxious state. As documented by the studies reviewed in the "adaptive value of anxiety section,' this pro-longed anxious state may substantially decrease individual fitness. Reciting psalms that are perceived to have a protective function would reduce the perceived threat probability (***Pp****t)* to the actual level of the attack probability (***p****t*), thereby protecting the organism from unnecessary physiological stress. Of course, given the high values of ***w****miss* in the context of missile attacks, it may be more advantageous to be overly cautious; however, in other contexts such as stressful working environments, chronic disease or drought and famine, ritualized behavior that would decrease the unnecessary anxiety may have positive health effects.

Interestingly, apart from positive health effects, there is yet another way that anxiety management may positively affect individual fitness. Imagine that a forager locates a valuable food source in a forest but spots traces of a dangerous predator, which activate the anxiety subsystem. The first decision the forager needs to make is whether to stay and forage or run away; if they decide to stay, the second decision pertains to the intensity of the stay—collect a few fruits or engage in unconstrained feeding?[16] If the forager's anxiety subsystem were hypersensitive, the forager would run away almost in every situation no matter the value of the food source. On the contrary, a hyposensitive anxiety subsystem would lead to unconstrained feeding even for food sources with relatively low value. The benefits of these strategies would depend on the actual probability of the hazard that the forager would be attacked by the predator. For instance, if the predator's traces would be several days old and/or the predator would be a member of a species that does not usually attack humans, the hypersensitive forager would lose food source in exchange for eliminating minimal risk (perceived as a large risk by the forager, though). The cost of the hypersensitive strategy would further increase with the value of the lost food source. It is precisely in such situations where the anxiolytic effects of ritualized behavior might be

beneficial: by dampening the anxiety subsystem through the performance of a protective ritual, the forager would be able to collect precious resources.[17]

Such a scenario could also be fitted to different contexts. For example, an anxious individual might face a dilemma whether to challenge an existing social hierarchy to accrue higher social status and the resulting benefits. Depending on the difference between the perceived and actual permeability of the social hierarchy and the value of social-status benefits, decreasing anxiety through ritualized behavior and challenging the hierarchy might be adaptive. Likewise, going on a few-days long trading trip on the open sea leaves the voyager vulnerable to the whims of the climate; but if successful, such a voyage might yield large gains for the voyager. An analogical decision-making process can be applied to battle raids, where a raider weighs the risks and benefits of joining the raid (how many raiders, how many defenders, what can be gained). Performing protective rituals may tip the decision toward perceived benefits.[18] Depending on the probability of actual threat and the value of potentially obtained goods, this may or may not be a profitable decision.

These examples suggest that ritualized behavior might help individuals take riskier strategies and that in many cases, such decisions might be beneficial.[19] However, this conjecture is built on the assumption that the process of optimizing the anxiety threshold (λ) is not well calibrated, partially due to inter-individual variance in trait anxiety. This assumption was supported in the section on the adaptive value of anxiety, which showed that setting the threshold too low may be disadvantageous if not downright harmful, as in the case of anxiety disorders. Furthermore, while our examples focused mostly on the binary decision of whether to engage in some risky action or not, other research suggests that ritual behavior may also positively impact the course of the risky action. For instance, praying in anxiogenic contexts frees cognitive resources for a subsequent challenging task (Adams, Kleider-Offutt, Bell, & Washburn, 2017), and superstitious rituals boost performance in various sports (Damisch, Stoberock, & Mussweiler, 2010; Foster, Weigand, & Baines, 2006) and social situations (Brooks et al., 2016).[20] By muting worrisome thoughts, rituals may enhance performance in risky situations, thus conferring additional benefits.

In the long-term, however, ritual behavior may also keep increasing anxiety levels by reminding performers of prospective threats, as pointed out by early critics of Malinowski (Radcliffe-Brown, 1952) and more recently by Boyer & Liénard (2006). Indeed, rituals are part of the religious complex and as such may increase anxiety by invoking punishing deities, demons, and other terrifying agents or by frequently reminding members of the existence of hazards that need to be mitigated. However, we note that rituals may serve many different functions, such as enforcing inter-individual cooperation, and in these contexts, reminding members of punitive deities or the danger of temptation may confer different adaptive benefits (Lang, 2020; Lang, Purzycki, et al., 2019). In our analysis, we focus on ritualized behavior that occurs spontaneously in anxiogenic situations, that is, when people are faced with prospective, externally or internally generated threats, effectively ignoring the rituals that occur regularly within the liturgical year.[21] Based on the dynamical model put forward by Lang (2020), ritualized behavior should be recruited only in anxiogenic situations to decrease anxiety, and after dampening the anxiety subsystem, ritual activity, should cease to baseline levels.[22]

Specific predictions regarding the adaptive value of ritualized behavior that occurs in anxiogenic contexts can be extrapolated from the model put forward in Eq. 13.2. First, assuming moderate costs of false alarms and missed threats, environments with low threat probability should generate a larger difference between perceived and actual threat. In such environments, anxiolytic ritualized behavior would confer adaptive benefits upon individuals who would suffer less from the chronic anxiety side-effects and who would be able to overcome

Table 13.1 Predictions on the Adaptive Value of Ritualized Behavior

	Threat probability	Cost of false alarms	Cost of threat miss	*Ritualized b. adaptive?*
Parameter strength	Low	low	high	*no*
	Low	moderate	moderate	*yes*
	Low	high	low	*yes*
	Moderate	low	moderate	*no*
	Moderate	moderate	low	*yes*
	Moderate	high	moderate	*yes*
	High	low	low	*no*
	High	moderate	low	*no*
	High	high	high	*no*

Note. These predictions might be extended by computer simulations where an emergence of ritualized behavior would occur in contexts where *pt*wmiss < (1-pt)*wfa*. In this table, we used values between 0 and 1 where low = 0.1, moderate = 0.5, and high = 0.9. Thus, most examples in this chapter would qualify as either low or moderate threat probability.

anxiety to garner more valuable resources. Second, assuming moderate threat probability and moderate cost of missed threats, the anxiolytic effects of ritualized behavior should be adaptive in environments with a limited amount of high-quality, strategic resources (high cost of false alarms). Third, even with a moderate threat probability and cost of false alarms, decreasing anxiety through ritualized behavior should be beneficial in environments comprising only threats with low harm (e.g., no natural predators). These three predictions illustrate the impact of manipulating the basic parameters of the model (see Table 13.1 for examples), which can be further combined in various permutations to attain more realistic scenarios.

These predictions could be tested either against real-world data, experimentally, or with computer simulations. On a general level, researchers could induce anxiety in the laboratory and assign various ritual and control tasks to participants, measuring whether rituals help decrease anxiety and whether this decreased anxiety, in turn, leads people to make riskier decisions and garner larger benefits. On a more specific level, computer simulations could utilize agent-based modeling or system dynamics modeling (Kaše, Hampejs, & Pospíšil, 2018; Lane & Shults, 2018; Shults et al., 2018, 2017) such that agents would differ in their sensitivity to threat (λ parameter) and the intensity of using of ritualized behavior to decrease anxiety. When foraging for limited resources, the environmental parameters to manipulate would be threat probability, the cost of false alarms (missed opportunities to gather valuable resources) and the cost of not detected hazard. Such a simulation might establish specific conditions under which ritualized behavior provides long-term adaptive benefits.

Conclusion

This chapter aimed to examine whether the purported anxiolytic effects of ritualized behavior may confer adaptive benefits to ritual performers. By examining the current models of anxiety, we concluded that the anxiety subsystem appears to be phylogenetically old and serves homologous function across the mammalian class. The deep rooting of the anxiety subsystem points to its likely adaptive value, which we identified as motivating precautionary action against prospective threats. However, we also suggested that high anxiety levels might be detrimental to the individual, especially in cases where the anxiety system is hyperactive and the environment

is relatively safe. Thus, decreasing excessive anxiety through ritualized behavior may be beneficial by reducing the somatic cost of physiological stress and allowing individuals to take riskier actions and potentially garner larger benefits. While this conclusion is rather premature and based on insufficient data availability, we put forward several predictions and proposed ways to test them, which should help elucidate the relationship between anxiety and ritualized behavior in the future.

Further investigation of this relationship may also aim to establish whether ritualized behavior is an adaptation, a question we avoided in the present chapter. The question of adaptation aims at the origins of the trait and selective pressures that could lead to the evolution of ritualized behavior. Unfortunately, there are even fewer data available to answer such a question than for the currently presented analysis, but three observations warrant skepticism regarding the suggestion that ritualized behavior might be an adaptation.

First, ritualized behavior is often part of complex religious systems, and analyzing only a single element of the system would prohibit us from understanding the emergent complexity of the system (Lang & Kundt, 2020; Sosis, 2019). In other words, if we would like to ask about adaptations, we should ask on the systemic level rather than on the level of specific elements of the system (Sosis, 2009). This problem repeatedly surfaced throughout this chapter when we argued that ritualized behavior often amalgamates with other elements like magical thinking and the belief in superhuman agents or when we discussed that some rituals are anxiogenic rather than anxiolytic. Understanding if and how specific religious systems constitute an adaptation to their environment would require a much deeper analysis of interactions of ritualized behavior with other elements of the complex adaptive religious system (Sosis, 2017).

Second, even if we would assume that ritualized behavior is an adaptation independent of its interaction with other components of the religious system (i.e., it was an adaptation before being co-opted by the religious system), it is not clear whether the main function of ritualization would be assuaging anxiety. Whereas we argued that ritualized behavior likely helps fitness maximization by downregulating the hyperactive anxiety subsystem, the fitness benefits of this downregulation may appear negligible in comparison with the well-researched role of ritual behavior in fostering within-group cooperation and inter-individual trust (Shaver et al., 2018; Sosis & Bressler, 2003; Xygalatas et al., 2013). Indeed, this brings us back to Rappaport who identified rituals as a communication platform that provides a shared code for repetitive transmission of indexical messages (1999): by allowing ritual participants to repetitively signal commitment to their group in an understandable way (e.g., through various costly behaviors), rituals serve to build trust and coalitions and minimize the free-rider problem that might have been exceptionally salient throughout the course of human evolution (Bulbulia, 2012; Chvaja & Řezníček, 2019; Irons, 2001; Lang, 2019; Sosis, 2003).

Finally, the model of ritualized behavior put forward by Boyer and Liénard (2006) explicitly suggests that ritualized behavior is not an adaptation but a by-product of the Hazard-Precaution System. These authors suggested that due to its focus on prospective threats and specific protective actions, ritualized behavior functions as a cognitive capture of the Hazard-Precaution System. In other words, by matching inputs of the Hazard-Precaution System, ritualized behavior appears to performers as a particularly salient and useful actions in anxiogenic situations. While this by-product view does not necessarily imply that ritualized behavior cannot be currently adaptive (as we have argued), it indicates that ritualized behavior did not originate to fulfill an anxiolytic function. However, to properly answer the question of whether ritualized behavior is an adaptation, future research should investigate different lines of evidence for ritual functions in other related species, in the history of the genus *Homo*, as well as in small-scale societies and identify selective pressures that might have led to the evolution this basic human act.

Notes

1 We are grateful to Jan Krátký, Justin E. Lane, and Petr Tureček for providing helpful comments on an earlier version of this chapter. ML acknowledges generous support from the Neuron Fund.

2 For a discussion of different factors that could mediate the effects of ritual on health apart from anxiety management, see Koenig et al. (1999) and Xygalatas et al. (2019).

3 Blanchard (2017) provides a systematic review of studies showing that the phenomenon of anxiety is well translatable between animal and human models.

4 Note that due to space constraints, we left out the question of whether the anxiety subsystem is an adaptation. To assume that a trait is an adaptation, we would have to detail the selective pressures that lead to the development of such a trait. While we are firmly convinced that anxiety is an adaptation, we focus only on its current adaptive value, which can be measured by assessing its fitness maximization potential.

5 This problem can be to some extent mitigated by herd behaviors whereby individual animals on the perimeter of the herd scan the environment and give alarm calls in the case of potential danger while the animals within the perimeter feed (Eilam, Izhar, & Mort, 2011; Manser, 1999).

6 The smoke detector principle was also utilized to examine other components of religious systems such as the origins of belief in superhuman agents. Known as the Hyperactive Agent-Detection, Device (HADD; Barrett, 2000; Guthrie, 1993), it was suggested that this cognitive "module" overrepresents agents in one's environment, leading to belief in the presence of invisible agents. However, an empirical test of this hypothesis suggested that this principle works only when coupled with strong expectations of the presence of other agents (Andersen, Pfeiffer, Müller, & Schjoedt, 2017), a result congruent with theories anchoring HADD principle within the predictive coding paradigm (Taves & Asprem, 2017; c.f., Lang & Kundt, 2017).

7 Note that this simplification does not speak to the adaptiveness of anxiety in absolute terms (how much anxiety is adaptive) but rather retains its focus on the relative terms, that is, deviations from the population average level of anxiety (c.f., Bulbulia & Slingerland, 2012).

8 Based on the scatter plots provided by the authors, the highest number of children, grandchildren and great-grandchildren is around mean anxiety scores, suggesting that their results might be partially driven by outliers. Furthermore, for the high end of the anxiety spectrum, the model predicts an unrealistic average of 15 children per participant, indicating that the assumed distribution of residuals might not have been well chosen. The majority of the sample also appeared to be drawn from the second and third generations, which were less likely to have grandchildren/children, further skewing the results.

9 For instance, the studies cited in this section rely on various and disparate psychometric tools to assess anxiety. While such tools should be correlated, they may often differ in the timespan over which the anxiety measure is assessed. Moreover, assessing anxiety only at one point during the study may reflect current moods and bias the results; ideally, future studies should assess variation in trait anxiety and its influence on biological fitness, taking into account also environmental unpredictability and individual vulnerability (Lang, 2020).

10 For a further review of the ethnographic evidence, see Poggie and Pollnac (1988) and a review paper by Dulaney and Fiske (1994). The latter paper sampled the Human Relations Area File for instances of ritual behaviors across cultures and found that rituals in anxiogenic contexts shared components like "fear that something terrible will happen", "measures to prevent harm", "disgust with bodily wastes", and, "repetitive action" (Dulaney & Fiske, 1994).

11 See Lang and Sosis (2017) for additional interpretations of these data.

12 See also Wood's model (2017) of self-signaling mechanisms positively impacting subjective well-being.

13 For more details, see Sosis (2003).

14 Note that in comparison to the model of ritualized behavior put forward by Boyer & Liénard, this approach does not assume that ritualized behavior cannot be routinized. For Boyer & Liénard, routine means that performers do not focus on the ritual at hand (hence, their working memory is not swamped). However, we find this assumption somewhat unrealistic, given that many rituals may be conducted daily or even several times a day. In our view, such routinized rituals are still well predictable and may help increase the interoceptive predictive success (i.e., decrease anxiety).

15 Another possible extension of Eq. 13.2 might include the difference between real and perceived costs ($\boldsymbol{w}$). Thus, Eq. 13.3 states that

(13.3) $R = \left(\frac{\boldsymbol{pnt}}{\boldsymbol{pt}} - \frac{\boldsymbol{Ppnt}}{\boldsymbol{Ppt}}\right) \times \left(\frac{\boldsymbol{wfa}}{\boldsymbol{wmiss}} - \frac{\boldsymbol{Pwfa}}{\boldsymbol{Pwmiss}}\right) - K$

where ***Pwfa*** is the perceived cost of false alarms and ***Pwmiss*** the perceived costs of undetected threat. Analogically to Eq. 13.2, if the perceived cost of a missed threat (***Pwmiss***) would be overestimated (***Pwmiss***–***wmiss*** > 0), the anxiolytic value of ritualized behavior would be more beneficial (by downregulating a threat exaggeration). On the other hand, increasing the perceived cost of false alarms (***Pwfa***) would decrease the anxiety threshold (λ) and, by the same token, decrease the value of ritualized behavior. That is, higher perceived cost of false alarms (***Pwfa***) would negate the effect of higher perceived probability of threat (***Ppt***) so that the system would be in equilibrium and would not require any additional calibrating mechanism such as ritualized behavior. However, we deem the positive correlation between ***Pwfa*** and ***Ppt*** very unlikely. Thus, for Eq. 13.3 to provide valuable insights, we need to postulate that if ***Ppt*** > ***pt***, then ***Pwfa*** ≤ ***wfa***. Likewise, there should be a positive correlation between ***Ppt*** and ***Pwmiss*** such that if ***Ppt*** > ***pt***, then ***Pwmiss*** > ***wmiss***.

16 This decision process can be simulated as a two-part hurdle model, where the first model simulates the probability of engaging in some action (binary decision) and the second part of the model simulates the positive values (after the hurdle was surpassed).

17 Notably, rituals would be ineffective for foragers with hypoactive anxiety subsystems because there is no anxiety to be decreased.

18 We are grateful to Luke Glowacki for this example.

19 For instance, across four studies, Brooks and Schweitzer (2011) found that participants with experimentally induced anxiety took less risky strategies in negotiations and, as a result, earned less money than non-anxious participants.

20 However, these studies subscribe to the broader definition of magico-religious behavior described above rather than being a strict example of ritualized behavior.

21 Again, these rituals may fulfil different functions, yet they may resemble anxiolytic rituals by their compulsive nature. Indeed, as noted by Radcliffe-Brown (1952), prohibiting people from performing prescribed rituals may also increase anxiety.

22 This dynamic could also explain the correlation between anxiety and the frequency of ritualized behavior used by Boyer & Liénard as an argument for the ironic outcomes of ritualized behavior. Looking only at cross-sectional data, anxious people should exhibit higher ritual frequency to dampen the anxiety subsystem, hence the correlation. However, longitudinal data should show that individuals exhibit various oscillation patterns in the frequency of rituals that is dependent on the frequency of anxiogenic situations.

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