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The role of ritual behaviour in anxiety reduction: an investigation of Marathi religious practices in Mauritius

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While the occurrence of rituals in anxiogenic contexts has been long noted and supported by ethnographic, quantitative and experimental studies, the purported effects of ritual behaviour on anxiety reduction have rarely been examined. In the present study, we investigate the anxiolytic effects of religious practices among the Marathi Hindu community in Mauritius and test whether these effects are facilitated by the degree of ritualization present in these practices. Seventy-five participants first experienced anxiety induction through the public speaking paradigm and were subsequently asked to either perform their habitual ritual in a local temple (ritual condition) or sit and relax (control condition). The results revealed that participants in the ritual condition reported lower perceived anxiety after the ritual treatment and displayed lower physiological anxiety, which was assessed as heart-rate variability. The degree of ritualization in the ritual condition showed suggestive albeit variable effects, and thus further investigation is needed. We conclude the paper with a discussion of various mechanisms that may facilitate the observed anxiolytic effects of ritual behaviour and should be investigated in the future.

This article is part of the theme issue 'Ritual renaissance: new insights into the most human of behaviours'.

1. Introduction

Ritual is a human universal, found without exception in all known past and present societies of *Homo sapiens* [1]. The cross-cultural pervasiveness of ritual behaviour raises questions about its evolutionary origins and possible adaptive functions in the human lineage. Although ritual appears in a wide variety of contexts, it is especially prevalent within the context of religious systems [2,3] where it probably helps secure three main effects: stabilizing risky coordination, increasing reproduction and improving health [4]. Here, we focus on the third suggested effect and investigate whether religious ritual plays a role in health management and, specifically, in anxiety regulation.

Anxiety is an emotion triggered by anticipated future threats and catastrophes, and is associated with somatic symptoms that mobilize an individual for action [5,6]. As such, anxiety fulfils important functions by allocating cognitive resources to further assessment of the probability and severity of the anticipated threat and, in turn, motivates precautionary, defensive and avoidant behaviours [7–9]. Indeed, large-scale longitudinal studies showed that low trait anxiety is associated with increased mortality, possibly owing to the frequent occurrence of risky behaviours [10,11]. Nevertheless, while a well-calibrated anxiety system may be protective against real hazards, the same studies showed that high trait anxiety, which is associated with routine overestimation of threat probability and severity, has long-term negative health effects owing to chronically high levels of physiological stress. These negative effects are markedly pronounced in various anxiety disorders that debilitate patients' lives [12] and increase the risk of suicide [13], but even healthy individuals who are on the high end of the anxiety spectrum may feel constantly anxious from very unlikely future

threats that are beyond their control [14]. Such prolonged pre-occupation causes chronic stress and physiological dysregulation [15], especially in environments rich in unpredictable and uncontrollable threats, for example during warfare or in areas with an increased risk of natural disasters.

Crucially for the current paper, it is precisely in association with uncontrollable (albeit hypothetical) threats that researchers observe an upsurge of magico-religious rituals. For example, ethnographic work suggests that the religious practices of fishermen are specifically concerned with possible future threats related to the whims of the weather that may potentially impede the fishing trip and even endanger their lives [16–18]. In a war context, the threat of missile attacks, which are unpredictable and beyond one's control, was found to encourage the use of protective rituals [19] and inter-group conflict was associated with increases in the frequency of religious behaviour that persisted even years after the ceasefire [20]. Furthermore, a large-scale cross-cultural comparison of 30 countries found that participants from districts with a higher chance of earthquakes reported more frequent religious service attendance [21]; and in a laboratory assessment of the relationship between anxiety and rituals, stressed individuals were more likely to use a protective ritual (knocking on wood) when talking about anxiety-provoking situations [22]. Finally, priming participants with randomness increased the perceived ritual efficacy [23].

To explain the frequent co-occurrence of anxiety and rituals, Bronislaw Malinowski suggested more than a century ago [18] that when faced with a prospect of uncontrollable threats, people are compelled to perform any action that is deemed effective to regain the feeling of control. According to Malinowski, magico-religious rituals are emotionally driven expressions of the desired goal, be it safety during warfare or success in hunt, that stem from the compulsion to exercise control over uncontrollable threats and to soothe the overwhelming anxiety. In other words, Malinowski theorized that rituals are inherently tied to anxiety-provoking situations because they help decrease anxiety that may impede normal functioning. While this hypothesis gained popularity among Malinowski's followers [16,24,25], the question whether rituals help actually decrease anxiety is still outstanding. Three studies provide indicative evidence in support of Malinowski's hypothesis: first, Sosis & Handwerker [26,27] found that Israeli women who recited psalms when threatened by missile attacks reported lower anxiety compared to women who did not engage in this religious practice; second, Snodgrass *et al.* [28] found that participation in the Holi and Navratri rituals among Indian refugees decreased both perceived anxiety and physiological stress proxied by cortisol assessment (but see [29]); and third, Xygalatas *et al.* [30] found that participation in an extreme ritual has long-term positive effects on perceived health and well-being (see also [31]). The contribution of these studies notwithstanding, they do not provide clear experimental evidence for the efficacy of ritual behaviour in anxiety management.

In the current study, we followed Malinowski's long-standing hypothesis and investigated whether rituals help decrease anxiety. Whereas previous theories already speculated about specific components of ritual behaviour facilitating this purported effect [8,32,33], the fundamental association between rituals and anxiety decrease has not yet, to our knowledge, been experimentally tested. To this end, we conducted a controlled study in a field setting, which allowed us to establish whether rituals in their cultural complexity (as described by

ethnographers) indeed facilitate anxiety decrease. Focusing on the rituals performed by Hindu women of the Marathi community in Mauritius, we first used a modified public speaking paradigm to elicit anxiety and subsequently asked participants either to perform their habitual ritual (the ritual condition) in its real-life context in the local temple or to rest for an equivalent amount of time in an empty room (the control condition) before delivering the speech. We assessed participants' perceived (self-reported) and physiological (heart-rate variability) anxiety throughout the experiment. We predicted that participants in the ritual condition would experience greater anxiety decrease after the ritual treatment compared to those in the control condition, which would be detectable both in the self-reported and physiological measures.

To gain insight into the particular components of rituals that may facilitate the predicted effect, we also examined one candidate mechanism related to ritual's structural properties [34], specifically its redundant, repetitive and rigid nature, grouped under the term 'ritualized behaviour' [8]. In our previous work, we have proposed that ritualized behaviour instils the feeling of control by decreasing internal psychological entropy caused by unpredictable and uncontrollable threats [32,35,36]. Unpredictable hazards threaten to disorganize the human neuro-cognitive system (i.e. increase entropy [37]), which is heavily based on its ability to predict possible scenarios and initiate appropriate behavioural schemas [38,39]. If only limited threat-related predictions are possible (such as during air strikes), the increasing psychological entropy drives people to perform substitutive activities that provide successful predictions and help fight neuro-cognitive disorganization manifested as psychological and physiological distress. Because ritualized behaviour is highly predictable (owing to its repetitiveness and rigidity), ritualizing movement patterns in uncertain situations may decrease the rate of unsuccessful predictions by providing sensory stimuli that are easily predictable and, therefore, decrease internal entropy of the neuro-cognitive system. In a laboratory assessment of this theory [32], participants who were placed in an anxiety-provoking situation displayed more ritualized behaviour in their movement patterns, and the level of anxiety predicted the degree of ritualization—an effect which was replicated in a subsequent study [40].¹ However, there is no direct evidence that performing repetitive movements in pre-defined rigid patterns also facilitates anxiety reduction. To this end, we obtained motion capture data throughout the ritual practices performed by participants in the ritual condition and quantified the movements' repetitiveness and rigidity, predicting that the amount of ritualization would be predictive of subsequent anxiety decrease.

2. Material and methods

(a) Participants

The experiment took place in the broader area of La Gaulette, a coastal village of approximately 2500 inhabitants in southwest Mauritius. We recruited 75 women from the local Marathi community (mean (*M*) age = 43.9, s.d. = 15.6), who were approached by local research assistants on the main streets of the Black River district (within 12 km from the study site) and invited to enrol in the study. Participants received a compensation of 150 Mauritian rupees (around 3.2 GBP, equivalent to over half a day's wage of an unskilled labourer). One participant dropped out during the study for reasons unrelated to the

experiment, leaving a sample of 74 subjects. The decision to recruit only women was driven by the observation that women in that community were much more likely to perform individual rituals in the temple. While men frequently take place in the collective rituals of the community, on an everyday basis it is typically women who visit the temple to make offerings to the various deities of the Hindu pantheon.

We used a between-subject design, assigning each participant to one of two conditions: ritual ($n=43$, M age = 45.5, $s.d.$ = 15.4) and control ($n=32$, M age = 41.8, $s.d.$ = 15.8). The lower number of participants in the control condition resulted from our decision to use the limited pool size preferentially for the ritual condition so as to allow for a within-subject analysis of the efficacy of ritualized movements on anxiety (see below). The study was approved by the institutional review boards of the Masaryk University and the University of Connecticut, and all participants provided written consent.

(b) Materials and measurements

To elicit anxiety, we used a combination of a threat prime and the public speaking paradigm. Specifically, we asked participants to prepare a speech about their readiness to deal with natural disasters (floods). As the island regularly faces natural disasters and had been severely impacted by deadly floods in the years preceding our study, this prime was particularly salient to the locals. To increase the stimulus' potential to trigger anxiety and its associated physiological response during the course of our study, participants were told that their speech would be recorded and assessed by a governmental expert, a common way to elicit anticipatory anxiety in laboratory experiments [41]. Note that the preparation period itself was sufficient to increase anxiety [32,41] and participants eventually did not deliver the speech to minimize intrusion.

To test the presumed anxiolytic effects of religious rituals, we compared two between-subject conditions: ritual and control. The ritual condition took place in the local Marathi temple, which was the main place of worship for our participants. During the morning hours of daily data collection, the temple was reserved only for individual participants (participants were alone in the prayer room). The temple comprised three main rooms—a sizable hall in which collective rituals take place, a small adjacent kitchen and a prayer room that holds 17 statues of Hindu deities along the walls and a Shiva lingam in the middle. While there might be some variation in the rituals performed in this room, people generally follow the same pattern of actions, praying to each deity by making offerings to their statues and performing clockwise circular movements with incense sticks or oil lamps in their hands.

For the control condition, we used the simplest contrast, that is, comparing religious ritual to no activity, so that we could record levels of anxiety as they developed naturally without any external influence. In other words, we aimed to establish whether performing culturally learned rituals in anxiogenic contexts has any positive anxiolytic effect at all. Participants in the control condition were situated in a non-religious location, a rented private property consisting of a similar size and spatial arrangement as the temple (comprising two rooms and a hallway) that served as our field laboratory. Each room was equipped with a table and chair, the only kinds of furniture found in the temple. Instead of praying, participants were asked to remain seated alone in silence and without movement for 11 min, which corresponded to the

average time of ritual performance in the ritual condition (note that to estimate the average prayer time, we first ran the ritual condition).

All participants completed two surveys. At the beginning of the experiment (survey 1), we administered the seven-item generalized anxiety disorder questionnaire (GAD-7; [42]) to assess proneness to anxiety ($\alpha=0.6$, $\omega_t=0.73$, $\omega_h=0.42$; see the electronic supplementary material, section S1.1) and a question on how anxious participants felt at the moment (on a scale 0–4). At the end of the experiment (survey 2), participants reported how anxious they felt during the speech preparation and at the current moment (after learning that they would not deliver the speech). In addition, we collected demographic information (age, education, occupation), and data on religiosity and frequency of ritual participation. In the ritual condition only, participants were also asked whether they specifically prayed about floods and whether the ritual helped them calm down (in that specific order). All materials were administered in the local Mauritian Creole language by local research assistants.

Physiological anxiety was assessed by measuring heart activity with a Zephyr BioHarness 3.0 heart-rate (HR) monitor [43]. This monitor is fitted on a chest strap with a data-logging module, allowing for wireless and continuous HR measurement. Owing to an equipment malfunction, we lost HR data from 10 participants in the ritual condition and seven participants in the control condition. In addition, one participant in the ritual condition refused to wear the HR monitor during the experiment. As a result, HR data from those participants are not included when modelling the dynamics of physiological anxiety. The main physiological variable recorded during the experiment was R-R interval. This is a measure of the temporal distance between two R peaks of the QRS complex, which signals ventricle depolarization. The sampling rate of the HR monitors was set at 250 Hz. We further used the R-R interval measurement to compute heart-rate variability (HRV) for each participant as our main physiological proxy for anxiety. Resulting from complex interactions between multiple neural, hormonal, and mechanical systems, HRV reflects the dynamics of the autonomic nervous system [44]. Specifically, HRV reflects vagal tone, which has been related to the ability to deal with stressors and self-regulate [45] (see the electronic supplementary material, section S1.2 for details on HRV computation).

To record participants' movements during the entire procedure, and especially during ritual performance, we fitted a Bodymedia SenseWear mini armband on participants' both upper arms [46]. This device is similar in size and weight to a wristwatch and can be worn under the sleeve. It assesses a host of variables related to physical activity and energy expenditure. To estimate the amount of ritualization during ritual performance, we used the inbuilt accelerometer and performed a recurrence quantification analysis (RQA) to arrive at two proxies of ritualization: recurrence rate (RR) and determinism (DET) of the hand-acceleration signal [47,48]. These two measurements have been previously used to quantify some of the defining aspects of ritualized behaviour, namely repetitiveness and rigidity [32,40]. While RR captures how frequently the hand-acceleration signal repeats itself, DET captures patterns in repetition (see the electronic supplementary material, section S1.3 for details on RR and DET computation). Finally, we used the step counter and physical activity levels computed by the SenseWear to control for any movement during periods when participants were supposed to sit still.

(c) Procedure

Upon enrolling in the study, participants were led individually to either the temple or the laboratory space, where a research assistant explained the procedure and placed the physiological monitors on them. To minimize discomfort from fitting the devices, the research assistants were female (as were the subjects). Subsequently, participants filled out survey 1. To obtain a baseline HR measurement, participants in both conditions were asked to remain seated and relax for a period of 5 min. Following the baseline period, they were given 3 min to prepare a speech on the precautionary actions one should take during natural disasters such as floods. Participants were informed that their speech would be recorded and subsequently evaluated by governmental public safety experts. They were not given the option to take any notes during this task. After the anxiogenic task, but before giving the talk, participants in the ritual condition were asked to move to the adjacent prayer room where they could perform their customary ritual alone. We provided all necessary paraphernalia for their rituals and offerings such as incense sticks, fruit, flowers, oil lamps, etc. Participants were free to choose what materials to use and in what quantity and were given no time constraints, so as to allow them to perform the ritual in the same way they usually did. After they finished their ritual, participants returned to the main temple hall, took their seat at the table, and were informed that they would not have to record their speech after all. Participants were asked to remain seated for a few more minutes (the recovery period) before filling out the final questionnaire. Five minutes later, they were handed survey 2 and at the completion of the study received the monetary compensation for their participation. In the control condition, participants went through the same procedure: first filling out survey 1, then baseline HR assessment, and later preparation period to elicit anxiety; however, after eliciting anxiety, participants in the control condition were asked to remain seated and silent for 11 min (the average time it took participants in the ritual condition to complete their ritual). Afterwards, we assessed their recovery HR and participants filled out survey 2 and received monetary compensation. Thus, in both conditions, we obtained anxiety measurements at three points: during baseline, during speech preparation and post-treatment (recovery), assessing the between-condition differences in post-treatment anxiety while holding baseline and preparation anxiety constant in our models. (Note that while we have recordings also for the ritual periods, the HR signal would be biased by movement.)

(d) Analysis

Physiological data were processed in MATLAB 2017b [49] and all statistical analyses were carried out in R, v. 3.5.3 [50]. We first visualized the self-reported anxiety data and identified the Tweedie distribution as the appropriate way to model the residuals. A Tweedie distribution can model semicontinuous data with a point mass at zero owing to its shape parameter that determines the mixture between the Poisson and gamma distributions [51]. After analysing the self-reported data with the *tweedie* package [51], we re-analysed the data with ordinary least squares (OLS) models and found no qualitative differences. Therefore, we present the OLS models in the main text and refer readers to the electronic supplementary material for precise estimates obtained with the Tweedie models. We also used OLS models to analyse HRV. We used a natural logarithm

to transform the HRV values, which is a standard measure to correct for their non-normal distribution [52] (see the electronic supplementary material, section S1.2).

As a general modelling approach, we analysed post-treatment self-reported and physiological anxiety while always holding constant baseline anxiety, the difference between baseline anxiety and preparation anxiety, and their interaction. Using this approach, we accounted for inter-individual variation in baseline anxiety as well as variation in reactivity to anxiogenic stimuli, which also varies inter-individually [52]. In the most basic model, we included these control variables and added the condition factor with the ritual condition set as the reference category. In the second step, we added theoretically important control variables that might influence anxiogenic reactivity (demographics, GAD-7) or might moderate the effectiveness of our treatment (religiosity, ritual frequency). Furthermore, we built additional models for the ritual condition only where we aimed to control for the basic differences between the ritual and control conditions (time spent on ritual performance, movement during ritual), assess the perceived effectiveness of ritual, and test whether the ritualized aspect of the religious practice will predict anxiety decrease.

3. Results

(a) Self-reported anxiety

First note that all coefficients in this section are unstandardized beta estimates and all confidence intervals (CIs) are 95%. There was no difference in baseline self-reported anxiety between the two conditions (β ritual versus control = -0.04 , (-0.59 , 0.51)). The anxiogenic stimulus successfully increased self-reported anxiety (β baseline versus preparation = 0.40 , (0.03 , 0.78)), and there was no difference between conditions in the level of that increase (β ritual increase versus control increase = -0.22 , (-0.98 , 0.55)).

The modal answer in the ritual condition to the question about perceived post-treatment anxiety was 0 (on a 0–4 scale) with a mean of 0.55 and s.d. of 0.89. Holding baseline self-reported anxiety constant and accounting for increases in anxiety during the preparation period, the OLS model estimated that participants in the control condition felt around twice as anxious as those in the ritual condition after treatment, and the upper 95% CI reached almost three times the level of post-treatment anxiety in the ritual condition (β ritual versus control = 0.51 , (0.07 , 0.95)). Holding constant age, education, religiosity, ritual frequency and chronic anxiety levels (GAD-7), the between-condition differences were even stronger (β ritual versus control = 0.70 , (0.24 , 1.16)). See figure 1 and the electronic supplementary material, table S1 for all estimates. Further modelling of these data using the Tweedie distribution revealed that the Tweedie model provided a better fit to the self-reported data than the OLS model, but there were no qualitative differences between the two models (see the electronic supplementary material, table S1).

Focusing on the ritual condition only, we further tested whether the length of ritual or the amount of movement during the ritual period substantially affected perceived post-treatment anxiety. We found that these variables had negligible predictive power (see the electronic supplementary material, table S2). Furthermore, we tested whether participants in the ritual condition associated the post-treatment

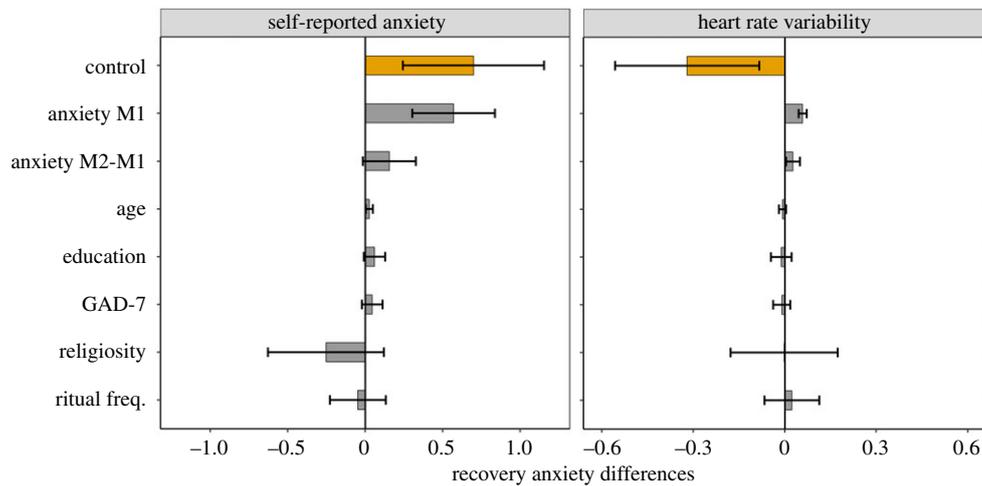


Figure 1. Estimated differences with 95% CI between the ritual and control conditions. As predicted, participants in the ritual condition had lower perceived post-treatment anxiety compared to those in the control condition after adjusting the model for baseline and preparation anxiety and their difference (anxiety M1; anxiety M2-M1) and control variables. Likewise, the physiological response mirrored these differences, with participants in the ritual condition having higher heart-rate variability during the recovery phase (i.e. lower physiological anxiety).

anxiety decrease with performing the ritual. On a 0–4 scale, where 4 meant that the ritual helped calm the participant ‘very much’, each step on this scale was associated with a 0.31 decrease in the perceived post-treatment anxiety ($\beta = -0.31, (-0.58, -0.04)$). Finally, the amount of ritualization measured as RR and DET of hand-acceleration patterns during the ritual performance did not explain a substantial amount of variation in post-treatment perceived anxiety (β recurrence = $-2.56, (-15.96, 10.85)$; β DET = $-1.79, (-4.63, 1.06)$); note that the large recurrence estimate is driven by the fact that we artificially restricted the mean RR to be approximately 2%, hence an increase of 1% is a relatively large increase on this scale—see the electronic supplementary material, table S2 for details).

(b) Physiological anxiety

As a measure of physiological anxiety, we assessed HRV (see the electronic supplementary material, section S1.2), which is an indicator of adaptive variability within the crucial regulatory systems of the human body. As such, higher HRV has been shown to predict longevity and behavioural flexibility in face of stressors [53,54]. In the context of the current study, decrease in HRV should correspond to physiological stress elicited by the public speaking paradigm while increase in HRV with lower physiological anxiety. Accordingly, HRV was negatively correlated with self-reported anxiety ($\beta = -0.33, (-0.63, -0.02)$) across the three measurement periods (baseline, preparation, recovery), suggesting that physiological stress generally corresponded with anxiety perceived by participants. Furthermore, similarly to self-reported anxiety, going from baseline to speech preparation decreased HRV values across the two conditions (β baseline versus preparation = $-0.08, (-0.15, -0.02)$), indicating that our stimulus also provoked physiological anxiety. However, contrary to the self-reported anxiety, we observed somewhat higher HRV during the baseline period in the control compared to the ritual condition (β ritual versus control = $0.32, (-0.007, 0.64)$). This suggests that participants in the control condition were more relaxed during baseline. The baseline difference further translated into a differential HRV decrease between the two conditions during speech preparation: participants in the control condition experienced

larger HRV decrease from baseline to the preparation period (β ritual decrease versus control decrease = $-0.12, (-0.25, 0.008)$). As discussed in the analysis section, we adjusted the statistical models for these unpredicted differences by including both baseline HRV and difference in HRV between the baseline and preparation periods in our models.

The basic model contrasting differences between conditions in HRV during the recovery period revealed lower HRV (i.e. larger physiological anxiety) in the control compared to the ritual condition ($\beta = -0.26, (-0.48, -0.04)$), and this difference was stronger after adjusting the model for demographic variables, GAD-7, religiosity and ritual participation ($\beta = -0.32, (-0.56, -0.08)$), supporting the prediction that religious ritual would decrease physiological anxiety (see figure 1 and the electronic supplementary material, table S3). Focusing further on the ritual condition only, the recovery HRV was not predicted by either the ritual length or the amount of movement during the ritual (see the electronic supplementary material, table S4). By contrast to the self-reported anxiety, the perceived calming effects of the ritual did not substantially affect HRV, although the direction of this effect was analogous to the model of perceived anxiety, that is, increasing HRV ($\beta = 0.06, (-0.09, 0.21)$). Finally, we did not observe any effect of hand-acceleration recurrence (RR) during ritual performance on subsequent recovery HRV ($\beta = -1.44, (-9.76, 6.88)$). There was a larger effect on HRV for the DET of hand-acceleration patterns, but the 95% CI crossed zero ($\beta = 0.75, (-0.74, 2.23)$).

4. Discussion

Our study investigated the effects of religious ritual on anxiety reduction among Mauritian women from the Marathi community. Using a modified public speaking paradigm to elicit anxiety, we found that participants in the ritual condition experienced greater anxiety reduction on both the self-reported and physiological level compared to the control condition. The test of a specific mechanism that might facilitate this effect, namely ritualization, revealed that the degree of ritualization had only a small and variable contribution to subsequent anxiety reduction. Together, these results suggest that habitual religious rituals may indeed play a causal role in anxiety

reduction, albeit the mechanisms by which such effects are attained need further investigation.

The observed effects of ritual practice on anxiety reduction are in accordance with what Mauritian Hindus themselves often report. Specifically, across over 100 ethnographic interviews that we conducted in Mauritius over the course of several years (unrelated to the current study), people commonly noted that performing temple rituals gives them 'peace of mind', 'inner peace', puts them 'at ease', and makes them feel 'calm', 'positive', or simply 'well'. Accordingly, in the present study, participants who reported that ritual performance helped to calm them down also experienced lower anxiety after ritual performance. By bringing the laboratory into the field and corroborating such phenomenological accounts with quantitative data at both the self-reported and physiological level, our study contributes to a rapprochement between laboratory and field methods and increases the ecological validity of our findings.

However, bringing experimental designs into field settings inevitably involves certain trade-offs between relevance and experimental control, and requires a balance between what is theoretically interesting and what is practically feasible [55]. For example, our study included only women because regular temple prayers in the studied community are typically performed by women. Although in other contexts similar rituals might be performed by men, we cannot know whether these effects would replicate in those contexts. The generality of our findings across both sexes is, therefore, still to be tested. Furthermore, the observed lower baseline HRV in the ritual condition might suggest that conducting the experiment in the local temple was stressful for our participants or that being in the temple itself could initially induce anxiety. Alternatively, conducting the study in an unfamiliar space might have contributed to slower recovery from anxiety in the control condition compared to the ritual condition, which took place in a familiar environment of the local temple. Future studies may test these alternative explanations by having the control condition take place in a familiar religious setting (or the ritual condition in a laboratory). Such a test might also account for the differential exposure to religious symbols, which were previously shown to positively affect death anxiety [56] and perhaps serve similar function for acute anxiety [57]. Another important limitation of the current study was the differential energy expenditure between the ritual and control conditions. Follow-up research may include an 'artificial ritual' condition where participants would perform movements similar to the ritual condition only without the habitual/religious aspect.

We believe that these comparisons should increase experimental control and improve inference of the relationship between rituals and anxiety; nevertheless, making such comparisons in real-world settings is challenging. Asking participants to perform artificially prescribed actions in a place of worship may be perceived as awkward, unnatural or even be ethically problematic. Hence, such manipulations are best performed in the laboratory where the objective is to isolate individual mechanisms in a neutral context, naturally complementing field experiments that investigate the phenomena of interest in their complexity. Indeed, the control condition in the current study provided only a simple baseline of anxiety dynamics to which we could compare the ritual effects exactly because we worried about the potential confounds of artificially disturbing the ritual ecosystem. As such, we documented initial experimental evidence that religious rituals

help decrease anxiety but without the extensive control typical for laboratory studies. The next logical step in testing this relationship is to manipulate individual building blocks of rituals in the laboratory where energy expenditure, familiarity with the environment or the presence of religious symbols could be standardized between conditions and mediating mechanisms of the anxiolytic ritual effects could be examined (e.g. [32,40]).

A productive compromise between laboratory and field studies is to use inobtrusive monitors that gather physiological and behavioural data during naturally occurring events [30,31,58]. While their explanatory power may be weaker compared to experimental manipulation, inobtrusive monitors allow for a good degree of control without the need to alter real-life events. Using this approach, we collected hand-acceleration patterns in the current study without the need to disturb participants during their solitary ritual performance, which allowed us to adjust our models for the differential movement patterns between the ritual and control conditions. Likewise, using these monitors afforded testing a possible mediating mechanism of the ritual anxiolytic effect, namely the degree of ritualization present during ritual performance. We predicted that participants displaying higher RR and DET in their movements would experience faster recovery from anxiety after the ritual.

While methodologically feasible, the results of RQA did not reveal substantial effects of RR and DET on anxiety reduction. This finding affords several possible explanations. For example, while spontaneous motor ritualization is characterized primarily by its repetitive and rigid structural properties, cultural rituals include a number of additional mechanisms of potential functional significance. Those mechanisms may be associated with influencing the odds of prospective hazards (magical thinking); evaluating action efficacy based on previous positive association (superstitious behaviour); and manipulating future hazard through powerful protective agents (belief in superhuman agents). Indeed, there is supportive evidence for each of these mechanisms being triggered by anxiogenic contexts. First, Friedland *et al.* [59] showed that when participants faced a choice between predicting or postdicting an outcome of a die roll, stressed participants more often chose prediction so as to influence the die roll. Second, anxiogenic situations provoke the use of various superstitious actions or lucky charms [60,61], especially when the stakes are high [25]. Finally, priming participants with randomness or low-control anxiogenic situations strengthened belief in powerful deities, [62–64] and previous research [60] showed that the presence of religious icons increases the perception of ritual efficacy. Thus, it is possible that owing to the complexity of religious rituals, ritualization may positively affect anxiety alleviation only in interaction with the aforementioned mechanisms. At the very least, such mechanistic interactions would certainly amplify the effects of individual mechanisms such as motor ritualization.

Nonetheless, the study by Karl & Fischer [40] suggested that ritualization alone may be sufficient to produce anxiolytic effects. In the current study too, the coefficients of DET were in the predicted direction for both measurements of recovery anxiety, although the 95% CI were too wide to afford univocal conclusions. This result suggests that if motor ritualization indeed has anxiolytic effects, these effects are rather subtle and we may have failed to detect them owing to limited sample size in the ritual condition (37 participants for the

self-reported measurement and 29 for the HRV measurement of recovery anxiety). Furthermore, in contrast to the laboratory experiments, the religious ritual we studied involved multiple movement sequences with intermittent preparation periods, which may have concealed the recurrent and deterministic patterns. A more subtle analysis focused only on specific sequences (e.g. when praying in front of the gods' statues) might better capture the effects of ritualized behaviour; alas, because we did not videotape the actual ritual performance, such nuanced analysis is not afforded by our data.

Furthermore, we proposed that the anxiolytic effects of ritualization are facilitated by increased predictive success in the cortical hierarchy and minimized internal entropy [32]. This theoretical framework should also be tested by measuring the mediating effects of ritually decreased internal entropy on anxiety alleviation. An indirect test might examine rituals with differential habituation rates, predicting that more habituated rituals should be more effective in decreasing internal entropy and, in turn, anxiety. A more direct test of the effects of ritualized behaviour on entropy minimization would be to assess whether ritualization helps to free cognitive resources that could be recruited to perform useful work (inverse of entropy). Moreover, while we have linked the increased predictive success of ritualized movements to a simple interoceptive appraisal of one own's actions, other mechanisms present in magico-religious rituals such as belief in powerful deities might increase predictive success on yet higher levels of cortical hierarchy, thus affording further assessment of this theoretical framework. For instance, ritual enactment of norms that are sanctified and enforced by a superhuman agent might decrease individual entropy and, thereby, anxiety by structuring social reality into organized patterns through which people can easily navigate and reduce uncertainty.

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Endnote

¹Note that the study by Karl & Fischer [40] also found that engaging in such ritualized behaviour, in turn, resulted in anxiety decrease; however, Karl and Fischer did not manipulate ritual performance *per se*.

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