Reports

Effects of Extreme Ritual Practices on Psychophysiological Well-Being

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Extreme ritual practices involving pain and suffering pose significant risks such as injury, trauma, or infection. Nonetheless, they are performed by millions of people around the world and are often culturally prescribed remedies for a variety of maladies, and especially those related to mental health. What is the actual impact of these practices on health? Combining ethnographic observations and psychophysiological monitoring, we investigated outcomes of participation in one of the world's most extreme rituals, involving bodily mutilation and prolonged suffering. Performance of this physically demanding ordeal had no detrimental effects on physiological health and was associated with subjective health improvements, and these improvements were greater for those who engaged in more intense forms of participation. Moreover, individuals who experienced health problems and/or were of low socioeconomic status sought more painful levels of engagement. We suggest two potential mechanisms for these effects: a bottom-up process triggered by neurological responses to pain and a top-down process related to increased social support and self-enhancement. These mechanisms may buffer stress-induced pressures and positively affect quality of life. Our results stress the importance of traditional cultural practices for coping with adversity, especially in contexts where psychiatric or other medical interventions are not widely available.

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Effects of Extreme Ritual Practices on Psychophysiological Well-Being

Religious beliefs and practices have major consequences for personal and public health. From dietary restrictions and substance use and avoidance to family planning, organ donation, and the prevention of sexually transmitted diseases, religious customs affect the quality of life of millions of people around the world (Koenig 2001, 2012; Zimmer et al. 2016). Previous research suggests that regularly engaging in certain religious activities may have beneficial health outcomes. Specifically, various studies have found positive effects of contemplative practices like prayer, yoga, and meditation on psychological and physical well-being (Bernardi et al. 2001; Gupta et al. 1997). Similar health benefits have also been shown for participation in collective rituals. For example, recent studies conducted in India have documented reduced stress following celebrations of the Hindu holidays Holi and Navratri (Snodgrass, Most, and Upadhyay 2017) and increased perceived well-being among participants in a massive pilgrimage (Tewari et al. 2012).

However, little is known about the effects of extreme religious rituals, that is, physically intense cultural practices that involve acute stress, pain, and/or bodily mutilation, although such practices are historically and cross-culturally widespread (Xygalatas 2012). Such ordeals may pose significant risks to participants' health, including injury, trauma, infection (Pellerin and Edmon 2013; Wong et al. 2012), and the transmission of infectious diseases (Memish et al. 2012). Despite those risks, however, such rituals are performed voluntarily by millions of people around the world (Rossano 2015; Xygalatas 2011) and in fact are often considered culturally prescribed remedies for a variety of maladies, most commonly those related to mental health (Jilek 1982). This folk association suggests that voluntarily undergoing short-term extreme suffering may positively affect one's health. Yet to this day there is limited evidence for this paradoxical relationship. A better understanding of this phenomenon is particularly important in the context of developing societies, where biomedical and folk health interventions often coexist, raising the question of whether these interventions are contradictory or might function in complementary ways. To examine this question, we investigated the effects of participation in the *kavadi attam* (burden dance), an extreme ritual performed annually by millions of Tamil Hindus around the world, on physical and psychological well-being.

Ethnographic Setting

The kavadi attam is part of a longer festival (e.g., the Thaipussam or the Chithirai) that involves preparations through fasting and prayer. On the day of the kavadi, male devotees pierce their bodies with numerous metallic objects, including needles, hooks, and rods impaled through both cheeks. Once these piercings are in place, devotees embark on a several-hours-long

pilgrimage to the temple of Lord Murugan, the most popular deity among Tamil Hindus, carrying portable altars on their shoulders. According to our measurements, these structures are often more than 3 m (10 ft) tall and can weigh up to 60 kg (130 lbs). Moreover, many men also walk on shoes made of nails or drag chariots the size of minivans by hooks attached to their skin. Women also participate but do not engage in the extreme activities. Instead, they carry a pot of milk or a miniature kavadi and have a single needle or a scarf over their mouth. Several hours later, when the pilgrims reach their destination, they must carry their kavadi up a steep hill before entering the temple, where they can finally lay down their burden and have their piercings removed.

Our study took place in the town of Quatre Bornes in Mauritius, an island nation in the Indian Ocean with a Hindu majority. The local shrine, known as the "Mountain Temple" (Kovil Montagne), is the oldest temple of Murugan on the island, and thousands of people visit it during the festival. The Thaipusam kavadi is a national holiday in Mauritius and is seen as one of the most important days of the year. Indeed, interviews conducted by the first author over the course of several years, as well as survey data collected by our team, suggest that in their overwhelming majority the members of the Tamil community consider the kavadi as the most important event in their spiritual lives.

Ethnographic work suggests that the kavadi is commonly seen as part of a reciprocal relationship with the deity, most often in the context of a vow undertaken in exchange for some favor (Ward 1984). Our field interviews revealed that people's stated reasons for the performance of the kavadi tend to fall under two main themes—one being self-centered, related to personal experience, or involving some form of exchange between the devotee and the god, and the other being outward oriented, pertaining to the relationship between the devotee and the religious community. When people speak about the specific benefits of participation, they most commonly mention healing and improved well-being for devotees and their families. In addition, our field observations also suggest that performing the kavadi brings increased social support and recognition within the community, indicating that social factors may be involved in the purported health benefits of participation.

During the preparations, friends and relatives gather at participants' houses to help them build their kavadi. After the ritual, each household hosts a large dinner attended by kith and kin. The kavadi is stripped of the decorative flowers and feathers but typically remains in the house or the yard as a perennial reminder of their participation, like the photographs of participants with their kavadis and piercings that decorate their walls. The festival is a frequent topic of conversation, and those who participate regularly are seen as more devout and trustworthy. This is not lost on the local politicians and high-ranking officials, who diligently attend every year.

Given the personal and cultural salience of this ritual, as well as the historical persistence of such ritual practices over the course of millennia, we theorized that the benefits of participation should exceed the costs. That is, while engaging in these rituals may be stressful and temporarily harm participants' physiological health, there might be long-term benefits associated with psychological well-being that outweigh these short-term costs. We therefore predicted that the extreme levels of pain and exertion will have no long-term negative physical effects, focusing our investigation on a number of markers of autonomic nervous and immune system responses, such as heart rate (HR), galvanic skin response (GSR), and sleep efficiency (SE). We remained agnostic toward potential positive physical health benefits of kavadi participation due to the lack of previous evidence.

On the contrary, we expected that participation would have a positive effect on psychological well-being. Previous studies showed beneficial health effects of social identification, connectedness, and belonging (e.g., Dressler et al. 2013), and all these factors may be at play during the performance of extreme rituals (Khan et al. 2015). Moreover, as participation in painful collective rituals increases social connectedness and investment in group identities (Bastian, Jetten, and Ferris 2014*a*), we hypothesized that those suffering from social marginalization would engage in more intense versions of the ritual to increase their overall well-being.

Methods

Participants and Procedure

We enrolled 39 males (mean age = 45.21, SD = 15.76), as only men engage in the extreme ritual actions: 19 subjects who carried a kavadi and underwent body piercings, matched with 20 controls from the same community (Tamil Hindus from the same town who attended the same temple) who did not perform the ritual. Participants were recruited by local research assistants through door-to-door contact. People of all socioeconomic backgrounds participate in the kavadi, so our sample was drawn from the general population (see supplemental PDF, available online).

Two participants dropped out early in the course of the study from the ritual group, leaving a total of 37 subjects. Participants wore a portable monitoring device that recorded stress levels, SE, and physical activity for three weekly periods over the span of 2 months: (*a*) 3 weeks before the kavadi (pre-ritual), (*b*) during the week of the festival, and (*c*) 3 weeks after the kavadi (post-ritual). Participants' HR activity was also recorded on a daily basis during these measurement periods. In conjunction with these measurements, survey instruments were administered at the end of pre- and post-ritual time points to assess various aspects of psychological well-being. On average, there were 23 days between pre-ritual and ritual and 23 days between ritual and post-ritual. The study was conducted in accordance with the ethical standards of the Declaration of Helsinki and approved by the Institutional Review Board of the Czech Association for the Study of Religions. Informed written consent was obtained from all participants.

Physiological Measures

The BodyMedia SenseWear mini armband (SWM) is a multisensor device that records physiological data related to sympathetic nervous system and immune system activity. It combines measures of electrodermal activity, skin temperature and heat flux, and acceleration of movement with demographic information (age, gender, and body mass index [BMI]) to estimate a wide range of indicators of general health, including stress, energy expenditure, physical activity, and metabolic equivalent units (Cha et al. 2018; Elfering and Grebner 2011; Geršak and Drnovšek 2016). The device is similar in size and weight to a wristwatch. It is worn under the sleeve, requires no input from the wearer, and provides no feedback, which makes it unobtrusive and easy to use.

The armband was worn on the left upper arm all day and night during each recording period and only removed for showering and downloading of data. Armband data showed that participants wore the device 92.2% of the time on average (more than 22 hours per day), with no significant differences between groups or time points. To ensure that the duration of the physiological data was consistent and comparable between conditions and time points, the analysis included only a period of 72 hours of continuous recording at a time. We monitored the following physiological indicators of health: (*a*) HR, an indicator of stress, measured daily using an Omron M6 monitor; (*b*) electrodermal activity, another key biomarker of stress (Horvath 1978), assessed in terms of GSR by measuring conductivity between two electrodes on the backside of the armband in direct contact with the skin (calibrated range: 56K–20M ohms); and (*c*) SE, an indicator of innate immune system activity (Majde and Krueger 2005), derived by an algorithm in the SWM estimating the number and duration of interruptions that participants experienced after falling asleep each night, expressed as a percentage relative to uninterrupted sleep.

To control for possible intervening variables, we collected data on age, BMI, and physical activity. Physical activity levels (PALs) were assessed by the armband as the average activity (in metric equivalence units) over total waking time. To account for the effects of relative humidity on apparent temperature and control for any confounding effects of seasonal changes on GSR in our statistical models, we assessed near-body temperature and ambient humidity using a combination of armband and meteorological data to create a heat index (HI) for each participant (Steadman 1979; see supplemental PDF).

Psychological Measures

The following clinically and cross-culturally validated instruments were administered at the end of pre- and post-ritual periods to assess psychological well-being: depression was measured using the Patient Health Questionnaire (PHQ-9; Kroencke, Spitzer, and Williams 2001); anxiety was assessed using the Generalized Anxiety Disorder Questionnaire (GAD-7; Spitzer et al. 2006); quality of life was measured with a short version of the EUROHIS-QOL including only the health-related items (Schmidt 2006); and self-assessed health was obtained using the Single-Item Health Status survey (SIHS; Bowling 2005) , which has been shown to be more parsimonious and on par with multi-item/multifactor instruments in predicting a number of health outcomes (DeSalvo et al. 2006).

Observational Data

A variable related to ritual pain was constructed on the basis of a median split on the number of piercings each participant endured (needles, hooks, and skewers) during the ritual (mean = 63.23, SD = 11.61, maximum = 403). The median split was motivated by the assumption that the effects of pain were not linear. Instead, our participants naturally clustered into two groups, with usually one or two piercings in the low pain group and 100 or more piercings in the high pain group.

Socioeconomic Status (SES)

To assess SES, we collected demographic information on educational achievement, occupation, and material wealth (Shavers 2007). Educational achievement was measured by years of formal education. To assess occupational status in a contextually meaningful way, we elicited the exhaustive list of occupations among our participants and asked 20 independent local raters unrelated to our sample to rate each occupation on a scale of 1–5, ranging from "not at all prestigious" to "very prestigious" (ICC[2,1] = 0.85). Finally, material wealth was measured by the number of real estate units (residential and commercial units and plots of land) and vehicles owned per household. These variables were factor scored to produce a composite measure of SES (see supplemental tables, available online).

Data Analysis

The relationships between outcome variables and predictors were analyzed in R (ver. 3.4.1; R Core Team 2012). Each model included an effect of condition, time, and condition × time interaction to assess the difference in changes from pre- to post-ritual within and between conditions. Since time periods were nested within individuals, we also included a random intercept for each individual. Furthermore, each model included theoretically important predictors to control for possible confounding variables (age, BMI, PAL, and HI). HR, quality of life, and self-assessed health were modeled assuming normally distributed residual errors; GSR data were modeled assuming gamma distribution; SE data were log transformed to account for the naturally sigmoid distribution of percentage data; and depression and anxiety were modeled using negative binomial distribution due to the fact that both measures come from a count process (with overdispersion).

Focusing on the ritual group, we built two logistic models examining whether SES and self-reported chronic illness predict

low- or high-intensity engagement in the ritual (pain indicated by a number of piercings) and two generalized linear models assuming gamma distribution of residual errors to predict stress during the ritual (indicated by GSR). To further examine the influence of ritual participation on our survey measures, we used pain and stress as predictors of the outcome variables while holding pre-ritual levels of those variables constant.

Six individuals (four in the experimental and two in the control condition) had incomplete data because they missed either the pre- or the postperiod. We thus performed the same set of analyses on two data sets: one excluding those individuals ($n = 31$) and one and imputing missing values ($n = 37$; see supplemental PDF for details). Here we report analyses conducted on the imputed data set. For the results of the reduced data set, see supplemental tables.

Results

Pre-ritual, there were no substantial differences between conditions in any of the physiological and activity measures, suggesting that no systematic disparities between control and experimental subjects were present before the ritual. We observed a considerable decrease in mean HR from pre-ritual to post-ritual for the ritual group (average change = 3.80 beats per minute), although this change was not significantly different from the change in the control group. There was also a substantial decrease in mean GSR from pre- to post-ritual in the ritual group (average change in tonic GSR = 0.42 μS) but no significant condition × time interaction. We found no substantial difference between conditions, times, or condition × time interaction in SE (average efficiency = 75%). Together, these results indicate that while we observed differences between time periods, the differences were caused by natural fluctuations or other unmeasured variables rather than by ritual participation (see table 1; fig. 1*A*–1*C*).

Looking at our survey measures, there were no substantial differences from pre- to post-ritual in the ritual group nor a significant condition × time interaction in depression or anxiety. Overall, we observed low levels of clinical anxiety (mean = 4.04 out of 21) and depression (mean = 3.22 out of 27), suggesting that there was not enough variance that could be potentially affected by ritual participation. Furthermore, we found no significant difference in quality of life from pre- to post-ritual periods in the ritual group (average change = 0.14 on a scale of 1–5), but there was a significant condition × time interaction, suggesting a different development of trajectories between conditions (increase in the ritual group and decrease in the control group; estimated difference $\beta = 0.29$; $P = .05$). Finally, we observed a significant increase in self-assessed health in the ritual group from pre- to post-ritual (average change = 0.49 on a scale of 1–5; $P = .04$), and this increase was significantly higher compared with that of the control group ($\beta = 0.61$; $P = .04$). See table 1 and figure 1*D*–1*G* for detailed β estimates.

Focusing on the ritual group, we first examined the relationship between sociodemographic factors and ritual intensity, regressing pain (no. piercings), and stress (indicated by GSR) during the kavadi on our measures of SES and self-reported chronic illness. We found that pain was predicted by SES: the odds of being in the high-pain group decreased by a factor of 8 with an increase of 1 SD in SES ($P = .05$). There was also a positive trend for self-reported chronic illness: having an illness increased the odds of being in the high-pain group by a factor of 10 ($P = .08$). However, due to the fact that the high-pain group consisted of only four individuals, these effects might be substantially overestimated.

Table 1. Hierarchical models of outcome variables measured before and after the ritual (imputed data set)

Variables	HR	GSR	SE	Depression	Anxiety	Quality of life	Perceived health
Intercept	78.28 (2.76)***	−.83 (.28)**	−.35 (.06)***	.63 (.39)	.97 (.34)**	4.09 (.11)***	2.85 (.26)***
Age (years)	−.14 (.11)	.01 (.01)	−.002 (.002)	−.02 (.01)	−.01 (.01)	.00 (.004)	−.01 (.01)
Body mass index	−.44 (.56)	.04 (.04)	.01 (.01)	−.01 (.06)	.02 (.05)	.00 (.02)	.06 (.05)
Heat index (°F)	…	.73 (.50)	…	…	…	…	…
Physical activity	−3.91 (5.29)	.03 (.04)	−.002 (.10)	.10 (.76)	.72 (.61)	.29 (.20)	.62 (.54)
Pre: ritual vs. control	2.86 (3.69)	−.31 (.34)	−.03 (.07)	.88 (.47)+	.57 (.42)	−.19 (.14)	.08 (.35)
Ritual: pre vs. post	−5.39 (2.48)*	−1.27 (.40)**	.01 (.05)	.32 (.49)	−.17 (.44)	.12 (.11)	.49 (.23)*
Ritual vs. control (pre–post)	4.56 (3.26)	.41 (.28)	.05 (.06)	−.85 (.63)	.18 (.56)	−.29 (.14)*	−.61 (.29)*
Observations	74	74	74	74	74	74	74

Note. Each model contains coefficients with SEM for important predictors, condition effect, time effect, and a condition × time interaction. Galvanic skin response coefficients assume gamma distribution with log link; sleep efficiency coefficients are on a log scale; depression and anxiety coefficients assume negative binomial distribution. Intercept is the ritual condition pre-ritual; the last predictor ["Ritual vs. control (pre-post")] represents condition × time interaction. Other predictors were centered on their mean. GSR = galvanic skin response; HR = heart rate; pre = pre-ritual; post = post-ritual; SE = sleep efficiency.

+ $P < .1$.

* $P < .05$.

** $P < .01$.

*** $P < .001$.

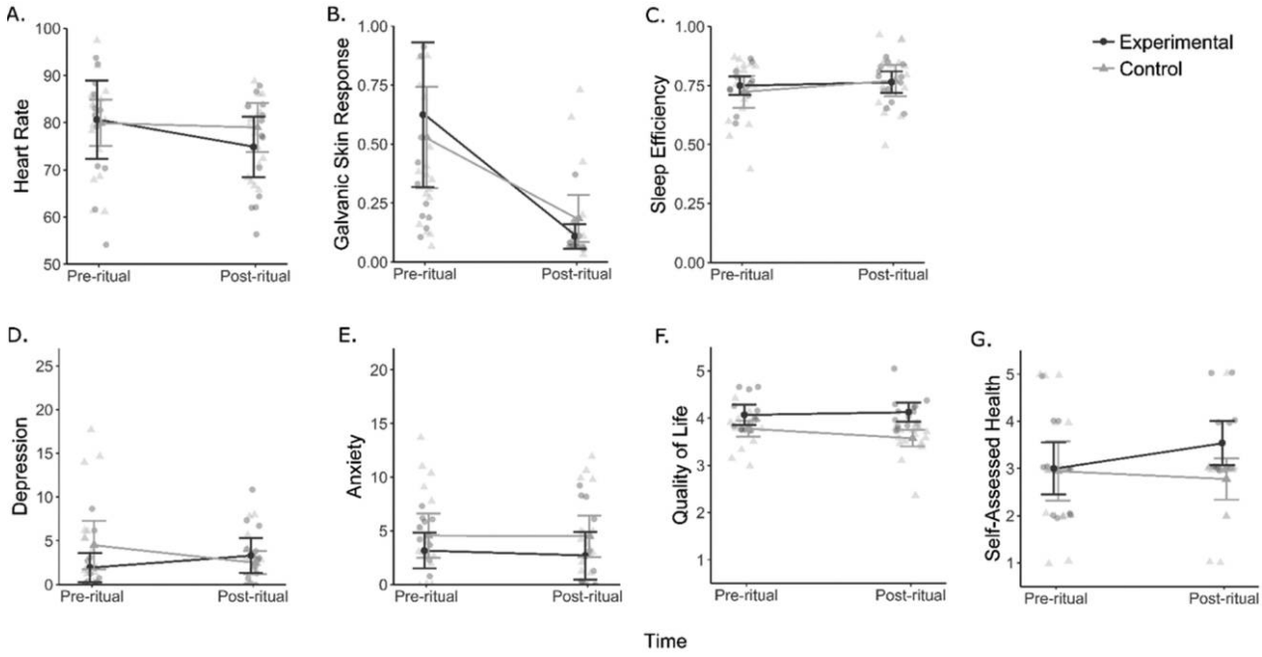

Figure 1. Effects of the *kavadi* ritual on physiological and psychological health. *A–C*, Participation in extreme rituals was not associated with any differences in our physiological health measurements post-ritual. *D*, *E*, Extreme rituals had no effect on clinical symptoms of depression or anxiety. *F*, *G*, We observed significantly higher increase in perceived quality of life and health in the experimental group. A color version of this figure is available online.

To further investigate the specific factors mediating the ritual effects on perceived quality of life and health, we used pain and stress as indicators of ritual intensity during the kavadi to predict changes in the post-ritual measurements (see fig. 2 for illustrations). Adjusting for pre-ritual levels, we found that neither pain nor stress during the kavadi substantially affected post-ritual quality of life (albeit both coefficients were positive βpain $= 0.26$; βstress $= 0.14$). However, higher pain suffered during the ordeal positively predicted self-assessed health post-ritual ($\beta = 0.72$; $P = .04$), and we observed a similar, albeit variable, trend for stress ($\beta = 0.35$). See table 2 and figure 3.

Discussion

Despite their potential risks, extreme rituals in many contexts are paradoxically associated with health and healing (Jilek 1982; Ward 1984). Our findings suggest that within those contexts, such rituals may indeed convey certain psychological benefits to their performers. Our physiological measurements show that the kavadi is very stressful and high in energetic demands (fig. 2*C*, 2*D*). But the ostensibly dangerous ordeal had no detectable persistent harmful effects on participants, who in fact showed signs of improvement in their perceived health and quality of life. We suggest that the effects of ritual participation on psychological well-being occur through two distinct but mutually compatible pathways: a bottom-up process triggered by neurological responses to the ordeal and a top-down process that relies on communicative elements of ritual performance (Hobson et al. 2017).

Specifically, the bottom-up pathway involves physical aspects of ritual performance related to emotional regulation. Ritual is a common behavioral response to stress (Lang et al. 2015; Sosis 2007), and anthropological evidence shows that in many cultures dysphoric rituals involving intense and prolonged exertion and/or altered states of consciousness are considered as efficient ways of dealing with various illnesses (Jilek 1982). In our study, those who suffered from chronic illnesses engaged in more painful forms of participation by enduring more piercings. Notably, higher levels of pain during the ritual were associated with improvements in self-assessed health post-ritual. Although the pain was relatively short-lived, there is evidence that the social and individual effects of participation can be long-lasting (Tewari et al. 2012; Whitehouse and Lanman 2014).

The sensory, physiological, and emotional hyperarousal involved in strenuous ordeals can produce feelings of euphoria and alleviation from pain and anxiety (Fischer et al. 2014; Xygalatas 2008), and there is evidence of a neurochemical basis for these effects via endocrine alterations in neurotransmitters such as endorphins (Boecker et al. 2008; Lang et al. 2017) or endocannabinoids (Fuss et al. 2015). These endocrine effects are amplified when performed collectively, as shown by studies

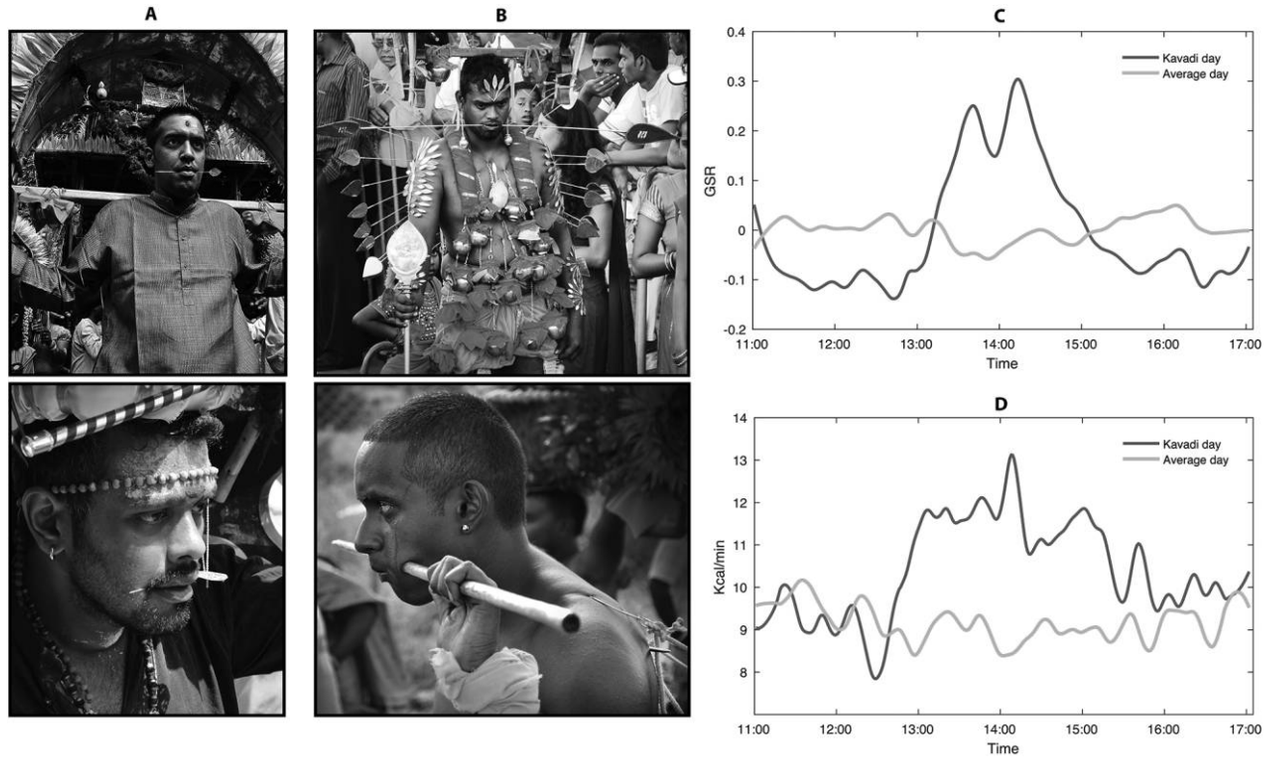

Figure 2. Levels of ritual intensity. *A*, Low-intensity participants have one or a few piercings on the face and carry the *kavadi* on their shoulders. *B*, High-intensity participants can have hundreds of piercings all over their bodies, including long spears or rods. The devotee on the top right is also carrying a kavadi affixed to his head. The devotee on the bottom right is dragging a large chariot by hooks attached to his back. *C*, Smoothed galvanic skin response (GSR) levels during the kavadi compared with those on an average day. GSR data were centered on their mean and averaged across participants to account for changes in heat index between our measurement periods. *D*, Mean smoothed lines for energy expenditure during the day of the kavadi and averaged days from the pre- and post-periods. Note the 14:00 peak on the day of the kavadi, marking the time that most participants reached the climax of the ritual when climbing the steps to the mountain temple. A color version of this figure is available online.

of communal chanting, dancing, and other common aspects of ritual (Tarr et al. 2015). While it is uncertain how long-lasting these effects are, such euphoric experiences may become self-referential for future well-being assessment.

At the same time, a top-down pathway involves social-symbolic aspects of ritual. Cultural expectations and beliefs in the healing power of the ritual may act as a placebo (McClenon 1997), buffering stress-induced pressures on the immune system (Rabin 1999). In addition, social factors can interact with and amplify the low-level effects of physiological arousal (Konvalinka et al. 2011). Performed collectively, these rituals can provide additional comfort through forging communal bonds, providing a sense of community and belonging, and building social networks of support (Dunbar and Shultz 2010; Xygalatas et al. 2013). The Thaipusam is the most important collective event in the life of this community, and higher investments in this ritual are ostensibly perceived by other members as signs of allegiance to the group, consequently enhancing participants' reputation (Watson-Jones and Legare 2016) and elevating their social status (Bulbulia 2004; Power 2017*a*). Multiple lines of research suggest that individuals are strongly motivated to engage in status-seeking efforts (Cheng, Tracy, and Henrich 2010; Willard and Legare 2017) and that there is a strong positive relationship between social rank and subjective well-being (Anderson et al. 2012; Barkow et al. 1975). Indeed, we found that individuals of lower socioeconomic status were more motivated to invest in the painful activities that can function as costly signals of commitment. Recent evidence from a field study in India shows that those who partake in these rituals indeed reap the cooperative benefits that result from increased status (Power 2017*b*).

In addition, the cost of participation can have important self-signaling functions. On the one hand, it can boost performers' perceived fitness and self-esteem, which positively affects mental health (Barkow et al. 1975). On the other hand, through a process of effort justification, such costs can strengthen one's attachment to the group and sense of belonging (Festinger 1962; Sosis 2003). This role of costly rituals in generating positive subjective states (Bastian et al. 2014*b*; Fischer et al. 2014; Wood 2016) and facilitating social bonding (Bastian, Jetten, and Ferris

Table 2. Models of pain and stress and of outcome variables for the ritual group measured after the *kavadi* ritual (imputed data set)

	Pain		Stress		Quality of life		Perceived health	
Variables	1	2	1	2	1	2	1	2
Intercept	−2.30 (1.05)*	−1.20 (.78)	4.06 (1.22)**	3.29 (.91)**	4.12 (.11)***	4.10 (.08)***	3.36 (.22)***	3.29 (.15)***
Illness	2.30 (1.33)$^{+}$	…	−1.59 (1.55)	…	…	…	…	…
Socioeconomic status	…	−2.11 (1.10)$^{+}$	…	−.05 (.80)	…	…	…	…
Pre	…	…	…	…	.29 (.31)	.43 (.29)	.59 (.20)*	.48 (.18)*
Stress	…	…	…	…	.14 (.26)	…	.35 (.49)	…
Pain	…	…	…	…	…	.26 (.17)	…	.72 (.30)*
Observations	17	17	17	17	17	17	17	17

Note. Each modeled number contains coefficients with SEM. Pain is modeled with logistic regression predicting the probability of being in the high-pain group. Stress is modeled with generalized linear model assuming gamma distribution. Quality of life and self-assessed health were modeled with ordinary least squares regression, holding their mean pre-ritual levels constant. Intercept is the mean of centered predictors. Pre = measurements pre-ritual.

$^{+}$ $P < .1$.

* $P < .05$.

** $P < .01$.

*** $P < .001$.

2014*a*; Whitehouse and Lanman 2014) may offer insights into the functions of painful religious practices.

Given the constraints of our naturalistic setting, there are several potential confounding factors that impose important limitations on the inferential power of our study. Rituals like the kavadi cannot be studied in controlled settings and pose extraordinary demands on field designs. However, these events always take place within specific contexts, and artificially reducing the complexity of these environments would result in an impoverished view of their nature.

There are always trade-offs between control and ecological validity, but there is an added benefit of combining ethnographic and experimental work, namely, that field observations can increase the researcher's confidence in the validity of the findings. Our study used a mixed methodology that combined objective and subjective measures, which allowed us to examine the ritual in its natural context. Inevitably, however, this setting presented significant challenges. Our sample size was restricted and random assignment was not possible. To compensate for this, any demographic differences between our experimental and control groups were accounted for in our statistical models. However, such differences may point to underlying confounding covariates that we did not include in our analyses due to the relatively small sample.

In addition, because this sample was derived from the general population of ritual participants, we were not able to specifically recruit enough individuals who suffered from depression or anxiety disorders. Ethnographic and clinical evidence suggests that participation in rituals, especially high-intensity ones, can have positive effects on those suffering from such conditions (Balbuena, Baetz, and Bowen 2013; Barton et al. 2013). However, in our sample, we observed floor effects and little variance in our measures of clinical depression and anxiety, which limited the utility of those measures in our study. Future studies that can obtain access to clinical populations that participate in similar rituals may be able to provide more evidence on that front.

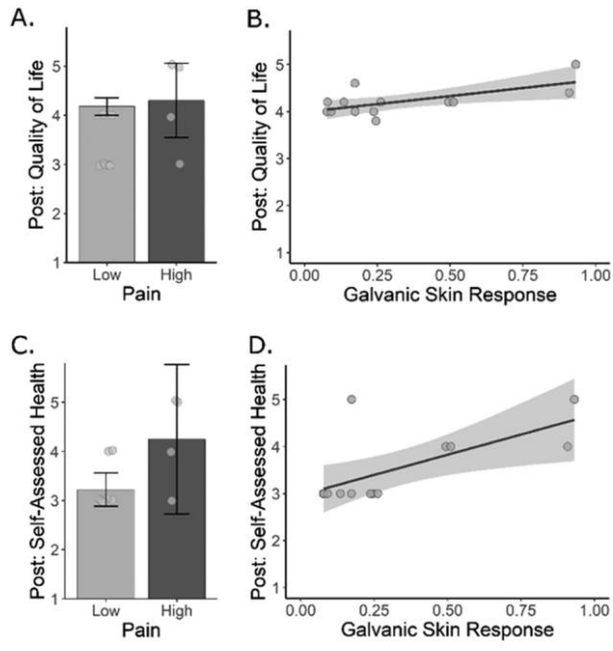

Figure 3. Effects of ritual intensity on psychological health. *A*, *B*, Pain and stress experienced during the *kavadi* ritual had no significant effect on perceived quality of life post-ritual. *C*, *D*, The number of piercings (indicator of pain during ritual) was positively associated with self-assessed health after the kavadi. Stress assessed by galvanic skin response showed a similar trend. A color version of this figure is available online.

Overall, our physiological measures of health were defined by what was theoretically interesting but also technologically feasible, as well as by the affordances of our field setting. Hormonal markers of psychosomatic stress would offer a valuable addition to our data (Snodgrass et al. 2017), but most available techniques cover only short time spans, which makes their use in longitudinal designs logistically problematic. The development of new methodologies might allow future studies to overcome these problems (van Holland, Frings-Dresen, and Sluiter 2011; Zahran et al. 2015). Further research may also expand the time span of the observations, examining the effects of repeated participation across the life span.

In summary, our findings suggest that people, and especially low-status individuals, may seek out extreme ritual practices because these practices can function as effective coping strategies within their local contexts. Thus, age-old cultural practices that seem risky, unpleasant, or dangerous can have real-life consequences for their practitioners by utilizing pain and suffering as strategies of resilience and coping with environmental stressors. Whether those effects are driven primarily by biological or social factors, or a combination thereof, should be clarified in further research. In any case, our results stress the importance and utility of traditional cultural practices for health management. Although these practices are not meant to substitute for biomedical interventions, their complementary utility should not be overlooked, especially in contexts where psychiatric or other medical interventions are not widely available or are associated with stigma.

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