**Effects of extreme ritual practices on psychophysiological well-being**

**Dimitris Xygalatas,1\* Sammyh Khan,2 Martin Lang,3,4 Radek Kundt,4 Eva Kundtová-Klocová,4 Jan Krátký,4 John Shaver5**

1 Department of Anthropology, University of Connecticut, Storrs, CT 06269, USA

2 School of Psychology, Keele University, Keele ST5 5BG, UK

3 4 Department of Human Evolutionary Biology, Harvard University, Cambridge, MA 02138, USA

4 Laboratory for the Experimental research of Religion (LEVYNA), Faculty of Arts, Masaryk University, Brno 60200, Czech Republic

5 Religious Studies Programme, University ofOtago, Dunedin 9016, New Zealand

\*correspondence: xygalatas@uconn.edu

**Abstract**

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, especially related to mental health. What is the observable impact of these practices on health? Combining ethnographic observations and psycho-physiological 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 those 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 impact 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.

**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 of 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 for participants’ health, including injury, trauma, infection (Pellerin and Edmond, 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, 2005; Xygalatas, 2011), and in fact are often considered culturally prescribed remedies for a variety of maladies, most commonly related to mental health (Jilek, 1982). This folk association suggests that voluntarily undergoing short-term extreme suffering may positively impact 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 co-exist, 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 *vel kavadi*, an extreme ritual performed annually by millions of Tamil Hindus around the world, on physical and psychological well-being.

**Ethnographic setting**

The kavadi is part of a longer festival (e.g. the Thaipussam or the Chithirai), which involves preparations through fasting and prayer. On the day of the kavadi, male devotees pierce their body with numerous metallic objects, including needles, hooks, and rods impaled through both cheeks. Once these piercings are in place, devotees embark on a several-hour-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 over three meters (10ft) tall and can weigh up to 60kg (130lbs). 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 they 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 celebration of the 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-centred, 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 of 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 them 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, galvanic skin response, and sleep efficiency. 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 impact 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, 2014a), 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 (M 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 until all the devices were in use. People of all socio-economic backgrounds participate in the kavadi, so our sample was drawn from the general population (see supplemental materials).

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, sleep efficiency, and physical activity for three weekly periods over the span of two months: a) three weeks before the kavadi (Pre-ritual); b) during the week of the festival; and c) three weeks after the kavadi (Post-ritual). Participants’ heart rate 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 multi-sensor 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) to estimate a wide range of indicators of general health, including stress, energy expenditure, physical activity, and metabolic equivalent units (Geršak and Cha et al., 2018; Drnovšek, 2016, Elfering and Grebner, 2011). The device is of similar 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, only removed for showering and data downloading. Armband data showed that participants on average wore the device 92.2% of the time (over 22 hours a 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 only included a period of 72 hours of continuous recording at a time. We monitored the following physiological indicators of health:

• Heart Rate (HR), an indicator of stress, measured daily using an OMRON© M6 heart rate monitor.

• Electrodermal activity, another key biomarker of stress (Horvath, 1978), assessed in terms of Galvanic Skin Response (GSR) by measuring conductivity between two electrodes on the backside of the armband in direct contact with the skin (calibrated range: 56k–20M ohms).

• Sleep Efficiency (SE), an indicator of innate immune system activity (Majde & 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, Body Mass Index (BMI), and physical activity. Physical Activity Levels (PAL) 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 Supplementary Information).

***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 (SIHS) (Bowling, 2005), which has been shown to be more parsimonious and on par with multi-item/multi-factor 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.

***Socio-Economic 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]=.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).

***Data analysis***

The relationships between outcome variables and predictors were analysed in R (v3.4.1) (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). Heart Rate, Quality of Life, and Self-Assessed Health were modelled assuming normally distributed residual errors; GSR data were modelled assuming gamma distribution; Sleep Efficiency data were log-transformed to account for the naturally sigmoid distribution of percentage data; and Depression and Anxiety were modelled 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 measurement). 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 Post- period. We thus performed the same set of analyses on two datasets: one excluding those individuals (n=31), and one and imputing missing values (n=37) (see Supplementary Information for details). Here we report analyses conducted on the imputed dataset. For results of the reduced dataset 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 BPM), 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, these differences were caused by natural fluctuations or other unmeasured variables rather than by ritual participation (see Tab. 1 and Fig. 1A.-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 from 1 to 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 β=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 from 1 to 5; p=.04), and this increase was significantly higher compared to the Control group (β=0.61; p=.04). See Tab. 1 and Fig. 1 D.-G. for detailed β-estimates.

 Focusing on the Ritual group, we first examined the relationship between sociodemographic factors and ritual intensity, regressing Pain (the number of piercings) and Stress (indicated by GSR) during the kavadi on our measures of socio-economic status (SES) and self-reported chronic illness. We found that Pain was predicted by SES: odds of being in the high pain group decreased by a factor of eight with an increase of one standard deviation in SES (p=.05). There was also a positive trend for self-reported chronic illness: having an illness increased 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 comprised only four individuals, these effects might be substantially overestimated.

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). Controlling 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 (β=0.72; p=.04), and we observed a similar, albeit variable, trend for Stress (β=0.35). See Tab. 2 and Fig. 3.

**Discussion**

Despite their potential risks, in many contexts extreme rituals 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. A1-2). 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 that are 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 for 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 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 physiological 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, 2017a). 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, 2017b).

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 impacts 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., 2014b; Fischer et al., 2014; Wood, 2016) and facilitating social bonding (Bastian, Jetten, and Ferris, 2014a; 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 tradeoffs between control and ecological validity, but there is an added benefit in 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, though, 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 controlled 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 get access to clinical populations that participate in similar rituals may be able to provide more evidence on that front.

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 only cover 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 timespan of the observations, looking at the effects of repeated participation across the lifespan.

In summary, our findings suggest that people, and especially low-status individuals, may seek 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 primarily driven by biological or social factors (or a combination thereof) should be clarified by further research. In either case, our results stress the importance and utility of traditional cultural practices for health management. Although these practices are not meant to substitute 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.

**Acknowledgments**

This study was funded by the Interacting Minds Centre at Aarhus University, Denmark; the LEVYNA Laboratory for the Experimental Research of Religion at Masaryk University, Czech Republic; and the Medical School of the University of Exeter, UK. Dimitris Xygalatas acknowledges support the University of Connecticut Humanities Institute.

**References**

Anderson, C., Kraus, M. W., Galinsky, A. D., & Keltner, D. (2012). The Local-Ladder Effect. *Psychological Science*, 23(7), 764–771.

Balbuena, L., Baetz, M., & Bowen, R. (2013). Religious Attendance, Spirituality, and Major Depression in Canada: A 14-Year Follow-up Study. *Canadian Journal of Psychiatry*, 58(4), 225–232.

Barkow, J. H., Akiwowo, A. A., Barua, T. K., Chance, M. R. A., Chapple, E. D., Chattopadhyay, G. P., et al. (1975). Prestige and Culture: A Biosocial Interpretation [and Comments and Replies]. *Current Anthropology*, 16(4), 553–572.

Barton, Y. A., Miller, L., Wickramaratne, P., Gameroff, M. J., & Weissman, M. M. (2013). Religious attendance and social adjustment as protective against depression A 10-year prospective study. *Journal of Affective Disorders*, 146(1), 53–57.

Bastian, B., Jetten, J., & Ferris, L. J. (2014a). Pain as Social Glue: Shared Pain Increases Cooperation. *Psychological Science*, 0956797614545886.

Bastian, B., Jetten, J., Hornsey, M. J., & Leknes, S. (2014b). The Positive Consequences of Pain: A Biopsychosocial Approach. *Personality and Social Psychology Review*, 1088868314527831.

Bernardi, L., Sleight, P., Bandinelli, G., Cencetti, S., Fattorini, L., Wdowczyc-Szulc, J., & Lagi, A. (2001). Effect of rosary prayer and yoga mantras on autonomic cardiovascular rhythms: comparative study. *BMJ*, 323(7327), 1446–1449.

Boecker, H., Sprenger, T., Spilker, M., Henriksen, G., Koppenhoefer, M., Wagner, K., et al. (2008). The runner's high: opioidergic mechanisms in the human brain. *Cerebral Cortex*, 18(11), 2523.

Bowling, A. (2005). Just one question: If one question works, why ask several? *Journal of Epidemiology and Community Health*, 59(5), 342–345.

Bulbulia, J. (2004). Religious costs as adaptations that signal altruistic intention. *Evolution and Cognition*, 10(1), 19–38.

Cha, E., Talman, M. S., Massey, A. H., Yan, F., & Rogers, A. E. (2018). Sleep, Lifestyle Behaviors, and Cardiometabolic Health Markers in Overweight/Obese Young Adults: A Pilot Study Using the SenseWear® Armband. *Biological Research For Nursing*, *20*(5), 541–548.

Cheng, J. T., Tracy, J. L., & Henrich, J. (2010). Pride, personality, and the evolutionary foundations of human social status. *Evolution and Human Behavior*, 31(5), 334–347.

DeSalvo, K. B., Fisher, W. P., Tran, K., Bloser, N., Merrill, W., & Peabody, J. (2006). Assessing measurement properties of two single-item general health measures. Quality of Life Research, 15(2), 191–201.

Dressler, W. W., Dengah, F., Balieiro, M. C., & dos Santos, J. E. (2013). Cultural consonance, religion and psychological distress in an urban community. *Paideia*, *23*(55), 151–160.

Dunbar, R. I. M., & Shultz, S. (2010). Bondedness and sociality. *Behaviour*, 147(7), 775–803.

Elfering, A., & Grebner, S. (2011). Ambulatory assessment of skin conductivity during first thesis presentation: Lower self-confidence predicts prolonged stress response. *Applied Psychophysiology Biofeedback*, *36*(2), 93–99.

Festinger, L. (1962). *A Theory of Cognitive Dissonance*. Stanford University Press.

Fischer, R., Xygalatas, D., Mitkidis, P., Reddish, P., Tok, P., Konvalinka, I., & Bulbulia, J. (2014). The Fire-Walker’s High: Affect and Physiological Responses in an Extreme Collective Ritual. *PLoS ONE*, 9(2), e88355.

Fuss, J., Steinle, J., Bindila, L., Auer, M. K., Kirchherr, H., Lutz, B., & Gass, P. (2015). A runner’s high depends on cannabinoid receptors in mice. *Proceedings of the National Academy of Sciences*, 112(42), 13105–13108.

Geršak, G., & Drnovšek, J. (2016). Sensewear body monitor in psychophysiological measurements (Vol. 57, pp. 437–441). Presented at the IFMBE Proceedings, Cham: Springer International Publishing.

Gupta, R., Prakash, H., Gupta, V. P., & Gupta, K. D. (1997). Prevalence and determinants of coronary heart disease in a rural population of India. *Journal of Clinical Epidemiology*, 50(2), 203–209.

Hobson, N. M., Schroeder, J., Risen, J., Xygalatas, D., & Inzlicht, M. (2017). The Psychology of Rituals: An Integrative Review and Process-Based Framework. *Personality and Social Psychology Review.* DOI: 10.1177/1088868317734944

Horvath, F. (1978). An experimental comparison of the psychological stress evaluator and the galvanic skin response in detection of deception. *Journal of Applied Psychology*, 63(3), 338–344.

Jilek, W. G. (1982). Altered states of consciousness in North American Indian ceremonials. *Ethos*, 10(4), 326–343.

Khan, S. S., Hopkins, N., Reicher, S., Tewari, S., Srinivasan, N., & Stevenson, C. (2015). Shared identity predicts enhanced health at a mass gathering. *Group Processes and Intergroup Relations*, *18*(4), 504–522.

Koenig, H. G. (2001). Religion and Medicine II: Religion, Mental Health, and Related Behaviors. *Int’l. J. Psychiatry in Medicine*, *31*(1), 97–109.

Koenig, H. G. (2012). Religion, Spirituality, and Health: The Research and Clinical Implications. *ISRN Psychiatry*, *2012*, 1–33.

Konvalinka, I., Xygalatas, D., Bulbulia, J., Schjoedt, U., Jegindø, E.-M. E., Wallot, S., et al. (2011). Synchronized arousal between performers and related spectators in a fire-walking ritual. *Proceedings of the National Academy of Sciences of the United States of America*, 108(20), 8514–8519.

Kroencke, K., Spitzer, R., & Williams, J. (2001). The PHQ-9: validity of a brief depression severity measure. *Journal of General Internal Medicine*, 16(606–613).

Lang, M., Krátký, J., Shaver, J. H., Jerotijević, D., & Xygalatas, D. (2015). Effects of Anxiety on Spontaneous Ritualized Behavior. *Current Biology*, 25, 1–6.

Lang, M., V. Bahna, J. Shaver, P. Reddish & D. Xygalatas (2017). Sync to link: Endorphin-mediated synchrony effects on cooperation. *Biological Psychology* 127:191-197.

Majde J.A., & J.M. Krueger (Dec 2005). Links between the innate immune system and sleep. *The Journal of Allergy and Clinical Immunology*. 116(6): 1188–98.

McClenon, J. (1997). Shamanic healing, human evolution, and the origin of religion. *Journal for the Scientific Study of Religion*, 345–354.

Memish, Z. A., Stephens, G. M., Steffen, R., & Ahmed, Q. A. (2012). Emergence of medicine for mass gatherings: Lessons from the Hajj. *The Lancet Infectious Diseases*, *12*(1), 56–65.

Pellerin, J., & Edmond, M. B. (2013). Infections associated with religious rituals. *International Journal of Infectious Diseases*, 17(11), e945–e948.

Power, E. A. (2017a). Discerning devotion: Testing the signaling theory of religion. *Evolution and Human Behavior*, 38(1), 82–91.

Power, E. A. (2017b). Social support networks and religiosity in rural South India. *Nature Human Behavior*, 1(3), 1–6.

R Core Team. (2012). *R: a language and environment for statistical computing, reference index version 2.15*. 1. R Foundation for Statistical Computing, Vienna, Austria.

Rabin, B. S. (1999). Religion and medicine. *The Lancet,* 353(9166), 1803–1804.

Rossano, M. J. (2015). The Evolutionary Emergence of Costly Rituals. *PaleoAnthropology*, (July), 78–100.

Schmidt, S. (2006). The EUROHIS-QOL 8-item index: psychometric results of a cross-cultural field study. *The European Journal of Public Health*, 16(4), 420–428.

Shavers, V. L. (2007). Measurement of socioeconomic status in health disparities research. *Journal of the National Medical Association*, 99(9), 1013.

Snodgrass, J. G., Most, D. E., & Upadhyay, C. (2017). Religious Ritual Is Good Medicine for Indigenous Indian Conservation Refugees: Implications for Global Mental Health. *Current Anthropology*, 58(2), 257–284.

Sosis, R. (2003). Why aren’t we all hutterites? *Human Nature*, 14(2), 91–127.

Sosis, R. (2007). Psalms for safety. *Current Anthropology*, 48(6), 903–911.

Spitzer, R. L., Kroenke, K., Williams, J. B. W., & Löwe, B. (2006). A brief measure for assessing generalized anxiety disorder: the GAD-7. *Archives of Internal Medicine,* 166(10), 1092–1097.

Steadman, R. G. (1979). The assessment of sultriness. Part I: A temperature-humidity index based on human physiology and clothing science. *Journal of Applied Meteorology*, 18(7), 861–873.

Tarr, B., Launay, J., Cohen, E., & Dunbar, R. I. M. (2015). Synchrony and exertion during dance independently raise pain threshold and encourage social bonding. *Biology Letters*, *11*(10), 1-4.

Tewari, S., Khan, S., Hopkins, N., Srinivasan, N., & Reicher, S. (2012). Participation in Mass Gatherings Can Benefit Well-Being. *PLoS ONE*, 7(10), e47291.

van Holland, B. J., Frings-Dresen, M. H. W., & Sluiter, J. K. (2011). Measuring short-term and long-term physiological stress effects by cortisol reactivity in saliva and hair. *International Archives of Occupational and Environmental Health*, 85(8), 849–852.

Ward, C. M. (1984). Thaipusam in Malaysia: A Psycho-Anthropological Analysis of Ritual Trance, Ceremonial Possession and Self-Mortification Practices. *Ethos*, 12(4), 307–334.

Watson-Jones, R. E., & Legare, C. H. (2016). The Social Functions of Group Rituals. *Current Directions in Psychological Science*, 25(1), 42–46.

Whitehouse, H., & Lanman, J. A. (2014). The Ties That Bind Us. *Current Anthropology*, 55(6), 674–695.

Willard, A. K., & Legare, C. H. (2017). Ritual wellbeing: a simplified model. *Religion, Brain & Behavior*, 7(3), 262–265.

Wong, S. M., Tang, J. J., Thevarajah, S., & Baba, R. (2012). Delayed granulomatous reaction after oral piercing during Thaipusam. *Annals of Dermatology*, *24*(3), 355–357.

Wood, C. (2016). Ritual well-being: toward a social signaling model of religion and mental health. *Religion, Brain & Behavior*.

Xygalatas, D. (2008). Firewalking and the brain: the physiology of high-arousal rituals. In J. Bulbulia, R. Sosis, E. harris, R. Genet, C. Genet, & K. Wyman (Eds.), *The Evolution of Religion* (pp. 197–203). Santa Margarita, CA: Collins Foundation.

Xygalatas, D. (2011). Ethnography, Historiography, and the Making of History in the Tradition of the Anastenaria, *History and Anthropology* 22 (1): 57–74.

Xygalatas, D. (2012). *The Burning Saints*. London: Equinox.

Xygalatas, D., Mitkidis, P., Fischer, R., Reddish, P., Skewes, J., Geertz, A. W., et al. (2013). Extreme Rituals Promote Prosociality. *Psychological Science*, 24(8), 1602–1605.

Zahran, S., Snodgrass, J. G., Maranon, D. G., Upadhyay, C., Granger, D. A., & Bailey, S. M. (2015). Stress and telomere shortening among central Indian conservation refugees. *Proceedings of the National Academy of Sciences*, 112(9), E928–E936.

Zimmer, Z., Jagger, C., Chiu, C. T., Ofstedal, M. B., Rojo, F., & Saito, Y. (2016). Spirituality, religiosity, aging and health in global perspective: A review. *SSM - Population Health*, *2*, 373–381.

**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.

**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 body, including long spears or rods. The devotee on the top-right is also carrying a kavadi affixed to his head, while the one in the bottom-right is dragging a large chariot by hooks attached to his back. (C) Smoothed GSR levels during the kavadi compared to an average day. GSR data were centered on their mean and averaged across participants to account for change 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 most participants reached the climax of the ritual when climbing the steps to the mountain temple.

**Figure 3. Effects of Ritual Intensity on Psychological Health**

**A.-B.** Pain and stress experienced during the kavadi ritual had no significant impact 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 kavadi. Stress assessed by GSR showed a similar trend.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | Heart Rate | GSR | Sleep Efficiency | 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) |
| BMI | -.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)Ϯ | .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 CNTRL(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 |
|  |

**Table 1. Hierarchical Models of Outcome Variables Measured Before and After the Ritual (Imputed Dataset)**.

*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; and Depression and Anxiety coefficients assume negative binomial distribution. Intercept is the Ritual condition Pre-ritual; Pre = Pre-ritual; Post = Post-ritual; the last predictor represents Condition\*Time interaction. Other predictors were centered on their mean.

Ϯp<.1; \*p<.05; \*\*p <.01; \*\*\*p<.001

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Pain | Stress | Quality of Life | Perceived Health |
| (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)Ϯ | - | -1.59 (1.55) | - | - | - | - | - |
| SES | - | -2.11 (1.10)Ϯ | - | -.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 |

**Table 2. Models of Pain and Stress and of Outcome Variables for the Ritual Group Measured after the Kavadi Ritual (Imputed Dataset)**.

*Note:* Each model contains coefficients with SEM. Pain is modelled with logistic regression predicting the probability of being in the High Pain group. Stress is modelled with generalized linear model assuming Gamma distribution. Quality of Life and Self-Assessed Health were modelled with ordinary least squares regression, holding their mean Pre-ritual levels constant. Intercept is the mean of centered predictors, and Pre = measurements Pre-ritual.

Ϯp<.1; \*p<.05; \*\*p<.01; \*\*\*p<.001