Received: 26 January 2024 | Revised: 10 May 2024 | Accepted: 23 May 2024

DOI: 10.1002/ajhb.24111

ORIGINAL ARTICLE

American Journal of Human Biology WILEY

Emotional contagion in a collective ritual

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Funding information

College of Liberal Arts and Sciences of the University of Connecticut; Masaryk University, Grant/Award Number: MUNI/A/1339/2023; Marie Skłodowska-Curie Actions, Grant/Award Number: COFUND#754513; Ministerstvo školstva, vedy, výskumu a športu Slovenskej republiky, Grant/Award Number: VEGA1/0724/23

Abstract

Collective gatherings are often associated with the alignment of psychophysiological states between members of a crowd. While the process of emotional contagion has been studied extensively in dyads as well as at the population level, our understanding of its operation and dynamics as they unfold in real time in real-world group contexts remains limited. Employing a naturalistic design, we investigated emotional contagion in a public religious ritual by examining the relationship between interpersonal distance and autonomic arousal. We found that proximity in space was associated with heightened affective synchrony between participants in the context of the emotionally laden ritual (a Hindu procession) compared with an unstructured walk along the same route performed by the same group. Our findings contribute to the understanding of collective emotions and their underlying psychophysiological mechanisms, emphasizing the role of cultural practices in shaping collective emotional experiences.

1 | INTRODUCTION

Collective gatherings incite strong emotions. Their role in eliciting states of exaltation and inducing affective, cognitive, and behavioral changes that can transform individuals into groups has received much theoretical attention since the inception of the social sciences. While several early thinkers focused primarily on negative aspects of shared arousal such as the loss of reason, individuality, and personal responsibility (Canetti, 1962; Freud, 1949; Le Bon, 1896), others also noted its potential to create positive feelings and enhance social cohesion (Durkheim, 1915; McDougall, 1920; Tarde, 1890; Whitehouse & Lanman, 2014). Contemporary research has provided support for these social effects, suggesting that participation in highly arousing communal events can generate positive affect, strengthen collective identities, and promote cooperative intentions (Gordon et al., 2020; Zumeta et al., 2016).

Thanks to their highly structured and emotional nature and their emphasis on shared meaning and attention, collective rituals seem particularly suited to bringing about the alignment of affective states (Fischer et al., 2014; Konvalinka et al., 2011) and to facilitate group bonding (Charles et al., 2020; Fischer et al., 2013; Jackson et al., 2018; Xygalatas et al., 2013). Indeed, evolutionary perspectives have highlighted emotional synchrony as a key feature of ritual that has played a pivotal role in the spread of religion, and perhaps even societal complexity itself (Atran & Henrich, 2010; Dunbar, 2020; Hobson et al., 2018; Lang, 2019; Lang & Kundt, 2023; Norenzayan et al., 2016; Xygalatas, 2023).

Despite the important implications of this view, our empirical knowledge of the psychophysiological processes underlying collective arousal remains limited due to the practical and methodological obstacles to studying group assemblies in real-life settings. In recent decades, new techniques have been developed for measuring affective alignment (Ardizzi et al., 2020; Wlodarczyk et al., 2020; Xygalatas et al., 2011), which have allowed researchers to document the various outcomes of synchronous arousal in both experimental setups where it is induced through the manipulation of behaviors (Jackson et al., 2018; Lang et al., 2017; Mogan et al., 2017; Reddish et al., 2013, 2014; Tarr et al., 2015) and naturalistic ones where it emerges spontaneously among members of a crowd (Baranowski-Pinto et al., 2022; Konvalinka et al., 2011; Páez et al., 2015). Yet, little is known about the dynamic social processes that lead to the spread of emotions within groups. This is largely due to two lacunae in the current literature.

First, although collective arousal ebbs and flows dynamically, most existing research has treated it as a static property of the group (Fischer & van Kleef, 2010; van Kleef & Fischer, 2016), and even studies that used dynamical analyses have typically been only interested in aggregate metrics rather than examining the fine-grained evolution of time series that would help understand the process of how collective arousal is generated (Baranowski-Pinto et al., 2022; Fusaroli et al., 2016; Konvalinka et al., 2011; Wallot et al., 2016). Second, although collective arousal is a fundamentally social phenomenon, most of the empirical literature has examined it in response to an external stimulus (e.g., an experimental manipulation or a highly structured naturalistic event) rather than tracking its spontaneous emergence through interpersonal interactions. Thus, to understand how individual contributions coalesce into a collective emotional state, it is crucial to capture these dynamic interactions as they unfold in real time.

In many collective gatherings, there is often a clear distinction between an audience and one or more performers who may act as affective conductors. For instance, the audience in a theater can be attuned to the emotions of the actors; spectators in sporting events react to the structure of the game; and a religious congregation may be swayed by the content and tone of a priest's sermon. However, far from being unidimensional, emotional processes are sensitive to the broader social environments in which they are embedded. Thus, rather than simply falling in line with the structure of these events, participants themselves become vectors of arousal that dynamically interact with others like nodes in a network as it unfolds in time (Saraei et al., n.d.). For example, a study of basketball fans showed that physical copresence (being in the stadium rather than watching on television) was a better predictor of synchronous arousal than any structural element of the game itself (Baranowski-Pinto et al., 2022).

This is even more obvious in other types of collective gatherings, for instance public demonstrations or religious pilgrimages, in which there is often no clear leader, focal event, or a consistent central stimulus guiding the crowd. Rather, affective synchrony in these situations seems to emerge from the interactions between participants themselves through mutual entrainment (Collins, 2004). This suggests an epidemiological model where affective states can be infectious, in that they are transmitted from person to person through contact in a process of emotional contagion (Christakis & Fowler, 2009, 2013; von Scheve & Ismer, 2013).

The idea of emotional contagion, that is, the tendency of individuals to converge emotionally through the automatic imitation and synchronization of non-verbal cues such as body movements and postures, vocalizations, and facial expressions (Hatfield et al., 1992), points to a mechanism for collective emotions which can be described in terms of interpersonal resonance of physiological arousal. This ability has deep evolutionary origins and is found in numerous species but plays particularly important roles among humans by facilitating communication and coordinating action (Parr & Waller, 2007; Pérez-Manrique & Gomila, 2022).

Although emotional contagion has been studied extensively under experimental paradigms, those have mostly focused on dyads and been confined to laboratory settings. In social contexts, however, communication often takes place among more than two individuals, resulting in dynamical networked structures that involve simultaneous interactions between multiple dyads

(Hatfield et al., 2014). On the other end of the scale spectrum, a prolific body of naturalistic research has demonstrated that contagion of both positive and negative emotional states can occur at a population level (Cacioppo et al., 2009; Coviello et al., 2014; Fowler & Christakis, 2008; Hill et al., 2010; Howes et al., 1985; Perkins et al., 2018). As important as these findings are, they rely on low-resolution snapshots across long time intervals, and it remains unclear whether they translate to the rapid and volatile nature of emotions involved in crowd dynamics. As a result, most of the evidence for emotional contagion in crowds comes from simulations rather than from real-world data (Hong et al., 2022; Huang et al., 2018; Liu et al., 2021; van Haeringen et al., 2023; Xu et al., 2020).

In the current study, we sought to examine one of the key mechanisms underpinning collective arousal by looking at the relationship between physical closeness and emotional convergence in the context of a group ritual. Using a naturalistic design, we used wearable devices to obtain continuous measurements of autonomic activation from members of a crowd engaged in a religious procession. We hypothesized that as interpersonal distance during the procession waxed and waned, proximity in space between individuals would predict synchrony in arousal.

Note, however, that collective rituals provide participants with much more than a space in which to congregate. By imbuing experiences with meaning and focusing attention to those experiences, cultural frameworks supply the emotional scaffolding upon which contagion can spread (Bruder et al., 2014; Manstead & Fischer, 2001). A group of people walking in the street may not feel or act like a crowd, but the same group of people marching down the same street in a religious procession may experience stronger and more similar emotional states because the cultural significance of the event and the reverence with which it is treated by everyone primes participants for deeper emotional engagement. Thus, the collective emotional atmosphere can amplify personal responses, facilitating a more intense and widespread emotional contagion.

To test this hypothesis, we compared the emotional responses of devotees during two distinct time periods: the procession itself, which served as the ritual condition; and the time when the same group covered the same route walking together towards the starting point of the procession earlier in the day, which served as a natural control condition. We predicted that the procession would generate higher arousal than the control period, and that the role of physical proximity in predicting affective synchrony would be stronger in the ritual setting. An alternative scenario is that empathic mimicry occurs automatically and is not context-dependent. Should this be the case, we should expect spatial proximity to predict affective synchrony equally in both periods. Finally, the null hypothesis would predict no effect of proximity and no difference between periods.

2 | METHODS

2.1 | Study setting

The study took place in Mauritius, an island nation in the Mascarene archipelago where our team has been conducting ethnographic fieldwork for several years. The island's demographic makeup is the direct historical outcome of Dutch, French, and British colonial practices that involved the importation of African slaves and later Asian indentured laborers to work primarily in sugar plantations. As a result, contemporary Mauritius is a mosaic of numerous religious and ethnolinguistic groups. The largest among them are Indo-Mauritian Hindus, almost half of the country's population, making Mauritius one of only three countries in the world (with India and Nepal) with a Hindu majority. Christians and Muslims make up most of the other half, while Buddhism, Chinese ancestral worship, and numerous other religious traditions are also represented. Each of these religious groups includes several subgroups and denominations. Moreover, there is a great degree of admixture and it is not uncommon for people to practice more than one religion (Xygalatas et al., 2018).

Mauritian Hindus, in particular, practice an eclectic mix of Hindu traditions that includes diverse influences from various parts of India (Eisenlohr, 2007). For instance, while most Mauritian Hindus draw their ancestry from northern India, festivals of southern (especially Tamil) origin are celebrated widely. Those include the Thimidi, which involves fire walking (Fischer et al., 2014); the Thaipusam Kavadi, consisting in body piercing and carrying heavy objects (Xygalatas et al., 2013); and the Kathi Poosai, which involves walking on swords. These high-arousal festivals share a common structure: in preparation for each festival, devotees spend 10 days of austerity, abstinence, and prayer. On the day of the focal ritual, devotees dressed in colorful saffron and pink garments gather at a beach or riverbank to perform purification rites. Then they embark on a religious procession led by temple officials and accompanied by music. During this procession, participants experience very high levels of emotional arousal (Xygalatas et al., 2019) and many of them appear to spontaneously enter altered states of consciousness as they begin to swirl, dance, cry, and are believed to be possessed by a deity. Emotions appear to spread, as the dancing and crying often travels like a wave across the procession. Finally, when they reach their destination, participants make offerings to the temple and may endure one final hardship, such as ascending a steep hill, traversing burning embers, or climbing a ladder made of upright swords.

The current study was situated in the context of the Kathi Poosai, also known in Mauritius as “Marche sur les sabres” (sword climbing). This is a festival dedicated to the Hindu goddess Mariamman, who is predominantly venerated in south India (Ramdoyal, 1994). Originally a fertility goddess (her name means “mother of rain”), Mariamman is worshipped in various female forms, one of the most prominent among them being Kali. Most Mauritian villages have one or more temples (*kalimai*) dedicated to Kali, who is seen as a guardian deity. People visit these shrines regularly to leave offerings and perform prayers aimed at bringing prosperity and protection from disease and misfortune (Chazan-Gillig & Ramhota, 2022; Xygalatas & Maňo, 2022).

We conducted the study in the coastal village of Pointe aux Piments in the northwestern district of Pamplemousses. On the morning of the ritual, devotees began to gather by the *kalimai*, where they interacted freely as they waited for the festivities to begin. At 11:10, they assembled and started walking together along the coastal road towards a beach in the southern part of the village. The crowd walked freely at a steady pace, covering the 1.1 km distance in approximately 19 min. This would be the same route they would later take in the context of the procession, and it served as the control period in our study.

After arriving at the beach, devotees bathed in the sea and performed various purification rites in preparation for the ceremony. At 13:00, the procession began. It moved slowly, taking about 51 min to cover the same 1.1 km distance back to the temple. This served as our focal period, that is, the ritual condition.

After reaching the temple, participants formed a line and began climbing barefooted a portal-frame-shaped ladder made of 52 swords in lieu of rungs, with their sharp edge facing upwards. The ceremony concluded with a communal meal served to everyone present. The sword climb itself was not part of our analysis due to the lack of variability in physical distance during this part of the ritual.

2.2 | Materials and procedures

Our data were collected as part of a project aimed at studying the effects of pain in the context of the sword-climbing ritual. Participants in that study were all male, because males are predominantly the ones engaging in the most painful activities. The current analysis focused on all participants who had proximity data, specifically, eight males aged 24–41 (mean = 32, SD = 6) among those who participated in the ritual. This provided 28 dyads (each subject paired with to everyone else), which was the unit of our analysis.

At the beginning of the festivities, each participant was given three lightweight devices: The Qstarz BT-Q1300ST is a GPS tracker that records longitude, latitude, and altitude at 5-second intervals. It is slightly over half the size of a credit card and weighs 22 grams (roughly as much as 3 one-euro coins). The device was placed in a pouch that is attached to a belt or belt loop. The BodyMedia SenseWear mini armband (SWM) is a biometric sensor that records electrodermal activity (EDA), a marker of sympathetic system activity, by measuring conductivity between two electrodes on the back side of the armband in direct contact with the skin (calibrated range: 56K–20M ohms). It has an inbuilt accelerometer and two thermometers, one in contact with the skin recording body temperature and the other on the back of the device recording ambient temperature. The device is of similar dimensions and weight to a wristwatch and is worn on the bicep of the nondominant arm. The Zephyr Bioharness is a chest strap that records cardiac electric impulses through electrodes embedded in the strap to calculate heart rate (HR) as beats per minute at intervals of 1 Hz. All data were recorded on the devices and later downloaded on a computer.

Participants wore the devices over a period of approximately 4 hours. Our analyses focused on two distinct periods: (a) the religious procession and (b) the group walk that occurred earlier on the same day along the same route, which served as a comparison. Moreover, data from the periods preceding each of these periods were used as additional control periods to perform robustness checks. Our dataset does not include group data from the sword climb that followed, as participants returned their devices as soon as they finished their own climb and before others were done. In any case, such data would be outside the scope of the current study due to the static nature of the sword climb, where practitioners remained stationary and in close proximity except for their own climb.

The study was approved by the institutional review boards of Victoria University in Wellington, New Zealand and the University of Connecticut in the USA, and all participants provided written consent.

2.3 | Data preparation and analysis

Data analysis was done using R 4.1 (R Core Team, 2021). EDA data were processed at a sampling rate of 16 Hz. A low-pass filter was applied using a moving window of 32 data points (2 s) to produce a smoothed baseline (tonic component). This was subtracted from the raw data to extract the phasic signal, which represents rapid and transient changes in skin conductance in response to specific stimuli or events.

To assess affective synchrony between pairs, defined as the temporal coupling of the phasic signal (Palumbo et al., 2017), we used cross-recurrence quantification analysis (CRQA), a technique used to quantify similarities between two time series as they unfold dynamically over time (Carello & Moreno, 2015; Shockley et al., 2002). In contrast with methods such as cross-correlation, which are limited to detecting linear trends, recurrence methods provide a deeper insight into the dynamics and interactions of complex systems by capturing fine-grained temporal patterns in time series data that may not be accessible via linear analyses. CRQA, for instance, examines how states in one physiological system recur in another to provide insights into the synchronization and coevolution of two systems over time. This is particularly important when analyzing physiological signals, where the underlying biological processes are complex and interdependent and do not typically follow linear patterns.

This method uses an embedding process to reconstruct a multidimensional phase space from each single-dimensional time series, unfolding the dynamics within the time series so that the system's behavior can be visualized and instances when two time series move through similar regions of the phase space can be identified. Such instances are then plotted in a matrix (cross-recurrence plot) from which measures of synchrony can be extracted. The percentage of recurrence (%REC) corresponds to the ratio of shared states (recurrence points) to the total number of potential recurrence points in the plot. A higher %REC thus indicates that two time series revisit the same states more frequently. Moreover, the percentage of determinism (%DET) provides a measure of the predictability or deterministic structure of these recurrences. It is derived from the ratio of the number of consecutive recurrent points (i.e., those that form diagonal lines) as a proportion of all recurrent points in the plot. A higher %DET indicates similarly developing states across time series compared with more haphazard short-live recurrence states and therefore form part of a deterministic structure.

We used the "crqa" package to perform a windowed CRQA for all pairs, with each window spanning 2 min (1920 data points for EDA, 120 for HR) with an overlap of 60 s (30 pre and 30 post) and the output timestamped with reference to the focal minute. Thus, for example, minute 12:01′ starts at 12:00:31″ and ends at 12:01:30″, and so on. This was done to reduce boundary effects and ensure the contextual relevance of the signal (Meynard & Wu, 2020). In other words, we performed one CRQA per pair per minute, obtaining a total of 1960 data points (28×70) for each metric.

Data were normalized to ensure a consistent scale between different time series. The delay and embedding parameters for the CRQA were selected by applying the average mutual information and false nearest neighbor methods (Wallot & Leonardi, 2018). However, for HR data, due to the relatively low sampling rate (1 Hz) that led to only 120 data points per window, the embedding parameter was set to 2. For both time series, the radius was adjusted to the lowest value that did not produce any zero values (0.2 for EDA and 0.3 for HR).

The "geosphere" package was used to process the GPS data and calculate distances between individuals in meters, which were averaged over each minute to match the frequency of the recurrence data. To make the tables more easily interpretable, distance data were z-scored and reversed to reflect spatial proximity.

3 | RESULTS

3.1 | Results

We examined data from two time periods: (a) the religious procession and (b) the free walk that took place earlier along the same route. A linear mixed model examining the fixed effects of period and adjusted for the random effects of subject showed that the tonic component of the EDA signal, an indicator of autonomic arousal over relatively long periods, was on average higher during the procession compared with the walk, with an estimate of 0.85 standard deviations (SE $= 0.002$, $p < .001$). The phasic component, indicating short-term emotional reactions, showed a similar pattern, although the effect size was much smaller, with an estimate of 0.01 standard deviations (SE $= 0.003$, $p = .026$). The HR data also showed higher levels of autonomic arousal during the procession, estimated to be on average 6.05 BPM higher (SE $= 0.140$, $p < .001$).

To examine the effect of spatial proximity on shared arousal, we used generalized linear mixed models to fit beta regressions on our recurrence measures (%REC and %DET), with distance and period as predictors and pair as a random factor (Figure 1). Because physical activity stimulates the sympathetic nervous system and we were interested only in changes caused by emotional arousal, we adjusted our models for movement, captured as mean velocity per time unit for each pair. Moreover, because warmer temperatures can increase sweat gland activity and thus lead to higher skin conductance, the EDA

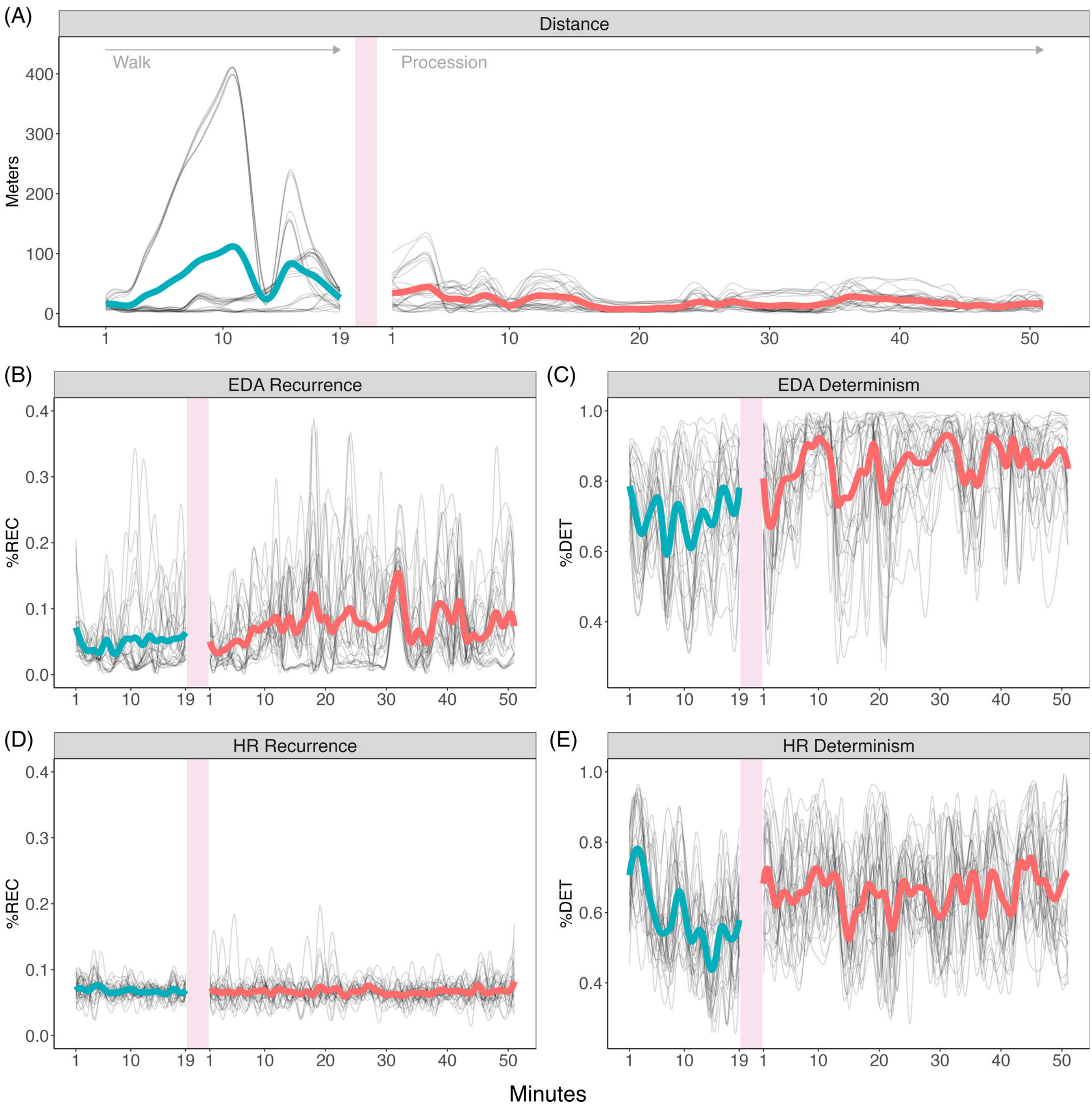

FIGURE 1 Splined lines (gray) for each pair with overlaid mean lines (colored) displaying distance between pairs (A) and the dynamics of recurrence (B) and determinism (C) of the phasic component of electrodermal activity (EDA), and recurrence (D) and determinism (E) of heart rate (HR) during the procession (right side, red line) and walk (left side, green line). While the same people walk along the same route in both periods, the religious context of the procession is associated with more synchronous and more structured affective responses overall.

models were adjusted for ambient temperature, which was averaged per time unit for each pair.

Looking at the EDA data, we found higher synchrony during the procession compared with the walk (Figure 2). Moreover, there was a main effect of proximity, which predicted both %REC and %DET, as well as an interaction between period and proximity, such that this effect was stronger during the procession compared with the walk. The HR data showed a similar pattern in terms of %DET, although the effects on %REC were not statistically significant at the conventional alpha level of .05 (Table 1).

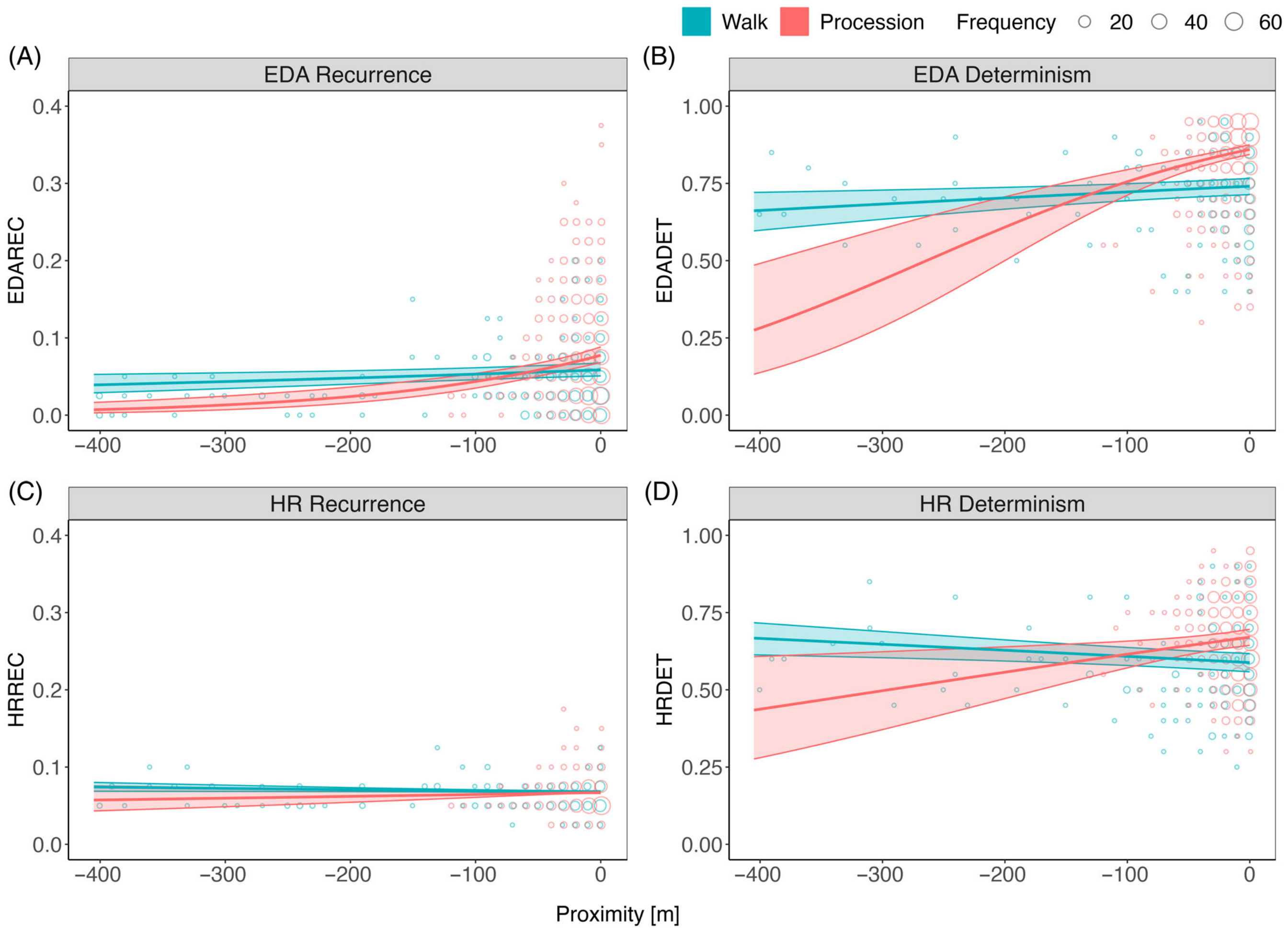

FIGURE 2 As proximity increases, emotional synchrony, as captured by the recurrence (left) and determinism (right) of the phasic component of the electrodermal activity (EDA) (up) and heart rate (HR) (down), also increases, and especially so during the ritual activity. In other words, the closer two individuals are in space in the context of the procession (but not during the free walk), the more coupled their physiological reactions, allowing for the spread of emotional states. Bubble size indicates the number of overlapping data points.

TABLE 1 Beta regression estimates and standard errors from generalized linear mixed models adjusted for the random effects of pair.

	EDA				Heart rate			
	Recurrence		Determinism		Recurrence		Determinism	
Intercept	−8.84 (0.85)	$p < .001$	−4.38 (0.93)	$p < .001$	−2.62 (0.03)	$p < .001$	0.60 (0.10)	$p < .001$
Procession	0.17 (0.04)	$p < .001$	0.61 (0.04)	$p < .001$	−0.02 (0.01)	$p = .088$	0.27 (0.03)	$p < .001$
Proximity	0.04 (0.02)	$p = .008$	0.04 (0.01)	$p = .007$	−0.01 (0.00)	$p = .035$	−0.03 (0.01)	$p = .004$
Temperature	0.18 (0.03)	$p < .001$	0.17 (0.03)	$p < .001$				
Velocity	0.17 (0.10)	$p < .079$	−0.23 (0.12)	$p = .049$	0.00 (0.03)	$p = .963$	−0.26 (0.08)	$p = .002$
Procession × proximity	0.21 (0.05)	$p < .001$	0.24 (0.05)	$p < .001$	0.03 (0.02)	$p = .101$	0.13 (0.04)	$p < .001$

Note: Higher recurrence rates indicate increased emotional synchrony among participants in the procession, while higher determinism rates suggest that the recurrent states are not random but follow a more predictable pattern, indicating a structured emotional response to the ritual's communal activities.
Abbreviation: EDA, electrodermal activity.

3.2 | Robustness checks

To check the robustness of these results, we listed a series of alternative interpretations that we could test with our data. First, could it be that the relationship between proximity and affective synchrony is simply driven by synchrony in movement but this is obscured by the nature of our analysis, that is, the fact that velocity was averaged over dyads? To assess this, we adjusted our models for the absolute difference in velocity within dyads at each time period (Table S1).

Second, could it be that the relationship between proximity and affective synchrony primarily occurs among people who are not moving much, and therefore appear to have more synchronized physiological responses simply because their lower levels of activity lead to less variance in autonomic arousal? To assess this, we repeated the analyses after excluding data points at the bottom 10% of velocity (i.e., when people were moving the least) (Table S2).

Third, given that participants were more dispersed in space during the walk (moving within a 401-m range) compared with the procession (125-m range), could the interaction effect be driven by those who were situated the farthest apart during the walk? To test this, we trimmed the dataset to the maximum distance found within the procession, which resulted in excluding approximately 2.3% of the data (Table S3). Across all these models, the result remained qualitatively consistent.

Finally, can we say that the relationship between distance and affective synchrony increased during the procession rather than decreasing during the walk? To assess this, we reran the analyses including a control period consisting of all recorded data points outside the walk and procession periods (i.e., the time before the walk and the time between the walk and the procession). This confirmed that the effect was increased during the procession rather than the other way around (Table S4).

4 | DISCUSSION AND FUTURE DIRECTIONS

Our study provides evidence of emotional contagion in a collective ritual, suggesting that individuals dynamically attune their affective states to one another. Research on emotional contagion emphasized different potential avenues through which affective synchrony is achieved (Parkinson, 2020). For instance, some scholars stress the role of automatic mimicry (Hatfield et al., 1992); while others emphasize shared attention (Collins, 2004) or the cognitive processing of contextual information (Manstead & Fischer, 2001). Nonetheless, these mechanisms are not mutually exclusive. Rather, they can describe different components of the same process: the capacity for mimicry is a necessary precursor for the emergence of emotional contagion, which is facilitated and amplified through social cues (Hatfield et al., 2014). In real-world situations, these components often occur simultaneously and in interaction with one another. Our findings may speak to this synthetic view, as the religious procession resulted in more heightened and more synchronous levels of arousal, with interpersonal coupling becoming stronger as physical proximity increased.

A religious ritual is a call to gather, which makes the mutual perception of emotional signals possible. But, while copresence can provide the necessary fuel, it may not be enough to spark emotional contagion. It is the structure of the ritual that elicits specific emotions in participants, and the cultural significance of the actions that creates and attentional shift, channeling participants' focus to the same stimuli to establish an intersubjective experience.

This interdependence highlights the importance of studying emotional contagion in real-life, real-time settings. However, there are always inevitable tradeoffs between control and relevance (Xygalatas, 2019). For instance, while our naturalistic setting allowed us to rule out individual differences between periods by using a within-subject design, it did not allow us to account for other potential uncontrollable confounding variables, such as time of the day or environmental factors (e.g., potential interruptions or distractions occurring on the road) that may variably influence participants' emotional and physiological responses. In addition, our participants were all male, and we do not know how these results would generalize among women, who in our ethnographic experience also engage in powerful emotional displays during those rituals.

An additional limitation pertains to our measurements. For example, while our use of physiological measures (EDA and HR) to infer emotional states allowed us to obtain continuous, fine-grained metrics that would be impossible to get through self-reports, other aspects of emotional experience, such as subjective feelings or cognitive appraisals, may be just as important for our understanding of emotional contagion. To compensate for the deficits of each type of measure, future designs may use a combination of both.

Moreover, our findings are derived from a specific cultural and ritual context, and whether they generalize to other contexts, both religious and secular is an open empirical question. Some obvious cultural particularities that may be at play include overall levels of religiosity and the prevalence of high-arousal rituals in a given society, but more subtle factors may be related to the role of enculturation in communicating emotions. For instance, while certain cultures encourage overt affective displays, others may value emotional restraint, placing differential constraints on the expression and transmission of emotions during collective events. Additionally, in cultures with more collectivist orientations, there may be stronger normative pressure to conform to the emotional expressions of others (Markus & Kitayama, 1991; Schouten et al., 2020), which might facilitate emotional contagion as individuals adjust their emotional states to align with the group.

The above possibilities also point to interesting new avenues for future research. One such avenue entails disentangling the effects of social (interpersonal), cultural (symbolic), natural (landscape), and artificial (built) environment and their respective interactions. In the context of a religious procession, for instance, we might expect that the emotional contagion is stronger when the crowd crosses symbolically salient parts of the route that have special spiritual significance for the community, such as crossroads, shrines, or bodies of water (Klocová et al., 2022), or when sacred symbols are displayed or music is playing. Our results may offer cause for speculating that this is indeed what is happening in this specific ritual, where we see that across all models the effects of proximity are stronger on %DET compared with %REC. This suggests that there is ebb and flow in the levels of synchrony, but when closely spaced individuals are coupled, they tend to have more consistent and predictable patterns of shared arousal, indicating a similar emotional experience.

Moreover, further studies may direct more attention to the nuances of emotional content. Our methodology allowed us to obtain high-resolution markers of autonomic arousal, but these measures do not provide information about the valence of the experienced arousal. In collective rituals with distinct roles, participants can experience different emotions. For instance, a study of emotional expressions during a fire walking ritual found quantitative convergence but qualitative polarization between different groups of participants: as some of them crossed a pit of burning embers while carrying their loved ones on their backs, they experienced similar trends in the level of arousal but opposite trends in valence, with fire walkers manifesting dysphoric emotions and passengers increasingly euphoric ones (Bulbulia et al., 2013). Although participants in the current study did not have similar divisions of labor during the ritual, we do not know to what degree the physiological synchrony also reflects the alignment of specific emotions.

Further related to emotional valence, anthropological theories have emphasized the role of shared dysphoric experiences, suggesting that it plays an especially potent role in group bonding (Atkinson & Whitehouse, 2011; Whitehouse et al., 2017; Whitehouse & Lanman, 2014). However, collective gatherings that evoke strong positive emotions, from sporting and artistic events to weddings, coronations, graduations, and numerous religions festivals, also seem to produce bonding effects (Xygalatas, 2014). Moreover, painful rituals can involve both negative and positive emotions (Fischer et al., 2014, 2023). This does, however, raise the question of whether negative emotions such as fear or rage or positive ones such as joy or awe flow faster within a network.

Finally, another crucial step towards understanding emotional contagion would be studying interpersonal variation in crowd settings. For instance, are more committed individuals (e.g., more religious individuals in a procession or more loyal fans in a game) more susceptible to catching the emotions of others in relevant contexts? Are more prestigious members of a community better able to transmit their affective states? And are socially proximal individuals (e.g., groups of friends) more likely to entrain during the procession, thereby reinforcing their bonds? As theoretical interest in social networks rapidly increases and new methods and technologies are becoming available for collecting and analyzing network data, we expect that these questions will spark new avenues of investigation with implications than range across numerous domains of social life, from religious rituals and cultural performances to political rallies and public riots. A better understanding of crowd emotions in these contexts may help improve crowd management, mitigate the spread of violence, and design more meaningful collective events and performances.

AUTHOR CONTRIBUTIONS

Conceptualization: D.X., R.F. *Investigation*: all authors. *Data curation*: M.L., R.F., D.X. *Formal analysis*: D.X., M.L. *Visualization*: M.L. *Writing—original draft preparation*: D.X. *Writing—review and editing*: all authors.

ACKNOWLEDGMENTS

Dimitris Xygalatas acknowledges support from the College of Liberal Arts and Sciences of the University of Connecticut; Martin Lang from grant MUNI/A/1339/2023 by Masaryk University, Czech Republic; and Ronald Fischer from Marie Skłodowska-Curie Actions grant COFUND#754513 and Ministerstvo školstva, vedy, výskumu a športu Slovenskej republiky grant VEGA1/0724/23.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data and code for this article are available in the Supplementary Material.

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How to cite this article: Xygalatas, D., Lang, M., Maňo, P., Krátký, J., & Fischer, R. (2024). Emotional contagion in a collective ritual. *American Journal of Human Biology*, e24111. https://doi.org/10.1002/ajhb.24111