Report

Current Biology

Effects of Anxiety on Spontaneous Ritualized Behavior

Highlights

- Stress can result in ritualized behavior
- Inducing anxiety lead to more redundant, repetitive, and rigid hand movements
- Ritualization might be an anxiety-reducing coping strategy

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In Brief

Lang et al. offer a novel insight into the link between anxiety and ritualized behavior, which may shed light on the persistence of ritual behavior throughout the animal kingdom and can potentially help gain a better understanding of psychiatric disorders like OCD or ASD, whose symptoms include over-ritualization.

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Effects of Anxiety on Spontaneous Ritualized Behavior

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SUMMARY

Environmental uncertainty and uncontrollability cause psycho-physiological distress to organisms [1–3], often impeding normal functioning [4, 5]. A common response involves ritualization, that is, the limitation of behavioral expressions to predictable stereotypic and repetitive motor patterns [6–8]. In humans, such behaviors are also symptomatic of psychopathologies like obsessive-compulsive disorder (OCD) [8, 9] and autism spectrum disorders (ASDs) [10, 11]. Although these reactions might be mediated by different neural pathways, they serve to regain a sense of control over an uncertain situation [12–15] by engaging in behavioral patterns characterized by *redundancy* (superfluous actions that exceed the functional requirements of a goal), *repetitiveness* (recurrent behaviors or utterances), and *rigidity* (emphasis on fidelity and invariance) [8, 9, 16, 17]. We examined whether ritualized behavior will manifest spontaneously as a dominant behavioral strategy in anxiogenic situations. Manipulating anxiety, we used motion-capture technology to quantify various characteristics of hand movements. We found that induced anxiety led to an increase in repetitiveness and rigidity, but not redundancy. However, examination of both psychological and physiological pathways revealed that repetitiveness and rigidity were predicted by an increase in heart rate, while self-perceived anxiety was a marginally significant predictor of redundancy. We suggest that these findings are in accordance with an entropy model of uncertainty [18], in which anxiety motivates organisms to return to familiar low-entropy states in order to regain a sense of control. Our results might inform a better understanding of ritual behavior and psychiatric disorders whose symptoms include over-ritualization.

RESULTS

Given that anxiety-related ritualization is manifested in diverse contexts (precautionary behavior [9, 12], human social behavior [19], and specific pathologies [8]), we investigated their potential common denominators. In contrast to previous studies that examined learned, habitual, and culturally specific behavioral scripts [20, 21], our study focused on gestural patterns displayed spontaneously as a distress reaction.

Sixty-two undergraduate students of Masaryk University were randomly assigned to either a high-anxiety (HA; n = 31) or a low-anxiety (LA; n = 31) group. To induce anxiety in the HA condition, we used a public-speaking task, where participants were asked to prepare a speech about a decorative object (see Figure S1) and later present it in front of a panel of experts [22]. After the manipulation, participants had to clean the object. We measured the time spent cleaning and hand-movement characteristics (obtained as acceleration patterns) using the GT3X ActiGraph motion sensor [23] placed on participants' wrists. We focused on cleaning because it is one of the most commonly ritualized actions both in psychopathological and ceremonial contexts [24, 25].

We operationalized ritualized behavior across three attributes: (1) *redundancy* (time spent cleaning the object and number of movements used), (2) *repetitiveness* (recurrence of hand-movement signal), and (3) *rigidity* (predictability of hand movements and their SD). To compute repetitiveness and rigidity, we used recurrence quantification analysis (RQA) [26] and compared each hand-movement acceleration signal against its delayed versions [27]. Whenever two signals shared the same acceleration pattern (they fell within a preselected radius; see Figure S2), a recurrence point was recorded. Hence, the percentage of recurrent points (%RR) can be understood as an indicator of repetitiveness (the percentage of movement patterns repeating over time). Furthermore, if recurrent points follow each other in time (movement patterns evolve in the same way), their predictability is high and they are said to be deterministic. Thus, the percentage of recurrent points exhibiting determinism (%DET) was used as an indicator of rigidity in movement trajectories.

We hypothesized that induced anxiety would increase gestural ritualization. Specifically, we predicted that HA participants would (1) spend more time cleaning the object and deploy more movements during cleaning, (2) display a higher percentage of recurrent movements, and (3) express more-deterministic movement trajectories and yield a lower SD of movement acceleration. To further explore the effects of induced anxiety, we built two additional models for every measure, looking at the effects of self-perceived anxiety during the preparation task and *Z*-scored heart-rate differences between the baseline and preparation periods.

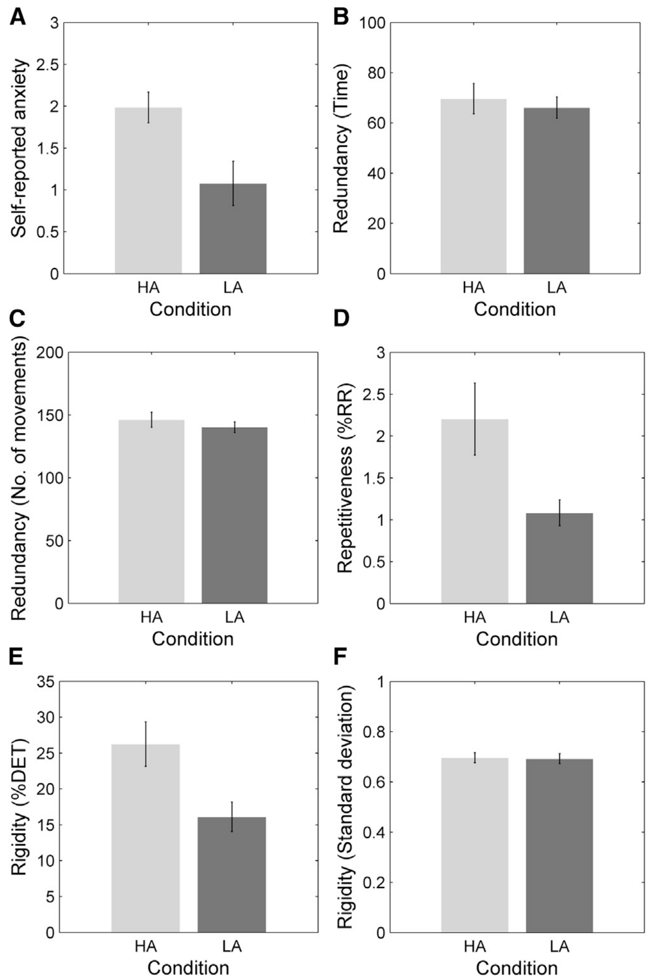

Figure 1. Mean Values with ±SEM from Measures of Ritualized Behavior for the High- and Low-Anxiety Conditions

(A) Significant difference in perceived anxiety during speech preparation.

(B) Non-significant difference in cleaning times.

(C) Non-significant difference for number of movements during cleaning.

(D) Participants in the HA condition displayed significantly higher recurrence rate of movement acceleration.

(E) Participants in the HA condition displayed significantly higher percent of deterministic movement-acceleration trajectories.

(F) Non-significant difference in the SD of movement acceleration.

Manipulation Check

Analysis of self-reported anxiety during speech preparation revealed a significant difference between conditions [t (60) = 3.431, p = 0.001], confirming that anxiety was higher for HA participants (mean = 1.986, SE = 0.184) relative to LA participants (M = 1.079, SE = 0.264; see Figure 1A). Subsequently, we analyzed changes in mean Z-scored heart rate between baseline and the preparation task. A linear mixed model (with periods nested in individuals) revealed a significant interaction between condition and time [t (45) = 6.087, p < 0.001]. Post hoc pairwise comparison with Tukey correction showed a significant increase in heart rate for the HA condition [t (50.2) = 7.839, p < 0.001], but not for the LA condition [t (50.2) = 0.654, p = 0.516]. Further analysis revealed a significant positive correlation between self-reported anxiety and heart rate (r = 0.322, p = 0.027).

Redundancy

To assess redundancy, we measured time of cleaning and number of hand movements during cleaning. We did not observe a main effect of condition on time spent cleaning (HA: mean = 69.710, SE = 8.592; LA: mean = 66.161, SE = 6.076; see Figure 1B) or number of movements (HA: mean = 188.387, SE = 20.137; LA: mean = 187.419, SE = 16.692; see Figure 1C). Likewise, we did not find heart-rate increase to be a significant predictor of redundancy measures. However, self-reported anxiety significantly predicted the number of movements and had a marginally significant positive effect on time spent cleaning (p = 0.080; see Table 1).

Repetitiveness

The repetitiveness of movements during the cleaning task was evaluated by computing the %RR of hand-movement acceleration. We found higher %RR in the HA condition (mean = 2.204, SE = 0.431) compared to the LA condition (mean = 1.084, SE = 0.155; see Figure 1D). Since the %RR data were strongly heteroscedastic (showing higher variance in the HA condition), we modeled both mean and dispersion to account for this difference. We observed a significantly higher mean %RR and significantly higher dispersion of %RR in the HA condition. Furthermore, mean Z-scored heart-rate increase was significantly associated with higher mean and dispersion of %RR. We did not observe any effect of self-perceived anxiety on our measure of %RR (see Table 1).

Rigidity

To assess the rigidity of movements, we computed the percentage of recurrence points forming deterministic lines, which are indicative of a signal's predictability. We found higher %DET in the HA condition (mean = 26.271, SE = 3.090) compared to the LA condition (mean = 16.141, SE = 2.058; see Figure 1E). Regression analyses revealed a significant difference between the HA and LA conditions and a significant positive relationship between %DET and heart-rate increase. No effects of self-perceived anxiety were observed (see Table 1). Since %DET did not display large variance between conditions, dispersion was modeled by the intercept. Contrary to our RQA results, the SD of movement acceleration was not significantly different between conditions (see Table 1; HA: mean = 0.697, SE = 0.020; LA: mean = 0.693, SE = 0.020; Figure 1F) and was not predicted by self-perceived anxiety or heart-rate increase. This suggests that the predictability of movement acceleration trajectories might be underlined by more-complex patterns unfolding over time. That is, HA participants structured their movements into sequences of predictable clusters, expressing rigidity and invariance of movement patterns inside these clusters (Figure 2; see also Figure S2).

DISCUSSION

Our results provide three-fold confirmation of the hypothesis that anxiety triggers ritualized behavior. We found that anxiety led to an increase of (1) gestural redundancy, (2)

Table 1. Estimated Means and SEs of Measures of Ritualized Behavior

	Redundancy		Repetitiveness		Rigidity	
	Time (s)	No. Movements	%RR: Mean	%RR: Dispersion	%DET	SD
Model 1						
Intercept	73.258 (16.639)***	135.047 (1.726)***	2.233 (0.333)***	0.177 (0.018)***	25.068 (2.128)***	0.697 (0.020)***
Condition (LA versus HA)	−3.548 (10.523)	−1.779 (11.899)	−1.146 (0.303)***	−0.080 (0.019)***	−7.818 (2.664)**	−0.004 (0.029)
Model 2						
Intercept	67.935 (5.133)***	118.773 (1.952)***	1.762 (0.309)***	0.154 (0.019)***	20.467 (2.308)***	0.701 (0.025)***
Reported anxiety (0–4)	8.390 (4.717)†	10.270 (5.174)*	−0.066 (0.157)	−0.007 (0.010)	0.356 (1.192)	−0.004 (0.013)
Model 3						
Intercept	69.745 (5.588)***	140.669 (1.517)***	1.430 (0.163)***	0.121 (0.011)***	19.748 (1.739)***	0.693 (0.018)***
Heart rate (*Z* scores)	−0.368 (6.012)	2.697 (7.920)	0.664 (0.200)**	0.040 (0.013)**	4.883 (1.640)**	0.020 (0.017)

Models 1–3 describe predictors used to predict our outcome variables. In model 1, HA condition is a reference category; in model 2, self-perceived anxiety = 0 is a reference category; and in model 3, mean heart rate increase is a reference category. †$p < 0.1$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

repetitiveness of movement, and (3) determinism and predictability of movement.

Although redundancy did not differ significantly between conditions and was not associated with heart-rate increase, perceived anxiety during the preparation task was a significant predictor of the number of movements during cleaning and a marginally significant predictor of time spent cleaning. In other words, participants who experienced more anxiety used more movements in the cleaning task, possibly as a coping strategy [9, 28].

Our measure of recurrent hand-movement trajectories showed a significantly higher recurrence in the HA condition. Although the object was not symmetrical and different parts required different types of movements, participants in the HA condition kept applying similar movements. These behavioral expressions were also significantly predicted by the *Z*-scored heart-rate increase (see Table 1). Looking at the dispersion of those data, we found a significant effect of condition and heart-rate increase, which suggests that there is individual variance in the extent to which participants are attracted to repetitive movement patterns while in a state of anxiety. The participants in the HA condition who did not display repetitive patterns of hand movements probably did not experience a sufficient amount of system destabilization. The dispersion might also be caused by other intervening variables (for example, desire for control), which we did not assess.

Finally, the measurement of %DET indicated that participants in the HA condition displayed more-predictable movement patterns. Once they returned to a familiar hand-movement acceleration pattern, they tended to follow this pattern for a longer time. Interestingly, such pattern sequencing may also help explain why we found no significant effect of treatment on mean SD of movement acceleration. Since the invariance of movements was bound to specific temporal clusters, it might be unnoticeable after averaging SDs over the temporal dimension. Importantly, we also observed a significant positive effect of heart-rate increase on %DET but no such effect on SD of hand-movement acceleration.

In summary, our findings show that ritualization may be a spontaneous response to anxiety. While the treatment significantly affected self-perceived anxiety, some participants in the LA condition also perceived the preparation task as stressful, and this cognitive appraisal appeared to be essential for an increase in redundancy. On the other hand, an increase in heart rate was more closely associated with the treatment and was a significant predictor of repetitiveness and rigidity. It is possible that a cognitive appraisal of anxiety affected only behaviors directly accessible to conscious control: duration of cleaning and number of movements used during cleaning (redundancy). The other two movement characteristics, repetitiveness and rigidity, are more dynamic and finer grained (hand-acceleration changes in a matter of milliseconds) and are presumably not accessible to conscious control; however, they were affected by physiological reactions to the stressor as indicated by heart-rate increase. The threat of public speaking appears to more directly induce physiological distress reactions compared to the overall psychological discomfort that participants experienced in both conditions. This interpretation is further supported by the significant, but rather moderate, positive correlation ($r = 0.322$) between self-reported anxiety and mean heart-rate change, which suggests that psychological and physiological processes can affect different, albeit concurrent, cognitive mechanisms [29].

We propose that these findings are in accordance with the entropy model of uncertainty [18]. When facing a complex, uncontrollable, and unpredictable situation, an organism's cognitive-behavioral system experiences a high-entropy state. Entropy is understood here as a reduced ability to predict successive states based on the current state [18]. The principle of entropy minimization holds that the goal of a cognitive-behavioral system is to minimize internal entropy and increase prediction success [30, 31]. Although a variety of experiential possibilities is crucial for an organism's success, a tradeoff between high-entropy risk and gains obtained from new environmental situations needs to be balanced at a manageable level—otherwise, low predictive abilities (followed by anxiety) could significantly impede functioning.

Translated to the context of the present study, the possibility of public speaking might have increased participants' psychological entropy and decreased their feeling of control [21]. To cope with such instability, organisms tend to return to familiar low-entropy states [18], often by performing repetitive and predictable actions that minimize the conflict between behavioral and perceptual affordances. Importantly, such behavioral expressions may be functionally detached from the anxiogenic

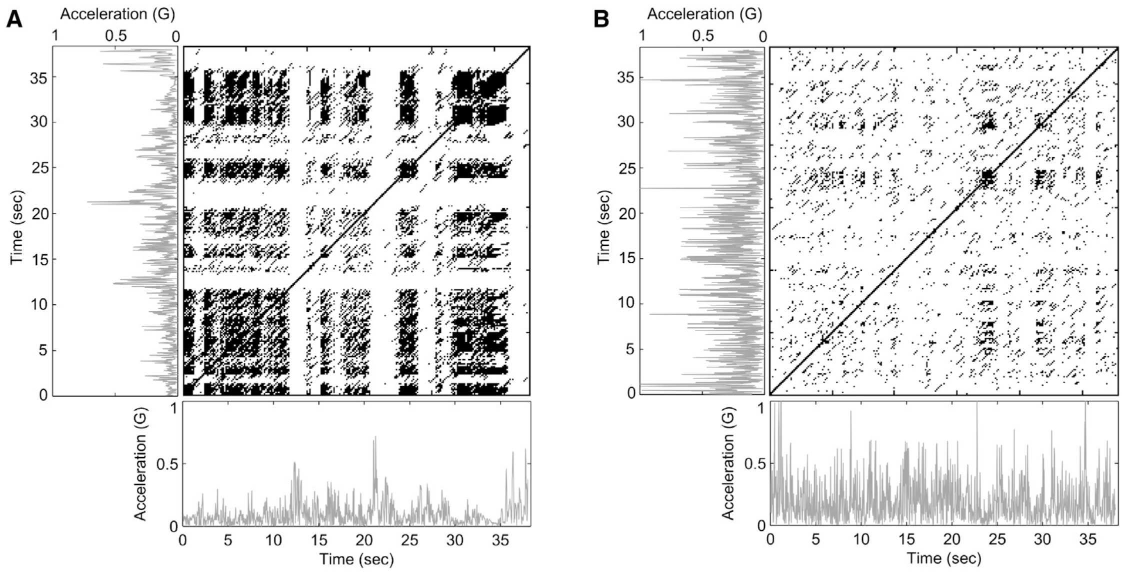

Figure 2. Recurrence Plots of Hand-Movement Acceleration

Illustrative recurrence plots built on the basis of dominant hand-movement acceleration of a participant in the HA condition (A) and a participant in the LA condition (B). Visible clusters in (A) are indicative of recurring movement patterns. Recurrence points are sparse and appear to be more evenly distributed in (B), suggesting more variable hand-movement acceleration trajectories.

situation and instead focus on increasing interoceptive predictive success [32], which might in turn lead to regaining a sense of control. The focus on instant interoception could also explain why low-entropy behaviors are often detached from the threatening stimuli, which from an external perspective might seem purposeless [12, 28]. In our experiment, we artificially restricted participants' behavioral expressions to the predefined task, where the readily accessible low-entropy state was tied to the act of cleaning. Without such a pre-defined task, subjects might turn to different types of ritualized behaviors, either spontaneous (e.g., marching up and down) or related to available cultural scripts (such as praying).

We hazard that the principle of entropy minimization can also be extrapolated to more-complex ritualized behaviors as those observed among gamblers and athletes and in religious rituals. Performance anxiety may result from low predictive possibilities caused by environmental complexity and uncertainty, and carrying out low-entropy stereotypical actions (rituals) may help regain a feeling of control over the situation [13, 20, 21, 33–35]. In turn, this regained sense of control might result in anxiety alleviation [11, 36] and, consequently, lead to better performance [37]. We note that our approach does not purport to explain all rituals. For example, recent research suggests that rituals may have a variety of positive consequences, related not only to alleviating aversive states [35] but also to producing positive reinforcement [38]. However, the mechanisms described here might still provide additional motivations for individual participation in such rituals. Furthermore, collective rituals are social events, and as such they are complex phenomena that are not always connected to anxiogenic situations.

Our results might also be explained by the model of ritualized behavior suggested by Boyer and Liénard [9, 28, 39, 40]. Ritualized movements might have functioned to overload working memory, thus suppressing intrusive thoughts about the threat of public speaking [41]. Differences in redundancy predicted by self-perceived anxiety could be also interpreted as an attempt to delay subsequent unpleasant tasks. Alternatively, participants could have engaged in ritualization as a form of adjunctive behavior, resulting from a process of reducing corticosteroid levels as a response to a stressful situation [42]. However, this matter can only be resolved by further empirical studies focusing on the cognitive processes involved in ritualization and controlling for the role of cognitive load. Future research may, for example, investigate how environmental affordances impact the level and dynamics of ritualization. In addition, allowing participants to move more freely or choose actions by themselves may reveal yet unknown links between personality types and ritualization. Likewise, a better understanding of the role of personality (for example, desire for control) may reveal mediating variables between anxiety and ritualized behavior. Most importantly, the current findings must be supplemented by the investigation of the effects of ritualized behavior on assuaging anxiety.

Overall, our study offers a novel insight into the link between anxiety and ritualized behavior. Although this link had long been theorized, our methodology allowed us to operationalize and evaluate these theories in a quantitative way. Our findings may shed light on the persistence of ritual behavior throughout the animal kingdom and can potentially help us gain a better understanding of psychiatric disorders like obsessive-compulsive disorder or autism spectrum disorders, whose symptoms include over-ritualization.

EXPERIMENTAL PROCEDURES

We recruited 32 female and 30 male Masaryk University students (mean age = 23.851, SD = 1.839), who received course credit for participation. The study was approved by the ethical committee of the Faculty of Arts, Masaryk University, and informed consent was obtained from all subjects. Participants were randomly assigned to either an HA (n = 31) or LA condition (n = 31) defined by the presence/absence of an anxiety-inducing task. Prior to the experiment, we told participants that we would be collecting physiological measurements during the experiment and fitted them with the equipment. Each participant wore a heart-rate monitor around their chest and one accelerometer on each wrist. Baseline heart rates were obtained at a resting state. Subsequently, participants were seated at a table with a decorative object placed in front of them (a round shiny metal object on a ceramic stand; 250 × 240 × 80 mm; Figure S1). In the HA condition, we used a modified version of the public-speaking task [22] to induce anxiety: participants were given 3 min to prepare a 5-min-long speech about the decorative object to be delivered in front of an art expert. They were also provided with a set of seven questions about the object they were required to answer during the speech (see the Supplemental Information). We informed HA participants that the experts were waiting in an adjacent room and would be rating their performance. Participants in the LA condition were instructed to think about the same object for 3 min and to try find answers to the same seven questions, but public speaking was not mentioned. During the preparation period, participants in both conditions were not allowed to touch the decorative object, which was clean. Before participants were to present the speech (HA) or end the task and leave (LA), they were asked to hold the object with both hands, facing its horizontal plane, and clean it with a wet cloth until they considered it to be clean. We did not provide a particular reason for cleaning so as to make the cleaning task appear redundant; however, since the object had a metallic shine, it could always be more clean or polished. Once participants decided that the object was clean, those in the HA condition were told that they would not have to make their presentation due to a momentary absence of the art expert. All participants subsequently filled out a final questionnaire concerning their feelings during the manipulation period (five items). All participants were debriefed after the end of data collection.

Data Analysis

Heart-rate data were *Z* scored to control for natural differences between participants. Due to a malfunctioning device, we lost heart-rate data from 15 participants; however, the lost data were almost equally distributed across conditions (eight and seven). Hand-movement acceleration data collected by ActiGraph motion sensors were preprocessed and filtered to extract individual movement characteristics. Recurrence and determinism of hand-movement acceleration were computed with MATLAB CRP Toolbox 5.17 [43], using RQA [26].

The relationships between independent and dependent variables were analyzed in R (v. 3.0.3, R Core Team, 2014). We fitted two models with a normal distribution for the manipulation check (heart-rate increase and self-reported anxiety) and three linear models for each of the five measures: models with a normal distribution for time of cleaning, mixed models with a normal distribution for SD of movement acceleration, mixed models with a negative binomial distribution for number of movements to account for the distribution of count data, and mixed models with a beta distribution for percentage of recurrence and determinism to account for the distribution of proportions with lower and upper bounds of 0 and 1 [44].

SUPPLEMENTAL INFORMATION

Supplemental Information includes Supplemental Experimental Procedures and two figures and can be found with this article online at http://dx.doi.org/10.1016/j.cub.2015.05.049.

AUTHOR CONTRIBUTIONS

M.L., J.K., D.J., J.S., and D.X. designed the study; M.L. analyzed the data; and M.L., J.K., and D.X. wrote the paper.

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