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Rituals, Repetitiveness and Cognitive Load

A Competitive Test of Ritual Benefits for Stress

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Abstract

A central hypothesis to account for the ubiquity of rituals across cultures is their supposed anxiolytic effects: rituals being maintained because they reduce existential anxiety and uncertainty. We aimed to test the anxiolytic effects of rituals by investigating two possible underlying mechanisms for it: cognitive load and repetitive movement. In our pre-registered experiment (osf.io/rsu9x), 180 undergraduates took part in either a stress or a control condition and were subsequently assigned to either control, cognitive load, undirected movement, a combination of undirected movement and cognitive load, or a ritualistic intervention. Using both repeated self-report measures and continuous physiological indicators of anxiety, we failed to find direct support for a cognitive suppression effect of anxiety through ritualistic behavior. Nevertheless, we found that induced stress increased participants' subsequent repetitive behavior, which in turn reduced physiological arousal. This study provides novel evidence for plausible underlying effects of the proposed anxiolytic effect of rituals: repetitive behavior but not cognitive load may decrease physiological stress responses during ritual.

Keywords Ritual · Stress · Cognitive load · Behavioral rigidity · Anxiety · Cultural evolution

Rituals are ubiquitous across cultures and time periods (e.g., Bell 2009) even though they incur substantial material and personal costs (Alcorta and Sosis 2005). As noted by Hobson et al. (2017a):

> A puzzling feature of many rituals is that they require a person to invest time and energy into completing the actions, often without immediate instrumental value. In a way then, rituals pose an economic cost problem (Irons 1996): why do

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people engage in these behaviors—often repeatedly, and over a lifetime—if they reveal no direct benefit to the self?

Rappaport (1999:24) proposed a widely used definition of ritual as "the performance of more or less invariant sequences of formal acts and utterances not encoded by the performers." This definition of rituals was expanded by later authors to include behaviors characterized by compulsion, rigidity, repetition, redundancy, order and boundaries, casual opaqueness, and goal demotion (e.g., Fux et al. 2013). Behaviors showing these ritualistic characteristics are often perceived as more efficient and effective (Legare and Souza 2012). Yet, do they actually have functional value? Boyer and Liénard (2006, 2008) proposed that diverse rituals are adapted to cultural and temporal demands of the societies in which they are performed but ultimately operate via similar underlying processes (for a review of functionalist approaches to ritual see Sosis and Handwerker 2011). One proposed function of rituals going back to observations by Malinowski (1954) is that rituals exert an anxiolytic effect on the individual (for a current review see Boyer and Liénard 2006, 2008; Hobson et al. 2017b). Preliminary evidence seems to support such claims: Anastasi and Newberg (2008) and Brooks et al. (2016) found that anxiety decreased after performing a ritual, but the mechanisms have not been examined to date.

Anxiety is multidimensional, having at least two major components: cognitive anxiety (also called "anxious apprehension") and physiological arousal (also called "anxious arousal") (Kowalski 2000; Renner et al. 2016; for neuroscience support for this distinction see Burdwood et al. 2016; Nitschke et al. 1999).

How rituals may reduce anxiety is an ongoing theoretical question, with cognitive load during ritual and repetitive behavior being two of the main theoretical mechanisms (Boyer and Liénard 2006, 2008; Lang et al. 2015). These two processes may differentially affect the two components of anxiety. We are the first to explicitly test these hypotheses in a pre-registered study (osf.io/rsu9x).[1] Real world rituals are often steeped in cultural meaning systems and may contain cultural-specific elements, such as songs or chants. Nevertheless, previous research also highlighted elements that rituals have in common, such as cognitive load and repetitive behavior (Boyer and Liénard 2006, 2008; Lang et al. 2015). Stripping rituals of their cultural meaning in a lab environment allows for a close examination of separate elements, which can inform research of rituals embedded in their cultural meaning system.

Anxiety and Cognitive Load

Anxiety is a process occupying cognitive resources over a sustained amount of time (Kim and Rocklin 1994). Given the limits of the cognitive system, if the system is busy, anxiety might be reduced. In support of the hypothesized cognitive load effects on anxiety, Vytal and colleagues (Vytal et al. 2013) found increases in cognitive anxiety for low and medium cognitive load conditions, but not when participants were given highly demanding cognitive tasks. In line with these findings, Boyer and Liénard

[1] To increase readability, some of our hypothesis have been renumbered; no changes were made to proposed methods or analysis.

(2006) theorized that rituals have an anxiolytic effect on anxious apprehension owing to the substantial cognitive load they exert on individuals. Anxious apprehension competes with the cognitive demands of rituals for limited cognitive resources, leading to a suppression of anxious apprehension if cognitive demands of a ritual are substantial enough. Hence, rituals are an evolutionary adaptive response to acute stress, reducing anxious apprehension through culturally conditioned but cognitively demanding performances. We explicitly test this mechanism by comparing the effect of cognitive load versus control tasks on stressed or control participants. We predict that:

> H1: Participants in the stress condition performing a cognitive load task will show a greater reduction in anxious apprehension after a stressor compared to a stressed group with no cognitive load tasks.

Boyer and Liénard (2006, 2008) made no explicit predictions about the effect of cognitive load on physiological arousal. Cognitive load might be most relevant for the cognitive anxious apprehension component of anxiety (Hembree 1988; Seipp 1991). Nevertheless, previous research found anxious apprehension and physiological arousal are correlated; cognitive load might therefore also reduce physiological arousal (Renner et al. 2016). We therefore also predict that

> H2: Participants in the stress condition performing a cognitive load task will show a greater reduction of physiological arousal after a stressor compared to participants who perform a control intervention.

Anxiety and Movement

Rituals are defined by repetitive and rigid movements (Fux et al. 2013). Previous research has speculated that the anxiolytic effect of rituals can be attributed to repetitive and rigid behavior (Lang et al. 2015). Similarly, anxiety may increase repetitive, ritualistic behavior. Lang et al. (2015) found that repetitive and rigid behavior increased under acute stress. One way to interpret this pattern is to examine anxiety effects on movement. Specifically, cognitive load from anxious apprehension reduced the attention available for processes of motion and resulted in a reduced ability to complete complex movement tasks, decreasing movement variability and favoring more constrained movement trajectories (Causer et al. 2011; Higuchia et al. 2002). Hence, repetitive and rigid behaviors may be a direct behavioral response to anxiety.

Yet, other research suggests that movement alone is sufficient to aid with stress recovery (Anderson and Shivakumar 2013). Lang et al. (2015) suggested that the anxiolytic effect of movement could be grounded in the entropy model of uncertainty. The entropy model proposes that when individuals are faced with complex, uncontrollable, or unpredictable situations, they experience a high-entropy state, characterized by a reduced ability to predict future states from the current state (Hirsh et al. 2012). In turn, individuals should aim to minimize internal entropy and increase predictive success (Clark 2013). Repetitive movement behavior might satisfy a fundamental need for order and structure, protecting against negative uncertainty and reestablishing perceived control and predictability of a situation (Hobson et al. 2017a; Sosis and Handwerker 2011).

We aim to disentangle these two mechanisms. First, using a manipulation of movement versus no movement (control) after stress, we examine whether movement indeed decreases anxiety (we have no specific expectations regarding which dimensions of anxiety are impacted by movement). In line with previous theory, we therefore predict:

> H3: Participants in the stress condition who perform a movement task (cleaning an object) will show a greater reduction of physiological arousal and/or anxious apprehension after a stressor compared to participants who perform a no-movement control task.

Second, using a straightforward test to distinguish the two different processes underlying increased rigidity post-stress, we can examine (a) whether induced anxiety increases repetitive and rigid behavior which (b) then leads to a greater reduction in physiological arousal or anxious apprehension at a subsequent time. We predict:

> H4a: Participants in the stress condition will show more rigid and repetitive behavior while performing an undirected movement intervention, compared to the control condition.
> H4b: Participants in the stress condition that exhibit greater behavioral rigidity or repetitiveness will show a greater reduction in physiological arousal or anxious apprehension.

If both hypotheses are supported, this would provide evidence for the anxiolytic effect of ritualistic behavior, ruling out the acute stress explanation offered in the cognitive literature.

Reassembling Functional Elements of Ritual

Rituals are characterized by high cognitive demands with unique movement patterns as part of the same performance (Alcorta and Sosis 2005). To the extent that rituals draw upon cognitive load and repetitive movement features, we should be able to simulate ritualistic effects if participants are simultaneously performing movements *and* experiencing cognitive load. Hence, we propose that a combination of cognitive load and movement interventions emulate rituals and lead to greater anxiety reduction compared with the control intervention and to greater anxiety reduction than the individual components alone. Similarly, the combination of these two functional features should resemble the effects of a ritual, allowing us to unpackage the underlying processes of rituals. We predict:

> H5a: Participants in the stress condition who perform a combined cognitive load/movement task will show a greater reduction of physiological arousal and/or anxious apprehension compared to participants who perform a control task or
> H5b: participants who perform either a cognitive load task or a movement task.

If the combination of movement and cognitive load successfully reduces physiological or psychological stress, we can then test whether the combination of the proposed ritual components (cognitive load and movement) mirrors the effect of a novel ritual task.

Our novel ritual task was modeled on previous research on rituals in a laboratory setting (Norton and Gino 2013). Our novel ritual contained repeated verbalization (enumerating performed movements that resemble ritual features such as repeated verbalization of phrases) combined with repeated movement (pre-specified movement patterns that follow definitions of ritual practice as being functionally opaque), as well as an attention-demanding script (switching between different items, which is another common feature of ritualist practice). If we find a significant anxiolytic effect of our combined cognitive load/movement condition, we would expect this effect to be similar to the anxiolytic effect of a novel ritual. Hence, the laboratory ritual and the combined cognitive load and cleaning task should result in comparable anxiety reducing effects (the full script for the novel ritual can be found at https://osf.io/48uj3/ and in the ESM).

> H6: Participants in the stress condition who either complete a full ritual intervention or the combined movement/cognitive load task will show an equal reduction in anxious apprehension and/or anxious arousal. These two interventions are expected to show a similar effect size compared to the control condition.

Method

Participants

Our study was pre-registered (osf.io/rsu9x). We ran a power analysis with G*Power (Faul et al. 2007) to calculate optimal sample sizes for the replication and extension of Lang et al. (2015). Assuming a power of .80 and a significance level of .05, the optimal total sample size for the study was 180. We oversampled participants ($N = 215$), but we had to exclude 35 participants because of problems recording their physiological data (excluded from Control: $n = 5$; Cleaning: 11; Cognitive Load: 5; Cleaning/Cognitive Load: 5; Ritual: 9), and four additional participants were excluded from the recurrence quantification analysis because of technical difficulties with their data. Figure 1 reports the final sample size and the experiment flow. Ethical approval was obtained from the Victoria University of Wellington School of Psychology Human Ethics Committee. Participants were awarded research participation credits for their time. Mean age was 19.19 years, with 137 female and 43 male participants.

Description of the Blocks

The full experimental procedures and materials are available online (osf.io/rsu9x), replicating and extending the protocol developed by Lang et al. (2015).

Stress Manipulation (Time 2)

Stress Participants completed a counting task adapted from the Trier Social Stress Test (TSST; Kirschbaum et al. 1993). Participants were instructed to count backwards from 1033, subtracting 13 each time. Participants had to restart after every error and were reminded to count faster approximately every sixty seconds. After 5 min the participants were told to stop counting.

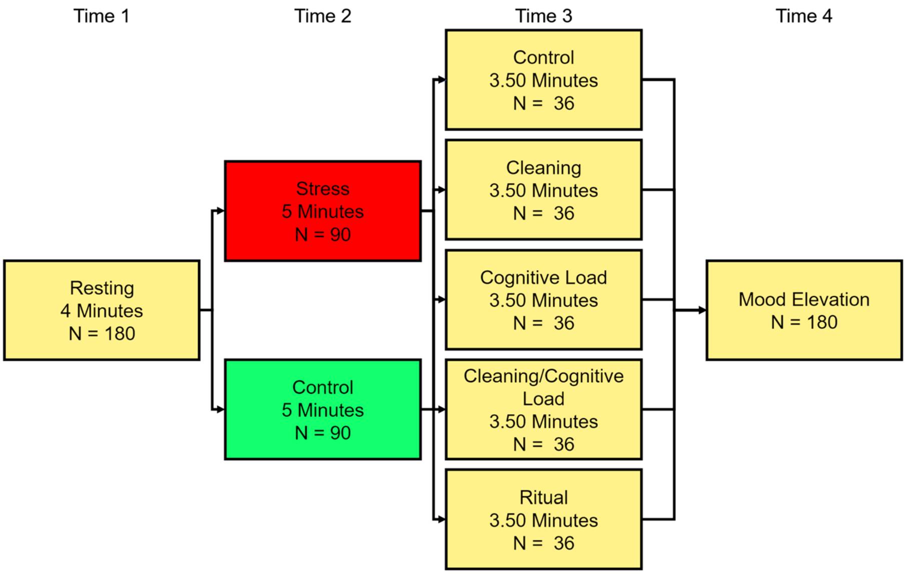

Fig. 1 Flowchart and participant distribution in each block

Control Participants in this condition received an object (identical to the object participants were later supposed to clean) and were asked to "Think about what this object represents to you" and "Think about what the object might mean to the artist." It was emphasized that the participant would not be questioned on their thoughts about the object. This control was chosen because the control intervention of the TSST, reading a text aloud from a script, might be interpreted by the participants as reciting behavior (common to many ritualistic behaviors).

Conditions to Test Ritualistic Effectiveness (Time 3)

Control Task Participants were provided with several images from the International Affective Picture System (IAPS; Lang et al. 2008) preselected to be low in valence (min = 4.77, max = 5.27, mean = 4.97) and arousal (min = 1.72, max = 2.65, mean = 2.29) based on the assessment by the IAPS and not containing pictures of humans (IAPS slide numbers 7175, 7187, 7004, 7217, 7090, 7020, 7080, 7006,7705, 7491). Participants were instructed to pay attention to the images.

Undirected Movement Task Participants were instructed to clean an object similar to the decorative object used in Lang et al. (2015). Participants could clean the object in any way they liked as long as they used their dominant hand, holding the object with their non-dominant hand at the base and not lifting it from the table.

Cognitive Load Task Participants were shown a poem on a screen and were told to memorize this poem and subsequently to face away from the screen and recite the poem. If they made mistakes, they were instructed to read through the poem again. Participants repeated this procedure until they were told to stop.

Combined Movement/Cognitive Load Task Participants were instructed the clean the object while memorizing and reciting the poem.

Ritual Task Participants were instructed to clean the object following a ritual script, detailing necessary motions, cleaning cloths, and verbal counting of motions. The ritual was pretested and found to be executable by participants unfamiliar with the procedure. The script can be found in the ESM and at https://osf.io/48uj3/.

Measures of Physiological Arousal

Galvanic Skin Resistance Because some participants in the current study were engaged in movement tasks, sensors were placed on the plantar surfaces of the feet (Fowles et al. 1981). GSR was amplified using an ML116 GSR Amp (ADInstruments, Australia).

Heart Rate Heart rate was recorded using non-intrusive Ag-AgCl foam-padded ECG electrodes. Three electrodes were placed in a Lead II pattern. Heart rate was calculated using the interbeat interval, converted to beats per minute.

Respiration Participants were fitted with a chest-strap measuring their respiratory activity.

Blood Pressure We collected participants' systolic and diastolic blood pressure using an automated mobile blood pressure recording device (M500IT, OMRON Germany). Two measurements were taken each time an individual was about to complete a self-report survey. Measurements were averaged to provide a single measurement for each time point (see Fig. 1).

Data Processing and Reduction The means for all physiological data, except blood pressure, were averaged for each block (pre-stressor baseline, stressor, intervention task, post-experiment baseline) and all measures were centered within individuals to remove individual differences.

Psychological Variables

We used the 20-item positive and negative affect schedule containing items such as "Distressed" or "Calm" (Watson et al. 1988); the six-item Spielberg state trait anxiety measure containing such items as "I am tense" (Marteau and Bekker 1992); the 15-item Penn State worry questionnaire containing such items as "I find it easy to dismiss worrisome thoughts" (Meyer et al. 1990; Molina and Borkovec 1994); and the 15-item mood and anxiety symptom questionnaire containing such items as "I feel faint" (Clark and Watson 1991). All scales were adapted for the current study, dropping items not suited for the experimental context and measured on a four-point scale ranging from 1 (Definitely Not Applicable) to 4 (Definitely Applicable). Reliability was above .7 at each time-point for each instrument. We report all items in the supplementary material.

We ran a principal components analysis to test the underlying dimensionality. Table 1 shows the results of the principal components analysis and the chance adjusted

Table 1 Principal components analysis at each of the four time-points

Scales	Component 1	Component 2
T1		
PSWQ	**.81**	−.02
MASQ	**.75**	.07
STA	**.66**	**−.55**
NA	**.87**	−.04
PA	.10	**.94**
Percentage of Variance	.48	.24
Chance Adjusted Eigenvalue	2.47	1.14
T2		
PSWQ	**.86**	−.09
MASQ	**.82**	.03
STA	**.80**	**−.45**
NA	**.91**	−.07
PA	−.05	**.98**
Percentage of Variance	.58	.23
Chance Adjusted Eigenvalue	3.03	1.03
T3		
PSWQ	**.78**	−.11
MASQ	**.82**	.02
STA	**.72**	**−.55**
NA	**.87**	−.02
PA	.01	**.97**
Percentage of Variance	.51	.25
Eigenvalue	2.71	1.10
T4		
PSWQ	**.78**	−.16
MASQ	**.81**	.00
STA	**.61**	**−.66**
NA	**.86**	−.04
PA	.06	**.95**
Percentage of Variance	.48	.27
Chance Adjusted Eigenvalue	2.59	1.16

PSWQ = Penn State Worry Questionnaire, MASQ = Massachusetts Anxiety Symptoms Questionnaire, STA = State Trait Anxiety Inventory, NA = Negative Affect, PA = Positive Affect. Bold entries indicate component loadings >.20

eigenvalues of the parallel analysis used to determine the number of factors. A clear two-factor structure emerged, separating positive affect from negative affect as measured by the PANAS. We therefore focus on self-reported stress (reversed positive effect) in contrast to autonomous indicators of physiological arousal. This is in line with division of anxiety into conscious anxiety and physiological arousal (e.g., Kowalski

2000) and allows us to investigate our hypotheses regarding conscious and automatic responses to anxiety.

Motion Tracking

We used Microsoft Kinect V2 to track participants' movement, filtering participants' movement data to extract wrist movement per frame. Recurrence quantification analysis was calculated with the publicly available crqa package for R (Coco and Dale 2014). We examined participants' repetitiveness (%RR) and rigidity (%DET) only during the movement period of the experiment. %RR quantifies repetitiveness by computing the probability of occurrence of similar states, and %DET indicates rigid deterministic movement (Cluff et al. 2011; Marwan et al. 2007). We used the optimize parameter function provided in R to obtain the optimal embedding dimension and lag parameters for each participant, with a maximum lag of 10 and a false nearest neighbor percentage of 10. This yielded between 2 and 5%RR for each participant, normalized to allow between-subjects comparisons.

Results

Manipulation Check

We performed a series of manipulation checks to determine the effect of our stress manipulation on reported stress, positive affect, and physiological measures of anxious arousal. We ran separate mixed effects ANOVAs with time as a within-subjects variable and stress condition as a between-subjects variable for each dependent variable. We followed up significant interactions of time and stress with separate *t* tests at each time-point. We found no baseline differences between stress, and we found significant group differences for all measures except for respiration and positive affect, which showed no difference in response to the stress manipulation. Overall, the manipulation was successful since self-report and physiological measures were significantly impacted by our stress manipulation. (See the ESM for further detail.)

Cognitive Load and Anxiety

H1: Anxiolytic effects of cognitive load. To test our first hypothesis—that stressed participants who performed a cognitive load condition would show reduced cognitive anxiety compared with the control—we performed a $2 \times 2 \times 3$ ANOVA with stress condition and task intervention as between-subjects variables and time as the within-subjects variable (Levels: Rest, Stress, Intervention). Since the crucial three-way interaction was not significant: $F_{2,\ 136} = 2.08$, $p = .13$, $\eta^2 = .01$, we did not find support for H1. We found a significant within-subjects main effect of time: $F_{2,\ 136} = 40.53$, $p < .001$, $\eta^2 = .18$ (greater cognitive anxiety after the stressor); a significant between-subjects main effect of stress: $F_{1,\ 68} = 62.96$, $p < .001$, $\eta^2 = .47$ (participants in the stress condition experienced higher cognitive stress overall); and a significant within-subjects interaction of time with stress condition: $F_{2,\ 136} = 108.15$, $p < .001$,

$\eta^2 = .49$ (participants in the stress condition self-reported increased and subsequently decreased stress). The other effects were not significant (max $p = .16$).

Overall, these results do not support our hypothesis in which we expected a significant three-way interaction between stress condition, intervention, and time, with a significant decrease in stress when experiencing cognitive load. Assignment to the cognitive load task did not significantly impact the recovery from stress.

H2: Anxiolytic effects of cognitive load on physical markers of stress. To test our second hypothesis—that participants who performed a cognitive load condition would show reduced physiological markers of stress compared with participants who performed a control condition—we performed a $2 \times 2 \times 3$ ANOVA with stress condition (control and stress) and intervention (control and cognitive load) as between-subjects variables and time as the within-subjects variable (Levels: Rest, Stress, Intervention) on the various measures of physiological arousal. We report the results separately for the various physiological measures.

Heart Rate The crucial three-way interaction was not significant: $F_{2,\ 136} = 1.80$, $p = .17$, $\eta^2 = .01$; therefore, we did not find support for hypothesis 2. We found a significant within-subjects main effect of time: $F_{2,\ 136} = 168.33$, $p < .001$, $\eta^2 = .67$ (greater heart rate during the stressor); a significant within-subjects interaction between stress and time: $F_{2,\ 136} = 25.87$, $p < .001$, $\eta^2 = .10$ (participants in the stress condition exhibited increased and subsequently decreased heart rates); and a significant within-subjects interaction of intervention and time: $F_{2,\ 136} = 4.59$, $p < .05$, $\eta^2 = .02$ (participants in the cognitive load task showed an increase, whereas participants in the control condition showed a decrease). The other effects were not significant (max $p = .72$).

Galvanic Skin Response (GSR) The crucial three-way interaction was not significant: $F_{2,\ 136} = 0.63$, $p = .54$, $\eta^2 = .00$; therefore, we did not find support for hypothesis 2. We found a significant within-subjects main effect of time: $F_{2,\ 136} = 152.56$, $p < .001$, $\eta^2 = .64$ (galvanic skin response increased during the stressor task); a significant between-subjects main effect of stress: $F_{1,\ 68} = 10.16$, $p < .01$, $\eta^2 = .13$ (with participants in the stress condition experiencing higher galvanic skin response overall); and a significant within-subjects interaction between stress and time: $F_{2,\ 136} = 16.81$, $p < .001$, $\eta^2 = .07$ (participants in the stress condition experienced increased and subsequently decreased GSR). The other effects were not significant (max $p = .40$).

Diastolic Blood Pressure The crucial three-way interaction was not significant: $F_{2,\ 136} = 1.08$, $p = .34$, $\eta^2 = .01$; therefore, we did not find support for hypothesis 2. We found a significant within-subjects main effect of time: $F_{2,\ 136} = 141.50$, $p < .001$, $\eta^2 = .64$ (greater diastolic blood pressure after the stressor); a significant between-subjects main effect of stress: $F_{1,\ 68} = 15.35$, $p < .001$, $\eta^2 = .18$ (participants in the stress condition experiencing higher diastolic blood pressure overall); a significant within-subjects interaction between stress and time: $F_{2,\ 136} = 7.72$, $p < .001$, $\eta^2 = .04$ (participants in the stress condition showed increased and subsequently decreased diastolic blood pressure); and a significant within-subjects interaction of intervention and time: $F_{2,\ 136} = 4.49$, $p < .05$, $\eta^2 = .02$ (participants in the cognitive load task showed an increase, whereas participants in the control condition showed a decrease). The other effects were not significant (max $p = .20$).

Systolic Blood Pressure The crucial three-way interaction was not significant: $F_{2, 136} = 0.77$, $p = .46$, $\eta^2 = .00$; therefore, we did not find support for hypothesis 2. We found a significant within-subjects main effect of time: $F_{2, 136} = 147.10$, $p < .001$, $\eta^2 = .61$ (systolic blood pressure after the stressor); and a significant within-subjects interaction between stress and time: $F_{2, 136} = 25.45$, $p < .001$, $\eta^2 = .11$ (with participants in the stress condition exhibiting increased and subsequently decreased systolic blood pressure). The other effects were not significant (max $p = .57$).

Overall, and similar to the self-report measures of cognitive anxiety, these results do not support our hypothesis.

Movement and Anxiety

H3: Anxiolytic effects of undirected movement behavior. To test our third hypothesis—that stressed participants who performed an undirected movement task would show reduced self-reported cognitive anxiety or reduced physiological arousal—we performed a $2 \times 2 \times 3$ repeated measures ANOVA with stress condition and intervention as between-subjects variables and time as the within-subjects variable (levels: Rest, Stress, Intervention).

Cognitive Anxiety The crucial three-way interaction was not significant: $F_{2, 136} = 1.09$, $p = .34$, $\eta^2 = .01$; therefore, we did not find support for H3. We found a significant within-subjects main effect of time: $F_{2, 136} = 27.22$, $p < .001$, $\eta^2 = .14$ (greater cognitive anxiety after the stressor); a significant between-subjects main effect of stress: $F_{1, 68} = 55.36$, $p < .001$, $\eta^2 = .44$ (participants in the stress condition experienced higher cognitive anxiety overall); and a significant within-subjects interaction of time with stress condition: $F_{2, 136} = 99.66$, $p < .001$, $\eta^2 = .51$ (with participants in the stress condition exhibiting increased and subsequently decreased cognitive anxiety). The other effects were not significant (max $p = .74$).

Heart Rate The crucial three-way interaction was not significant: $F_{2, 136} = 0.15$, $p = .86$, $\eta^2 = .00$; therefore, we did not find support for H3. We found a significant within-subjects main effect of time: $F_{2, 136} = 183.33$, $p < .001$, $\eta^2 = .68$ (greater heart rate during the stressor); a significant between-subjects main effect of stress: $F_{1, 68} = 6.00$, $p < .05$, $\eta^2 = .08$ (participants in the stress condition experiencing higher heart rate overall); and a significant within-subjects interaction between stress and time: $F_{2, 136} = 17.12$, $p < .001$, $\eta^2 = .06$ (participants in the stress condition showed increased and subsequently decreased in heart rate). The other effects were not significant (max $p = .89$).

Galvanic Skin Response The crucial three-way interaction was not significant: $F_{2, 136} = 0.82$, $p = .44$, $\eta^2 = .01$; therefore, we did not find support for H3. We found a significant within-subjects main effect of time: $F_{2, 136} = 62.99$, $p < .001$, $\eta^2 = .46$ (galvanic skin response increased during the stressor); a significant between-subjects main effect of stress: $F_{1, 68} = 7.56$, $p < .01$, $\eta^2 = .10$ (participants in the stress condition experienced higher galvanic skin response overall); and a significant within-subjects interaction between stress and time: $F_{2, 136} = 4.42$, $p < .05$, $\eta^2 = .03$ (participants in the stress condition exhibited increased and subsequently decreased galvanic skin response). The other effects were not significant (max $p = .52$).

Diastolic Blood Pressure The crucial three-way interaction was not significant: $F_{2, 136} = 1.09$, $p = .34$, $\eta^2 = .01$; therefore, we did not find support for H3. We found a significant within-subjects main effect of time: $F_{2, 136} = 124.18$, $p < .001$, $\eta^2 = .61$ (greater diastolic blood pressure after the stressor); a significant between-subjects main effect of stress: $F_{1, 68} = 12.27$, $p < .001$, $\eta^2 = .15$ (participants in the stress condition experienced higher diastolic blood pressure overall); and a significant within-subjects interaction between stress and time: $F_{2, 136} = 7.15$, $p < .001$, $\eta^2 = .04$ (with participants in the stress condition having increased and subsequently decreased blood pressure).The other effects were not significant (max $p = .23$).

Systolic Blood Pressure The crucial three-way interaction was not significant: $F_{2, 136} = 1.84$, $p = .16$, $\eta^2 = .01$; therefore, we did not find support for H3. We found a significant within-subjects main effect of time: $F_{2, 136} = 138.49$, $p < .001$, $\eta^2 = .60$ (systolic blood pressure increased after the stressor); and a significant within-subjects interaction between stress and time: $F_{2, 136} = 20.81$, $p < .001$, $\eta^2 = .09$ (participants in the stress condition showed increased and subsequently decreased blood pressure). The other effects were not significant (max $p = .53$).

Overall, although we found a significant impact of the stress manipulation on undirected movement behavior, we found no support for our hypothesis. Low-intensity movement had no general effect on recovery from stress, neither for cognitive anxiety nor for physiological arousal.

H4a: Stress increases recurrent or deterministic behavior. To test hypothesis 4a, we performed a Student's independent-sample t test comparing the effect of stress and control condition on participants' dominant hand repetitiveness (%RR) and rigidity (%DET) during the undirected movement task. This test on a subset of our sample is a direct replication of the methods used by Lang et al. (2015)Participants in the stress condition ($M = 3.64$%RR) exhibited significantly more repetitive movement while cleaning the object compared with those in the control condition ($M = 3.08$): $t_{34} = -2.16$ [−1.07, −0.03], $p < .05$; Cohen's d indicated a medium effect size (−0.72 [−1.42, −0.02]). We further examined the effect of stress on deterministic movement of the dominant hand. We found no significant effect of the stress condition ($M = 27.18$%DET) compared with those in the control condition ($M = 25.45$): $t_{34} = -0.51$ [−8.56, 5.10], $p = .61$; Cohen's d indicated a negligible effect size (−0.17 [−0.85, 0.51]). This partially supports H4a and the findings of Lang et al. (2015); we expected higher recurrence of movement under stress, but we did not find higher rigidity.

H4b: Recurrent behavior leads to a greater stress reduction. In the next step, we extended the study conducted by Lang et al. (2015) by explicitly testing whether increased behavioral rigidity and repetitiveness decreases stress responses. We examined the effect of participants' recurrence on stress recovery from time two (stress condition) to time three (task intervention), controlling for stress at time two in the undirected movement intervention. We fit four models, increasing the number of predictors for each physiological measure, general stress, and positive affect. The first model was the baseline in which time 2 values of the dependent variable predicted time 3 values. The second model included %RR of participants' dominant hand. The third model included stress condition, with higher values denoting the stress condition (control 0 vs. stress 1). In the last model, we included an interaction between stress condition and recurrence to test whether participants in the stress condition had a higher reduction in stress from time 2 to time 3 if they exhibited more repetitive motions. This is the crucial part of our analysis.

Overall, we found marginally significant interaction effects of recurrence and stress condition on heart rate ($B = -.37$ [$-.73$, $-.01$], $p = .09$) and diastolic blood pressure ($B = -.53$ [-1.02, $-.04$], $p = .08$) in model 4. This supports our hypothesis that increased recurrence would predict greater reduction in markers of anxiety. We show the interactions in Figs. 2 and 3 with recurrence rate on the x axis and change in heart rate or diastolic blood pressure from the stress block to the intervention block on the y axis. The separate lines indicate assignment to the group.

The graphs show that participants in the stress condition exhibited greater reduction in heart rate and diastolic blood pressure from the stress to the intervention block if they performed more recurrent behavior. We provide the full regression models for all the analyses and all dependent variables in the ESM. We did not find significant effects for cognitive anxiety, systolic blood pressure, or galvanic skin response. We also report the correlations between all dependent measures in the supplementary material.

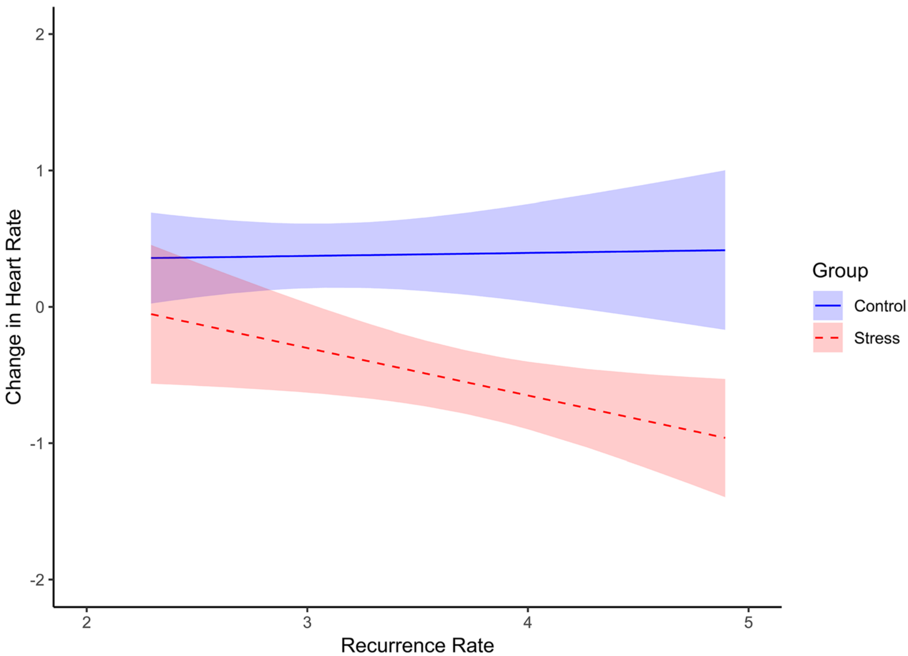

Fig. 2 Interaction of stress and recurrence on heart rate during the intervention task controlling for heart rate during the stress block

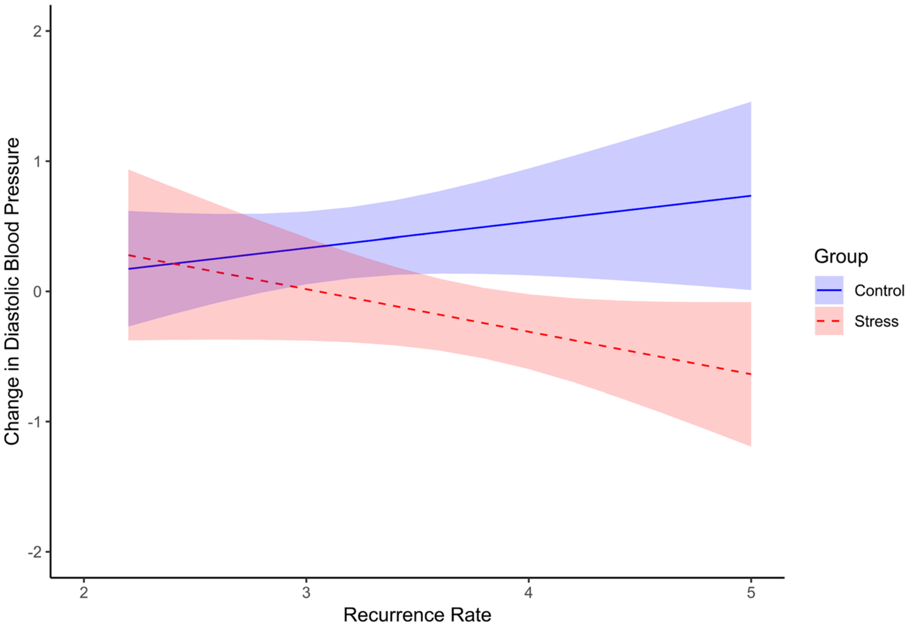

Fig. 3 Interaction of stress and recurrence on diastolic blood pressure during the intervention task controlling for diastolic blood pressure during the stress block

Unpackaging Ritual

H5a: Simulating anxiolytic ritual effects through cognitive load and behavioral actions. To test H5a—that stressed participants who performed a combined cognitive load/movement condition would show reduced stress compared with the control—we performed a 2 × 2 × 3 ANOVA with stress condition (control and stress) and intervention (control and cognitive load) as between-subjects variables and time as the within-subjects variable (levels: Rest, Stress, Intervention).

Cognitive Anxiety The crucial three-way interaction was not significant: $F_{2, 136} = 0.11$, $p = .90$, $\eta^2 = .00$; therefore, we did not find support for H5a. We found a significant within-subjects main effect of time: $F_{2, 136} = 23.59$, $p < .001$, $\eta^2 = .11$ (greater cognitive anxiety after the stressor); a significant between-subjects main effect of stress: $F_{1, 68} = 37.69$, $p < .001$, $\eta^2 = .36$ (participants in the stress condition experienced higher cognitive stress overall); and a significant within-subjects interaction of time with stress condition: $F_{2, 136} = 123.38$, $p < .001$, $\eta^2 = .57$ (participants in the stress condition showed increased and subsequently decreased stress). The other effects were not significant (max $p = .88$).

Heart Rate The crucial three-way interaction was significant: $F_{2, 136} = 3.30$, $p < .05$, $\eta^2 = .01$. We examined the three-way interaction further by conducting individual ANOVAs at each of the three separate measurement blocks. During the intervention block, we found a significant interaction of stress condition and intervention: $F_{1, 68} = 5.02$, $p < .05$, $\eta^2 = .07$. According to our hypothesis, stressed participants in the combined intervention should experience a lower hear rate than participants in the control intervention. In support of H5a, we found that participants in the stress condition who took part in the combined undirected movement/cognitive load intervention had lower heart rates ($M = -.36$) than participants in the control intervention ($M = -.17$).

In addition, we found a significant within-subjects main effect of time: $F_{2,\ 136} = 178.74$, $p < .001$, $\eta^2 = .63$ (greater heart rate during the stressor); a significant within-subjects interaction between stress and heart rate: $F_{2,\ 136} = 30.49$, $p < .001$, $\eta^2 = .11$ (participants in the stress condition experienced increased and subsequently decreased heart rates); a significant within-subjects interaction of intervention and time: $F_{2,\ 136} = 3.09$, $p < .05$, $\eta^2 = .01$ (participants in the combined condition showed an increase in heart rate over time whereas those in the control intervention showed a decrease); and a marginally significant between-subjects interaction of stress and intervention: $F_{1,\ 68} = 3.27$ $p = .08$, $\eta^2 = .05$ (participants in the control condition had higher heart rates during the combined task intervention).The other effects were not significant (max $p = .81$).

Galvanic Skin Response The crucial three-way interaction was not significant: $F_{2,136} = 0.24$, $p = .79$, $\eta^2 = .00$; therefore, we did not find support for H5a. We found a significant within-subjects main effect of time: $F_{2,\ 136} = 103.61$, $p < .001$, $\eta^2 = .57$ (greater galvanic skin response during the stressor); and a significant between-subjects main effect of stress: $F_{1,\ 68} = 6.12$, $p < .05$, $\eta^2 = .08$ (with participants in the stress condition experiencing higher galvanic skin response overall).The other effects were not significant (max $p = .89$).

Diastolic Blood Pressure The crucial three-way interaction was marginally significant: $F_{2,\ 136} = 2.66$, $p = .07$, $\eta^2 = .01$. We examined the three-way interaction further by conducting individual ANOVAs at each of the three measurement blocks. During the intervention block, we found a significant main effect of intervention: $\mathrm{F}_{1,\ 68} = 5.89$, $p = .02$, $\eta^2 = .08$ (the intervention affected recovery regardless of stress group assignment). We found no further significant effects (max $p = .20$). We expected a significant interaction between stress and intervention during the intervention time block. The lack of a trend in the expected direction indicates no support for H5a.

We did find a significant within-subjects main effect of time: $F_{2,\ 136} = 165.57$, $p < .001$, $\eta^2 = .66$ (greater diastolic blood pressure after the stressor); a significant between-subjects main effect of stress: $F_{1,\ 68} = 11.42$, $p < .001$, $\eta^2 = .14$ (with participants in the stress condition experiencing higher diastolic blood pressure overall); a significant within-subjects interaction between stress and time: $F_{2,\ 136} = 12.10$, $p < .001$, $\eta^2 = .05$ (participants in the stress condition showed increased and subsequently decreased blood pressure); a significant within-subjects interaction of intervention and time: $F_{2,\ 136} = 4.10$, $p < .05$, $\eta^2 = .02$ (participants in the combined condition showed an increase in diastolic blood pressure over time whereas participants in the control intervention showed a decrease); and a marginally significant between-subjects interaction of stress and intervention: $F_{1,\ 68} = 3.62$ $p = .06$, $\eta^2 = .04$ (participants in the control condition had higher diastolic blood pressure in the combined intervention). The other effects were not significant (max $p = .18$).

Systolic Blood Pressure The crucial three-way interaction was not significant: $F_{2,136} = 0.15$, $p = .87$, $\eta^2 = .00$; therefore, we did not find support for H5a. We found a significant within-subjects main effect of time: $F_{2,\ 136} = 149.18$, $p < .001$, $\eta^2 = .59$

(systolic blood pressure was greater after the stressor); a significant within-subjects interaction between stress and time: $F_{2,\ 136} = 32.46$, $p < .001$, $\eta^2 = .13$ (participants in the stress condition experienced increased and subsequently decreased blood pressure). The other effects were not significant (max $p = .81$).

Although we found a predicted effect of the combined movement and cognitive load task on heart rate recovery, this only partially supports our hypothesis because we found no further significant effects.

H5b: Differential anxiolytic effects of cognitive load, undirected movement, and combined undirected movement/cognitive load on self-reported stress. To test H5b, we compared the anxiolytic effects of undirected movement, cognitive load, and the combination of movement and cognitive load on self-reported stress. We performed a $2 \times 3 \times 3$ ANOVA with stress condition (control and stress) and intervention (undirected movement, cognitive load, and combined movement/cognitive load) as between-subjects variables and time as a within-subjects variable (levels: Rest, Stress, Intervention).

Cognitive Anxiety The crucial three-way interaction was not significant: $F_{4,204} = 1.02$, $p = .40$, $\eta^2 = .01$. Therefore, we did not find support for H5b. We found a significant within-subjects main effect of time: $F_{2,\ 204} = 55.27$, $p < .001$, $\eta^2 = .18$ (greater cognitive anxiety after the stressor); a significant between-subjects main effect of stress: $F_{1,\ 102} = 93.17$, $p < .001$, $\eta^2 = .47$ (with participants in the stress condition reporting higher cognitive stress overall); and a significant within-subjects interaction of time with stress condition: $F_{2,\ 204} = 141.60$, $p < .001$, $\eta^2 = .47$ (participants in the stress condition reported increased and subsequently decreased anxiety). The other effects were not significant (max $p = .50$).

Heart Rate The crucial three-way interaction was not significant: $F_{4,204} = 1.11$, $p = .36$, $\eta^2 = .01$. Therefore, we did not find support for H5b. We found a significant within-subjects main effect of time: $F_{2,204} = 203.81$, $p < .001$, $\eta^2 = .58$ (higher heart rate during the stressor); and a significant within-subjects interaction between stress and time: $F_{2,\ 204} = 42.57$, $p < .001$, $\eta^2 = .12$ (participants in the stress condition experienced increased and subsequently decreased heart rate). The other effects were not significant (max $p = .90$).

Galvanic Skin Response The crucial three-way interaction was not significant: $F_{4,204} = 0.31$, $p = .87$, $\eta^2 = .00$; therefore, we did not find support for H5b. We found a significant within-subjects main effect of time: $F_{2,\ 204} = 107.40$, $p < .001$, $\eta^2 = .49$ (galvanic skin response increased during the stressor); a significant between-subjects main effect of stress: $F_{1,\ 102} = 17.47$, $p < .001$, $\eta^2 = .15$ (with participants in the stress condition experiencing higher galvanic skin response overall); and a significant within-subjects interaction between stress and time: $F_{2,\ 204} = 7.32$, $p < .001$, $\eta^2 = .03$ (participants in the stress condition reported increased and subsequently decreased galvanic skin response).The other effects were not significant (max $p = .95$).

Diastolic Blood Pressure The crucial three-way interaction was not significant: $F_{4,204} = 0.15$, $p = .96$, $\eta^2 = .00$. Therefore, we did not find support for H5b. We found a significant within-subjects main effect of time: $F_{2,\ 204} = 176.77$, $p < .001$, $\eta^2 = .57$ (greater diastolic blood pressure after the stressor); a significant between-subjects main effect of stress: $F_{1,\ 102} = 6.32$, $p < .05$, $\eta^2 = .06$ (with participants in the stress condition experiencing higher diastolic blood pressure overall); and a significant within-subjects interaction between stress and time: $F_{2,\ 204} = 26.86$, $p < .001$, $\eta^2 = .09$ (participants in the stress condition experienced increased and subsequently decreased blood pressure). The other effects were not significant (max $p = .92$).

Systolic Blood Pressure The crucial three-way interaction was not significant: $F_{4,204} = 0.58$, $p = .68$, $\eta^2 = .00$; therefore, we did not find support for H5b. We found a significant within-subjects main effect of time: $F_{2,\ 204} = 192.92$, $p < .001$, $\eta^2 = .59$ (systolic blood pressure was greater after the stressor); a significant between-subjects main effect of stress: $F_{1,\ 102} = 5.49$, $p < .05$, $\eta^2 = .05$ (participants in the stress condition experienced higher systolic blood pressure overall); and a significant within-subjects interaction between stress and time: $F_{2,\ 204} = 28.37$, $p < .001$, $\eta^2 = .09$ (participants in the stress condition exhibited increased and subsequently decreased blood pressure). The other effects were not significant (max $p = .99$).

These results did not support our hypothesis, which predicted a differential effect of the combined cognitive load/undirected movement condition compared with the separate elements. The ESM presents a table with the F-statistics of all hypothesis side by side to enable easier comparison between the effects of the different interventions.

H6: Anxiolytic effects of ritualized behavior and combined cognitive load/undirected movement does not differ. Our sixth hypothesis was dependent on our fifth hypothesis being supported. Because it was not, we did not test H6 since it would not yield interpretable results.

Discussion

Rituals are a ubiquitous event across cultures and time periods, and there has been much speculation as to mechanisms that could explain the persistence of ritualistic behavior. One of the widely cited hypotheses (e.g., Hobson et al. 2017a) is that ritualistic behavior is a reaction to acute stress, aimed at reducing stress responses. The presumed anxiolytic effect of rituals is attributed to two main features of rituals: repeated and rigid behavior (Lang et al. 2015) and cognitive load (Boyer and Liénard 2008). We provided the first explicit test of the proposed causal pathways by testing whether an increase of ritualized behavior as a response to stress in turn results in a reduced stress response. We found that acute stress increases rigid behavior, which in turn increases physiological anxiety. In contrast, cognitive load did not reduce stress responses. We next provide further theoretical discussion of the main findings and implications for the theory of ritual.

Findings in Relation to Cognitive Load

Boyer and Liénard (2008) proposed that rituals exert cognitive load effectively suppressing anxiety. Our first and second hypotheses aimed to test whether participants who were instructed to memorize and recite a short poem would show reduced self-reported cognitive anxiety or physiological arousal. Overall, we did not find support for the theory that cognitive load reduces stress above the reduction occurring in the control intervention, neither for self-reported stress nor for physiological stress. This result contrasts with previous studies (e.g., Vytal et al. 2012) which found that cognitive load reduced anxiety.

This divergent finding could be attributed to several factors. First, our task might not have been cognitively demanding enough to elicit a suppression of stress. Vytal et al. (2012) used an n-back task in which participants had to remember object properties and positions for an increasing number of slides. Vytal et al. (2012) showed that cognitive load needs to be high enough to suppress anxiety, and our poem memory task might not have created a substantial enough cognitive load to suppress anxiety.

A different possible explanation is that the poem memory task was conceptually too close to the stress task in which participants had to count back from a set number. Participants might have interpreted our cognitive load intervention as an additional stressor; instead of providing relief from stress, it may have acted as an additional stressor. In line with these findings, in the control condition, those individuals who had not experienced a stressor but had to memorize the poem then experienced an increase in heart rate and in diastolic and systolic blood pressure ($p < .05$). Hence, it may be that our cognitive load induced mild stress responses, while not being sufficiently demanding to suppress the stress responses.

These findings are important to consider in the context of other studies that have been argued to support the cognitive load hypothesis. The often-cited study by Anastasi and Newberg (2008) found that participants who performed a well-rehearsed ritual well-known to them, such as performing the rosary, showed reduced stress. This suggests that practice is a significant component, and this diminishes the plausibility of the cognitive load argument. One option that is worth exploring is that only well-rehearsed tasks that are cognitively demanding but familiar have stress-reducing functions.

Findings in Relation to Repetitive Motor Tasks

Our third hypothesis predicted that participants who took part in an undirected movement task would show reduced self-reported stress or reduced physiological stress. Overall, we found no support for this hypothesis; we found no significant effect on either self-reported stress or physiological stress compared with the control task which did not involve movement. Although high-exertion motor tasks have been found to reduce stress (Anderson and Shivakumar 2013), our findings show that performing a low-intensity motor task alone does not reduce individuals' stress. It might be that more high-intensity movements could decrease anxiety (see research on exercise: e.g., Salmon 2001).

Nevertheless, motor performances in rituals are characterized by the performance of more or less invariant sequences of behaviors (Rappaport 1999). We provide a first replication of the study by Lang et al. (2015), who found that induced stress leads to increased ritualistic behavior. Our findings overall confirm the study by Lang et al. (2015): participants' behavioral repetitiveness in the stress condition (i.e., the rate at which similar movements recurred over time) was significantly higher than for participants in the control condition. We did not, however, find an effect of stress on deterministic movement (i.e., the rate at which movements form recurring patterns).

Overall, this indicates that repetitive, ritualized behavior might indeed represent a reaction to acute stress. Importantly, we used a different method of recording participants' movement than Lang et al. (2015). We used a Kinect camera to unobtrusively capture participants' hand movements whereas Lang and colleagues used Actigraph sensors strapped to participants' wrists (which may have affected hand movement and/or awareness of the movement tracking). This different method of recording movement might explain the divergent finding on participants' movement rigidity. At the same, the use of different methodologies increases the confidence in the finding that behavioral repetitiveness is a response to acute stress as this result cannot be attributed to method bias.

Importantly, we are the first to experimentally test the speculations by Lang et al. (2015) that this behavioral repetitiveness and rigidity might be instrumental in reducing individuals' stress after a stressful event. We tested this idea explicitly by examining the effect of repetitiveness during an undirected movement task on participants' self-reported and physiological stress while controlling for previous stress-levels to assess rates of change. We found that behavioral repetitiveness significantly reduced heartrate and diastolic blood pressure for participants in the stress condition compared to the control condition. This important finding lends support to the hypothesis by Lang et al. (2015) that behavioral repetitiveness in low-intensity motor tasks is instrumental in reducing stress. Nevertheless, future research is necessary to determine how this repetitive behavior is produced (for an interesting discussion in this direction, see Krátký et al. 2016).

Combined Effects of Cognitive Load and Movement Elements

In real-world rituals, repetitive behavior and cognitive load seldom appear separated from each other. Therefore, we examined the combined effect of undirected motor behavior and cognitive load on participants' stress reduction. Overall, as with the individual components, we did not find a significant effect of this combined condition on stress recovery compared with the control intervention. Heart rate recovery was an exception; we found that participants who performed the combined cognitive load and movement (cleaning) task showed greater heart rate reduction. Because no other physiological arousal marker showed the same result, and we did not find a general differential effect of the combined cognitive load with movement condition compared with the other tasks, we do not want to over-interpret this finding.

Our results contrast with those of previous studies that used tasks that combined movement elements with cognitive load and reported an anxiolytic effect of rituals (Anastasi and Newberg 2008; Brooks et al. 2016). One possible reason for this might be demand effects in previous studies. The major difference between our method and that of Brooks et al. (2016) is that they explicitly told participants they had to perform a ritual or random behavior. This might have primed participants with specific expectations about the efficacy of the behaviors. In our interventions we never stated that the behaviors participants had to perform were connected to rituals. It might be crucial that participants identify behavior as ritualistically meaningful in order for the behavior to be effective (e.g., similar to a placebo). Legare and Souza (2012) found that participants rated behaviors as more effective if they contained elements that made them clearly identifiable as rituals. Similarly, Anastasi and Newberg (2008) showed a significant reduction of self-reported stress through reciting the rosary. Groups in their study were not randomly assigned; participants who recited the rosary daily were assigned to the rosary condition, whereas participants who never recited the rosary were assigned to the control. Therefore, their study provides no indication whether rituals have an effect independent of the familiarity of their content and context. This line of reasoning suggests a different explanation for ritualistic effects, making demand characteristics (e.g., placebo effects) a more likely explanation.

A further shortcoming of previous research is that typically no stress induction took place in advance; therefore, it is questionable whether the performance of a specific ritual reduces stress below the baseline. To properly test the *stress-reduction* effects of ritual, it is important to experimentally create conditions that are stressful to allow an explicit test of the proposed hypotheses.

Theoretical Implications

In our study we tried to test the anxiolytic effect of rituals through an experimental differentiation of plausible underlying mechanisms. We found support for the argument that rigid behavior reduces stress, with participants in the high stress condition who showed more rigid behavior experiencing a greater reduction in heart rate and diastolic blood pressure. On the other hand, we found no effect of repeated movement on cognitive anxiety. This finding lends support to the argument that ritualized rigid behavior represents a coping mechanism for acute stress rather than the expression of constrained movement trajectories under stress found in earlier studies (Higuchia et al. 2002).

Limitations

A limitation important to consider while evaluating the results of our study is that we used a student sample in an English-speaking context. This sampling bias comes with inherent problems such as generalizability owing to education status, culture, and age. Although sampling of students is still a common practice in experimental research on rituals (e.g., Lang et al. 2015), a greater diversity of participants in future studies would be desirable. Second, we included self-report measures of anxious apprehension and arousal, but our structural analysis revealed that our participants did not make this distinction. Our factor analysis suggested a positive-negative affect distinction. This highlights the importance of assessing stress not only by means of self-report but also by using objective physiological measures. Best practice research on anxiety should employ multimethod designs including self-report and objective measures to allow for reliable differentiation of anxious apprehension and anxious arousal. Last, the rituals and behaviors we used in our current study were novel to the research participants; it is possible that participants need to be familiar with a ritual or behavior to enable an anxiolytic effect instead of it being evaluated as stressful. We nevertheless incorporated a number of specific elements of rituals based on Rappaport's (and others') definitions to experimentally create a condition that is as close as possible to a real-world ritual.

Future Research

Our current research focused on deconstructing rituals in a lab environment to assess the function of individual components. Nevertheless, real-world rituals are often embedded in specific environmental and social contexts that might interact with components of the ritual (for examples, see Pfeiffer 1982). Future research should extend the current work in either a field setting or a lab environment using tasks that reflect rituals familiar to the participants. For example, Anastasi and Newberg (2008) showed a significant reduction of self-reported stress through reciting the rosary. Participants who recited the rosary were familiar with the practice, and for them, ritual features, such as repetition and cognitive load, and ritual meaning might have interacted to produce the observed calming effect. Our selected behaviors were appropriate for a sample of university students. Nevertheless, in future research with populations outside Western university contexts different behaviors need to be used to allow for an ecologically valid test of our hypothesis.

Furthermore, our current research looked at rituals and their calming effects as a response to stress. We found that repetitive behavior can decrease markers of stress. Nevertheless, a number of rituals (such as initiation rites, preconflict rituals, religious rituals showing devotion) deliberately cause stress (Fischer et al. 2014; Pfeiffer 1982; Xygalatas et al. 2013). This stress has been theorized to lead to increased memory retention and transmission of important cultural knowledge (Whitehouse 1995). Although studies have shown improved performance as a consequence of ritual practice (e.g., Brooks et al. 2016), less is known about the effect of stressful rituals on memory function (see Xygalatas et al. 2013). Future research should investigate under which circumstances rituals are perceived as stressful or calming.

Last, although our research examined the potential stress-reducing effect of rituals, this cannot be assumed to be the exclusive function of rituals (for a review of alternative functions, see Hobson et al. 2017b). A further proposed function of rituals is increasing prosocial behavior and group functioning, which has received support in previous research in the field (e.g., Fischer et al. 2013; Ruffle and Sosis 2007; Sosis and Ruffle 2003) and in the lab (e.g., Mogan et al. 2017; Wen et al. 2016). In the current research we showed that ritualistic behavior can reduce stress, which could point to an evolutionary adaptive function of repetitive behavior. While our current research cannot resolve the discussion whether rituals are a by-product, or an adaptation future research should examine this further. Future research should also focus on multiple outcomes, such as stress and prosocial behavior to clarify how those outcomes might relate.

Conclusion

In summary, our study adds novel insights to the literature on rituals and anxiety. This is, to the best of our knowledge, the first study to explicitly and fully test in an experimental paradigm the process proposed by Malinowski (1954). We did not find effects of cognitive demands. The major supportive finding is that induced acute stress leads to increased behavioral repetitiveness, which in turn leads to a greater reduction of physiological arousal. More attention to the role of behavioral patterns in ritual is needed since behavioral repetitiveness is a core component of ritual and appears to play an important functional role. This anxiolytic effect could provide an explanation for the persistence and abundance of ritualized practice and behavior in humans.

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