

**Rituals, repetitiveness and cognitive load: a competitive test of ritual benefits for stress**

Johannes A. Karl

[Johannes.karl@vuw.ac.nz](mailto:Johannes.karl@vuw.ac.nz)

Ronald Fischer

Victoria University of Wellington, New Zealand

**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](https://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.

## **Rituals, repetitiveness and cognitive load: a competitive test of ritual benefits for stress**

Rituals are ubiquitous across cultures and time periods (for example see Bell, 2006) even though they incur substantial material and personal costs (Alcorta & Sosis, 2005). As noted by Hobson, Bonk, and Inzlicht (2017, p.1):

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

Rappaport (1999, p.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, Eilam, Mort, Keren, Lawson, 2013). Behaviors showing these ritualistic characteristics are often perceived as more efficient and effective (Legare & 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 & 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 & Liénard, 2006; 2008; Hobson, Schroeder, Risen, Xygalatas, & Inzlicht, 2017). Preliminary evidence seems to support such claims: Anastasi and Newberg (2008), and Brooks et al. (2016) found

that anxiety decreased after performing a ritual, yet, the mechanisms have not been examined to date.

Anxiety is multidimensional, with at least two major components: cognitive anxiety (also called anxious apprehension) and physiological arousal (also called anxious arousal) (Kowalski, 2000; Renner, Hock, Bergner-Koether, & Laux, 2016; for neuroscience support for this distinction see: Burdwood et al., 2016; Nitschke, Heller, & Miller, 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 & Liénard, 2006; 2008; Lang et al., 2015). These two processes may differentially affect the two components of anxiety. We are the first to explicit test these hypotheses in a pre-registered study<sup>1</sup> ([osf.io/rsu9x](https://osf.io/rsu9x/)). Real world rituals are often steeped in cultural meaning systems and might 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 & 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 & Rocklin, 1994). Given the limits of the cognitive system, if the system is busy, anxiety might be reduced. In support for cognitive load effects on anxiety, Vytal, Cornwell, Letkiewicz, Arkin, and Grillon (2013) found increases in cognitive anxiety for low and

---

<sup>1</sup> To increase readability some of our hypothesis have been renumbered; no change to proposed methods or analysis of the study were made.

medium cognitive load conditions, but not when participants were given highly demanding cognitive tasks. In line with these findings, Boyer and Liénard (2006) theorized that rituals exert an anxiolytic effect on anxious apprehension due to the substantial cognitive load that 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 vs 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; Seip, 1991). Nevertheless, previous research found anxious apprehension and physiological arousal are correlated; cognitive load might therefore also reduce physiological arousal (Renner, Hock, Bergner-Koether, Laux, 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 speculated that anxiolytic effect of rituals can be attributed to repetitive and rigid behavior (Lang et al., 2015). Similarly, anxiety may increase repetitive, ritual-like 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 due to anxious apprehension reduced the attention available to movement processes and result in a reduced ability to complete complex movement tasks, decreasing movement variability and more constrained movement trajectories (Causer, Holmes, Smith, & Williams, 2011; Higuchia, Imanakab, & Hatayamac, 2002). Hence, repetitive and rigid behaviors may be a direct behavioral response to anxiety.

Yet, other research suggested that just movement alone is sufficient to aid with stress recovery (Anderson & 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 if 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, Mar, & Peterson, 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., 2017; Sosis & Handwerker, 2011).

We aim to disentangle these two mechanisms. First, using a manipulation of movement vs no-movement control after stress, we can examine whether movement indeed decreases anxiety (we have no specific expectations which dimensions of anxiety are impacted by movement). In line with previous theory, we therefore we 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, a straightforward test to differentiate the two different processes underlying increased rigidity post-stress, we can a) examine whether induced anxiety increases repetitive and rigid behavior, which b) then leads to a greater reduction of physiological arousal or anxious apprehension at a later time point. 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 in the cognitive literature.

### **Re-assembling functional elements of ritual**

Rituals are characterized by high cognitive demands with unique movement patterns as part of the same performance (Alcorta & 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 experiencing cognitive load AND perform movements. Therefore, we propose that a combination of cognitive load and movement interventions emulate rituals and therefore lead to both greater anxiety reduction compared to 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) mirror the effect of a novel ritual task. Our novel ritual task was modelled on existing research on laboratory rituals (Norton & Gino, 2013).

Our novel ritual contained repeated verbalization (enumerating performed movements which resembles ritual features such as repeated verbalization of phrases) combined with repeated movement (pre-specified movement pattern that follow definitions of ritual practice as functionally opaque), as well as an attention demanding script (switching between different cleaning 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 on <https://osf.io/48uj3/> and the Supplementary Online Material).

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](https://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 due to recording problems with their physiological data (Control: 5; Cleaning: 11; Cognitive Load: 5; Cleaning/Cognitive Load : 5; Ritual: 9) and further four participants were excluded from the recurrence quantification analysis due to 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 of participants was 19.19 years with 137 female and 43 male participants.

#### **INSERT FIGURE 1 ABOUT HERE**

#### **Description of the Blocks**

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

#### **Stress Manipulation.**

**Stress.** Participants completed a counting task adapted from the Trier social stress test (Kirschbaum et al., 1993). Participants were instructed to count backwards from 1033 subtracting 13. Participants had to restart after every error and were reminded to count faster approximately every sixty seconds. After 5 minutes the participants were told to stop counting.

**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**

**Control task.** Participants were provided with several images from the international affective picture system (IAPS; Lang, Bradley, & Cuthbert, 2008). These were pre-selected 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 to not contain 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 object used by Lang et al. (2015). Participants could clean the object in any way they liked using 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 in front of them and were told to memorize this poem and to subsequently face away from the screen while reciting 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 to clean the object while memorizing and reciting the poem.

**Ritual task.** Participants were instructed to clean an 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 Supplementary Online Material 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, a placement at the plantar surfaces of the feet was chosen (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 placement. Heart rate was calculated using the inter-beat 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 every time an individual was about to complete a self-report survey. Measurements were averaged to provide a single measurement for each time point.

***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, Clark, & Tellegen, 1988); the 6-item Spielberg state trait

anxiety measure containing items such as “I am tense,” (Marteau & Bekker, 1992); the 15-item Penn State worry questionnaire containing items such as “I find it easy to dismiss worrisome thoughts” (Meyer, Miller, Metzger, & Borkovec, 1990; Molina & Borkovec, 1994); and the 15-item mood and anxiety symptom questionnaire containing items such as “I feel faint” (Clark & 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 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 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 conscious 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.

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

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

Notes. 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.

### **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 & Dale, 2014). We examined participants' repetitiveness (%RR) and rigidity (%DET) only during the movement period of the experiment. The %RR quantifies repetitiveness by computing the probability of occurrence of similar states while %DET indicates rigid deterministic movement (Cluff, Boulet, & Balasubramaniam, 2011; Marwan, Carmen, Thiel, & Kurths, 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 2-5 % 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-subject variable and stress condition as a between-subject 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 found significant group differences for all measures beside 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 supplementary online material for further detail).

## Cognitive Load and Anxiety

**H1: Anxiolytic effects of cognitive load.** To test our first hypothesis that stressed participants that performed a cognitive load condition would show reduced cognitive anxiety compared to the control, we performed a 2x2x3 ANOVA with stress condition and task intervention as between-subject variables and time as a within-subject variable (Levels: Rest, Stress, Intervention). The crucial three-way interaction was not significant:  $F(2, 136) = 2.08$ ,  $p = .13$ ,  $\eta^2 = .01$ , therefore, we did not find support for our hypothesis 1. 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 experiencing higher cognitive stress overall); a significant within-subject interaction of time with stress condition:  $F(2, 136) = 108.15$ ,  $p < .001$ ,  $\eta^2 = .49$  (participants in the stress condition increased and subsequently decreased in self-reported 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 to participants who performed a control condition, we performed a 2x2x3 ANOVA with stress condition (control and stress) and intervention (control and cognitive load) as between-subject variables and time as within-

subject 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 our 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-subject interaction between stress and time:  $F(2, 136) = 25.87, p < .001, \eta^2 = .10$  (participants in the stress condition had increased and subsequently decreased heart rates); a significant within-subject 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 our 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:  $F(1, 68) = 10.16, p < .01, \eta^2 = .13$  (participants in the stress condition experiencing higher galvanic skin response overall); a significant within-subject 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 our 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-subject interaction between stress and time:  $F(2, 136) = 7.72, p < .001, \eta^2 = .04$  (participants in the stress condition increased and subsequently decreased in diastolic blood pressure); a significant within-subject 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 our 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); a significant within-subject interaction between stress and time:  $F(2, 136) = 25.45, p < .001, \eta^2 = .11$  (participants in the stress condition increased and subsequently decreased their 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 2x2x3 repeated measures ANOVA with stress condition and intervention as between-subject variables and time as within-subject 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 our hypothesis 3. 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 experiencing higher cognitive anxiety overall); a significant within-subject interaction of time with stress condition:  $F(2, 136) = 99.66, p < .001, \eta^2 = .51$  (participants in the stress condition increased and subsequently decreased in 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 our hypothesis 3. 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); a significant within-subject interaction between stress and time  $F(2, 136) = 17.12, p < .001, \eta^2 = .06$  (participants in the stress condition 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 our hypothesis 3. 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 experiencing higher galvanic skin response overall); a significant within-subject interaction between stress and time:  $F(2, 136) = 4.42, p < .05, \eta^2 = .03$  (participants in the stress condition increased and subsequently decreased in 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 our hypothesis 3. 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 experiencing higher diastolic blood pressure overall); a significant within-subject interaction between stress and time:  $F(2, 136) = 7.15, p < .001, \eta^2 = .04$  (participants in the stress condition had 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 our hypothesis 3. 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); a significant within-subject interaction between stress and time:  $F(2, 136) = 20.81, p < .001, \eta^2 = .09$  (participants in the stress condition increased and subsequently decreased in blood pressure) The other effects were not significant (max  $p = .53$ ).

Overall, while we found a significant impact of the stress manipulation, we found no support for our hypothesis. Low intensity movement had no general effect on the 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 rigidity (%RR) and determinism (%DET) during the undirected movement task only. Therefore, the test on a subset of our sample is a direct replication of the findings by Lang et al. (2015). Participants in the stress condition ( $M$

$M = 3.64$ ) exhibited significantly more recurrence while cleaning the object compared to 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 dominant hand determinism. We found no significant effect of the stress condition ( $M = 27.18$ ) on participants' dominant hand determinism compared to 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 Hypothesis 4a and the findings of Lang et al. (2015) as we expected higher recurrence of movement under stress, but we did not find higher determinism.

**H4b: Recurrent behavior leads to a greater stress reduction.** In the next step, we aimed to extend 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 fitted four models increasing in the number of predictors for each physiological measure, general stress, and positive affect. The first model was the baseline model in which time two values of the dependent variable predicted time three values. The second model included participants' dominant hand recurrence. The third model included stress condition with higher values denoting the stress condition (control vs. stress). 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 two to time three if they expressed more recurrence. 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:  $-.53$  [-1.02,

$-.04], p = .08$  in model 4. This supports our hypothesis where we predicted that increased recurrence would predict greater reduction of markers of anxiety. We show the interactions in Figures 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 the assignment to the group.

### **INSERT FIGURE 2 ABOUT HERE**

### **INSERT FIGURE 3 ABOUT HERE**

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

## **Unpackaging Ritual**

**H5a: Simulating anxiolytic ritual effects through cognitive load and behavioral actions.** To test hypothesis 5a, that stressed participants who performed a combined cognitive load/ movement condition would show reduced stress compared to the control, we performed a 2x2x3 ANOVA with stress condition (control and stress) and intervention (control and cognitive load) as between-subject variables and time as within-subject 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 our hypothesis 5a. 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 experiencing higher cognitive stress overall); a significant within-subject interaction of time with stress condition:  $F(2, 136) = 123.38, p < .001, \eta^2 = .57$  (participants in the stress condition increased and subsequently decreased in 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:  $F(1, 68) = 5.02, p < .05, \eta^2 = .07$ . To support our hypothesis stressed participants in the combined intervention should experience a lower heart rate compared to stressed participants in the control intervention. Supporting our hypothesis 5a, in the stress condition, participants who took part in the combined undirected movement /cognitive load intervention had lower heart rates ( $M = -.36$ ) compared to participants that took part 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-subject interaction between stress and  $F(2, 136) = 30.49, p < .001, \eta^2 = .11$  (participants in the stress condition experienced increased and subsequently decreased heart rates); a significant within-subject interaction of intervention and time:  $F(2, 136) = 3.09, p < .05, \eta^2 = .01$  (participants in the combined condition increased in heart rate over time in contrast to the control intervention who showed a decrease); and a marginally significant between-subject interaction of stress and intervention:  $F(1, 68) = 3.27, p = .08, \eta^2 = .05$  (participants in the

control condition had higher heart rate 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 our hypothesis 5a. We found a significant within-subjects main effect of time  $F(2, 136) = 103.61, p < .001, \eta^2 = .57$  (galvanic skin response the stressor); a significant between subjects main effect of stress:  $F(1, 68) = 6.12, p < .05, \eta^2 = .08$  (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 separate measurement blocks. During the intervention block, we found a significant main effect of intervention:  $F(1, 68) = 5.89, p = .02, \eta^2 = .08$  (the intervention affected recovery regardless of stress group assignment). We found no further significant effects (max  $p = .20$ ). We expected a significant interaction stress and intervention during the intervention time block. There was no trend in the expected direction. This did not support our hypothesis 5a.

In addition, we found 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:  $F(1, 68) = 11.42, p < .001, \eta^2 = .14$  (participants in the stress condition experiencing higher diastolic blood pressure overall); a significant within-subject interaction between stress and time:  $F(2, 136) = 12.10, p < .001, \eta^2 = .05$  (participants in the stress condition increased and subsequently decreased in blood pressure); a significant within-subject interaction of intervention and time:  $F(2, 136) = 4.10, p < .05, \eta^2 = .02$  (Participants in the combined condition increased in diastolic blood pressure over time in

contrast to participants in the control intervention, who showed a decrease); and a marginally significant between-subject 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 our hypothesis 5a. 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-subject 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  $p = .81$ ).

While we found a predicted effect of the combined movement and cognitive load task on heart rate recovery, this only partially supports our hypothesis, as 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 hypothesis 5b, we compared the anxiolytic effects of undirected movement, cognitive load, and the combination of movement and cognitive load. We performed a 2x3x3 ANOVA with stress condition (control and stress) and intervention (undirected movement, cognitive load, and combined movement/cognitive load) as between-subject variables and time as within-subject variable (levels: Rest, Stress, Intervention), on self-reported stress.

**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 our hypothesis 5b. 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:  $F(1, 102) = 93.17, p < .001, \eta^2 = .47$  (participants in the stress condition reporting higher cognitive stress overall); a significant within-subject 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 our hypothesis 5b. 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); a significant within-subject 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 our hypothesis 5b. 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:  $F(1, 102) = 17.47, p < .001, \eta^2 = .15$  (participants in the stress condition experiencing higher galvanic skin response overall); and a significant within-subject 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 our hypothesis 5b. 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:  $F(1, 102) = 6.32, p < .05, \eta^2 = .06$  (participants in the stress condition experiencing higher diastolic blood pressure overall); a significant within-subject 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 our hypothesis 5b. 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 experiencing higher systolic blood pressure overall); a significant within-subject interaction between stress and time:  $F(2, 204) = 28.37, p < .001, \eta^2 = .09$  (participants in the stress condition had 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 to the separate elements. We present a table with the F-statistics of all hypothesis side by side in the supplementary material to allow for an 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, that our combined cleaning/ cognitive load condition would have the same anxiolytic effect as a novel ritual, was based on a supported fifth hypothesis,

which stated that combined cleaning/ cognitive load would significantly reduce stress.

Because our fifth hypothesis was not supported we did not test our sixth hypothesis, as 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 plausible mechanisms that could explain the persistence of ritualistic behavior. One of the widely cited hypotheses (see for example: Hobson et al., 2017) 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 in previous research. The first feature is repeated and rigid behavior (Lang et al., 2015) and the second feature is cognitive load (Boyer & 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 some 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 physiological stress. This result contrasts with previous studies (e.g., Vytal et al., 2012) which found 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 diastolic and systolic blood pressure ( $p < .05$ ). Hence, it may be plausible that our cognitive load induced mild stress responses, while not being sufficiently demanding to take up enough cognitive resources 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 that 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 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 as we found neither a significant effect on self-reported stress nor physiological stress compared to the control task which did not involve movement. While high exertion motor tasks have been found to reduce stress (Anderson & Shivakumar, 2013), our findings show that performing a low intensity motor task alone does not reduce individuals' stress. It might be plausible that more high intensity movements may 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 behaviours (Rappaport, 1999). We provide a first replication of 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 compared to participants in the control condition. We did however not find an effect of stress on behavioral determinism (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 in comparison to Lang et al. (2015). We used a Kinect camera to unobtrusively capture participants' hand movement compared to Lang et al., who used Actigraph sensors strapped to participants' wrists (which may have affected hand movement and/or awareness of the movement tracking). This different methodology of recording movement might explain the divergent finding on participants' movement determinism. 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 determinism 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, Lang, Shaver, Jerotijević, Xygalatas, 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 to stress recovery in the control intervention. Heart rate recovery was an exception, where 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 since we did not find a general differential effect of the combined cognitive load with movement condition compared to the other tasks, we do not want to over-interpret this finding.

Our findings contrast with previous studies that used tasks that combined movement elements with cognitive load and reported an anxiolytic effect of rituals (Brooks et al., 2016, Anastasi & Newberg, 2008). One possible reason for this might be due to demand effects in previous studies. Comparing our methods with Brooks et al. 2016, the major difference was that Brooks et al. (2016) explicitly told participants that 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 ritualistic meaningful in order for them to become effective (e.g., 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 *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, Imanakab, & Hatayamac, 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 due to education status, culture and age. While sampling of students is still a common practice in experimental research of 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 allow an anxiolytic effect instead of it being evaluated as stressful. We nevertheless incorporated a number of specific elements of rituals as by Rappaport's and

other's definition 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 in 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 that recited the rosary were familiar with the practice and for them rituals 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 behaviour can decrease markers of stress. Nevertheless, a number of rituals (such as initiation rites, pre-conflict 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). While studies have shown increased performance as consequence of ritual practice (e.g. Brooks et al., 2016), less is known about the effect of stressful rituals on memory function (see Xygalatas, Schjødt, et al., 2013).

Future research should investigate under which circumstances rituals are perceived as stressful or calming.

Last, while our current 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., 2017). 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, Callander, et al., 2013, Ruffle & Sosis, 2007; Sosis & Ruffle, 2003) and in the lab (e.g. Mogan et al., 2017; Wen et al., 2016). In the current research we showed that ritualistic behaviour can reduce stress, which could point to an evolutionary adaptive function of repetitive behaviour. 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 behaviour 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 fulfil an important functional role. This anxiolytic effect could provide an explanation for the persistence and abundance of ritualized practice and behavior in humans.

## References

- Alcorta, C. S., & Sosis, R. (2005). Ritual, emotion, and sacred symbols. *Human Nature*, 16(4), 323–359. doi:10.1007/s12110-005-1014-3
- Anastasi, M. W., & Newberg, A. B. (2008). A preliminary study of the acute effects of religious ritual on anxiety. *The Journal of Alternative and Complementary Medicine*, 14(2), 163–165. doi:10.1089/acm.2007.0675
- Anderson, E., & Shivakumar, G. (2013). Effects of exercise and physical activity on anxiety. *Frontiers in Psychiatry*, 4, 27. doi:10.3389/fpsyg.2013.00027
- Boyer, P., & Liénard, P. (2006). Why ritualized behavior? Precaution Systems and action parsing in developmental, pathological and cultural rituals. *The Behavioral and Brain Sciences*, 29(6), 595–613–50. doi:10.1017/S0140525X06009332
- Boyer, P., & Liénard, P. (2008). Ritual behavior in obsessive and normal individuals. *Current Directions in Psychological Science*, 17(4), 291–294. doi:10.1111/j.1467-8721.2008.00592.x
- Brooks, A. W., Schroeder, J., Risen, J. L., Gino, F., Galinsky, A. D., Norton, M. I., & Schweitzer, M. E. (2016). Don't stop believing: Rituals improve performance by decreasing anxiety. *Organizational Behavior and Human Decision Processes*, 137, 71–85. doi:10.1016/j.obhdp.2016.07.004
- Burdwood, E. N., Infantolino, Z. P., Crocker, L. D., Spielberg, J. M., Banich, M. T., Miller, G. A., & Heller, W. (2016). Resting-state functional connectivity differentiates anxious apprehension and anxious arousal. *Psychophysiology*. doi:10.1111/psyp.12696
- Causer, J., Holmes, P. S., Smith, N. C., & Williams, A. M. (2011). Anxiety, movement kinematics, and visual attention in elite-level performers. *Emotion*, 11(3), 595–602. doi:10.1037/a0023225
- Clark, L. A., & Watson, D. (1991). Tripartite model of anxiety and depression: Psychometric evidence and taxonomic implications. *Journal of Abnormal Psychology*, 100(3), 316–336. doi:10.1037/0021-843X.100.3.316
- Clark, A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science. *Behavioral and Brain Sciences*, 36(3), 181–204. doi:10.1017/S0140525X12000477
- Cluff, T., Boulet, J., & Balasubramaniam, R. (2011). Learning a stick-balancing task involves task-specific coupling between posture and hand displacements. *Experimental Brain Research*, 213, 15–25. doi:10.1007/s00221-011-2768-y
- Coco, M. I., & Dale, R. (2014). Cross-recurrence quantification analysis of categorical and continuous time series: an R package. *Frontiers in Psychology*, 5, 510. doi:10.3389/fpsyg.2014.00510

- Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G\*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39, 175–91.
- Fischer, R., Callander, R., Reddish, P., & Bulbulia, J. (2013). How Do Rituals Affect Cooperation? *Human Nature*, 24(2), 115–125. doi:10.1007/s12110-013-9167-y
- Fischer, R., Xygalatas, D., Mitkidis, P., Reddish, P., Tok, P., Konvalinka, I., & Bulbulia, J. (2014). The Fire-Walker's High: Affect and Physiological Responses in an Extreme Collective Ritual. *PLoS ONE*, 9(2), e88355. doi:10.1371/journal.pone.0088355
- Fux, M., Eilam, D., Mort, J., Keren, H., & Lawson, E. T. (2013). Are Motor Collective Rituals as Rigid as They Seem? A Test Case of a Zulu Wedding Dance. *Journal of Cognition and Culture*, 13(1–2), 17–32. doi:10.1163/15685373-12342082
- Fowles, D. C., Christie, M. J., Edelberg, R., GRINGS, W. W., Lykken, D. T., & Venables, P. H. (1981). Publication recommendations for electrodermal measurements. *Psychophysiology*, 18(3), 232–239. doi:10.1111/j.1469-8986.1981.tb03024.x
- Hembree, R. (1988). Correlates, Causes, Effects, and Treatment of Test Anxiety. *Review of Educational Research*, 58(1), 47–77. doi:10.3102/00346543058001047
- Higuchia, T., Imanakab, K., & Hatayamac, T. (2002). Freezing degrees of freedom under stress: Kinematic evidence of constrained movement strategies. *Human Movement Science*, 21, 831–846.
- Hirsh, J. B., Mar, R. A., & Peterson, J. B. (2012). Psychological entropy: A framework for understanding uncertainty-related anxiety. *Psychological Review*, 119(2), 304–320. doi:10.1037/a0026767
- Hobson, N. M., Schroeder, J., Risen, J. L., Xygalatas, D., & Inzlicht, M. (2017). The psychology of rituals: An integrative review and process-based framework. *Personality and Social Psychology Review*, 108886831773494. doi:10.1177/108886831773494
- Irons, W. (1996). Morality, religion, and human nature. In W. M. Richardson & W. Wildman (Eds.), *Religion and Science: History, Method, Dialogue* (pp. 375–399). New York: Routledge, Inc.
- Kim, S. H., & Rocklin, T. (1994). The temporal patterns of worry and emotionality and their differential effects on test performance. *Anxiety, Stress & Coping*, 7(2), 117–130. doi:10.1080/10615809408249339
- Kirschbaum, C., Pirke, K. M., & Hellhammer, D. H. (1993). The “Trier Social Stress Test”—a tool for investigating psychobiological stress responses in a laboratory setting. *Neuropsychobiology*, 28(1–2), 76–81. doi:119004
- Krátký, J., Lang, M., Shaver, J. H., Jerotijević, D., & Xygalatas, D. (2016). Anxiety and ritualization: Can attention discriminate compulsion from routine? *Communicative & Integrative Biology*, 9(3), e1174799. doi:10.1080/19420889.2016.1174799

- Kowalski, R. M. (2000). Anxiety. In *Encyclopaedia of Psychology*. American Psychological Association.
- Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2008). *International affective picture system (IAPS): Affective ratings of pictures and instruction manual. Technical Report A-8*. Gainesville, FL.
- Lang, M., Krátký, J., Shaver, J. H., Jerotijević, D., & Xygalatas, D. (2015). Effects of anxiety on spontaneous ritualized behavior. *Current Biology* (Vol. 25). <https://doi.org/10.1016/j.cub.2015.05.049>
- Legare, C. H., & Souza, A. L. (2012). Evaluating ritual efficacy: Evidence from the supernatural. *Cognition*, 124(1), 1–15. doi:10.1016/j.cognition.2012.03.004
- Malinowski, A. W. (1954). *Argonauts of the Western Pacific. An Account of Native Enterprise and Adventure in the Archipelagoes of Melanesian New Guinea*. London: George Routledge & Sons.
- Marteau, T. M., & Bekker, H. (1992). The development of a six-item short-form of the state scale of the Spielberger State-Trait Anxiety Inventory (STAII). *British Journal of Clinical Psychology*, 31(3), 301–306. doi:10.1111/j.2044-8260.1992.tb00997.x
- Marwan, N., Carmen Romano, M., Thiel, M., & Kurths, J. (2007). Recurrence plots for the analysis of complex systems. *Physics Reports*, 438, 237–329. doi:10.1016/j.physrep.2006.11.001
- Meyer, T. J., Miller, M. L., Metzger, R. L., & Borkovec, T. D. (1990). Development and validation of the Penn State Worry Questionnaire. *Behaviour Research and Therapy*, 28(6), 487–495. doi:10.1016/0005-7967(90)90135-6
- Mogan, R., Fischer, R., & Bulbulia, J. A. (2017). To be in synchrony or not? A meta-analysis of synchrony's effects on behavior, perception, cognition and affect. *Journal of Experimental Social Psychology*, 72, 13–20. doi:10.1016/J.JESP.2017.03.009
- Molina, S., & Borkovec, T. D. (1994). *The Penn State Worry Questionnaire: Psychometric properties and associated characteristics*. John Wiley & Sons.
- Nitschke, J. B., Heller, W., Palmieri, P. A., & Miller, G. A. (1999). Contrasting patterns of brain activity in anxious apprehension and anxious arousal. *Psychophysiology*, 36(5), 628–637. doi:10.1111/1469-8986.3650628
- Norton, M. I., & Gino, F. (2013). Rituals Alleviate Grieving for Loved Ones, Lovers, and Lotteries. *Journal of Experimental Psychology: General*, 143(1), 266–272. doi:10.1037/a0031772
- Pfeiffer, J. E. (1982). The creative explosion: An inquiry into the origins of art and religion. New York: Harper & Row.

- Rappaport, R. (1999). *Ritual and Religion in the Making of Humanity* (Cambridge Studies in Social and Cultural Anthropology). Cambridge: Cambridge University Press.  
doi:10.1017/CBO9780511814686
- Renner, K.-H., Hock, M., Bergner-Köther, R., & Laux, L. (2016). Differentiating anxiety and depression: the State-Trait Anxiety-Depression Inventory. *Cognition and Emotion*, 1–15. doi:10.1080/02699931.2016.1266306
- Ruffle, B. J., & Sosis, R. (2007). Does it pay to pray? Costly ritual and cooperation. *The B.E. Journal of Economic Analysis & Policy*, 7(1), 1-35.
- Salmon, P. (2001). Effects of physical exercise on anxiety, depression, and sensitivity to stress: A unifying theory. *Clinical Psychology Review*, 21(1), 33–61.  
doi:10.1016/S0272-7358(99)00032-X
- Sarason, I. G. (1988). Anxiety, self-preoccupation and attention. *Anxiety Research*, 1(1), 3–7.  
doi:10.1080/10615808808248215
- Seipp, B. (1991). Anxiety and academic performance: A meta-analysis of findings. *Anxiety Research*, 4(1), 27–41. doi:10.1080/08917779108248762
- Sosis, R., & Handwerker, W. P. (2011). Psalms and Coping with Uncertainty: Religious Israeli Women's Responses to the 2006 Lebanon War. *American Anthropologist*, 113(1), 40–55. doi:10.1111/j.1548-1433.2010.01305.x
- Sosis, R., & Ruffle, B. J. (2004). Religious ritual and cooperation: Testing for a relationship on Israeli religious and secular Kibbutzim. *Current Anthropology*, 44, 713-722.
- Vytal, K. E., Cornwell, B. R., Letkiewicz, A. M., Arkin, N. E., & Grillon, C. (2013). The complex interaction between anxiety and cognition: insight from spatial and verbal working memory. *Frontiers in Human Neuroscience*, 7, 93.  
doi:10.3389/fnhum.2013.00093
- Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS Scales. *Journal of Personality and Social Psychology*, 54(6), 1063–1070.
- Watson, D. (1988). Intraindividual and interindividual analyses of positive and negative affect: their relation to health complaints, perceived stress, and daily activities. *Journal of Personality and Social Psychology*, 54(6), 1020–30.
- Wen, N. J., Herrmann, P. A., & Legare, C. H. (2016). Ritual increases children's affiliation with in-group members. *Evolution and Human Behavior*, 37(1), 54-60.
- Whitehouse, H. (1995). *Inside the cult: religious innovation and transmission in Papua New Guinea*. Clarendon Press.
- Xygalatas, D., Schjoedt, U., Bulbulia, J., Konvalinka, I., Jegindø, E.-M., Reddish, P., ... Roepstorff, A. (2013). Autobiographical Memory in a Fire-Walking Ritual. *Journal of Cognition and Culture*, 13(1–2), 1–16. doi:10.1163/15685373-12342081

### Author Sketches

**Johannes Alfons Karl.** Holds a MSc in Cross-Cultural Psychology from the Victoria University of Wellington and is currently pursuing a PhD in Psychology at the Victoria University of Wellington. His research focuses on experimental approaches to ritualistic behaviour, mindfulness, and connectedness to nature.

**Ronald Fischer** is a Professor in Psychology at Victoria University of Wellington, New Zealand and completed his PhD in Social Psychology at Sussex University, UK. His work broadly focuses on the evolution of cultural ritual as well as cultural differences in psychological functioning, especially in relation to values, personality and well-being.