

Rituals, rigidity and cognitive load: A competitive test of ritual benefits for stress

by

Johannes Alfons Karl

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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](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.

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## **Rituals, Rigidity and Cognitive Load: A Competitive Test of Ritual Benefits for Stress<sup>1</sup>**

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 (1993) proposed a widely used definition of ritual as behaviors characterized by compulsion, rigidity, repetition, redundancy, order and boundaries, casual opaqueness, and goal demotion. Behaviors showing these ritualistic characteristics are often perceived as more efficient and effective (Legare & Souza, 2012).<sup>2</sup> 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. One proposed evolutionary function of rituals going back to observations by Malinowski (1954) is that rituals exert an anxiolytic effect: rituals reduce anxiety and therefore allow for the smooth functioning of society (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.

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<sup>1</sup> The current manuscript has been submitted in this form for publication and is presented here in unaltered form. Throughout the text footnotes indicate relevant appendices that report additional reviews and information, and results not included in the publication due to word count restrictions.

<sup>2</sup> An extension of this section, providing broader information and an extended discussion of ritual definition can be found in Appendix A.

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)<sup>3</sup>.

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 explicitly test these hypotheses in a pre-registered study<sup>4</sup> ([osf.io/rsu9x](https://osf.io/rsu9x)).

### **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 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

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<sup>3</sup> A more extended overview of the differentiation between anxious apprehension and anxious arousal can be found in Appendix B.

<sup>4</sup> To increase readability, some of our hypotheses have been renumbered; no change to proposed methods or analysis of the study were made.



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 (Rappaport, 1993).

Anthropologists speculated that anxiolytic effect of rituals is specifically attributed to repetitive and rigid behavior (Malinowski, 1954; 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).

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 Malinowski, 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 unpack 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.

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=200), but we had to exclude 20 participants due to recording problems with their physiological data 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.

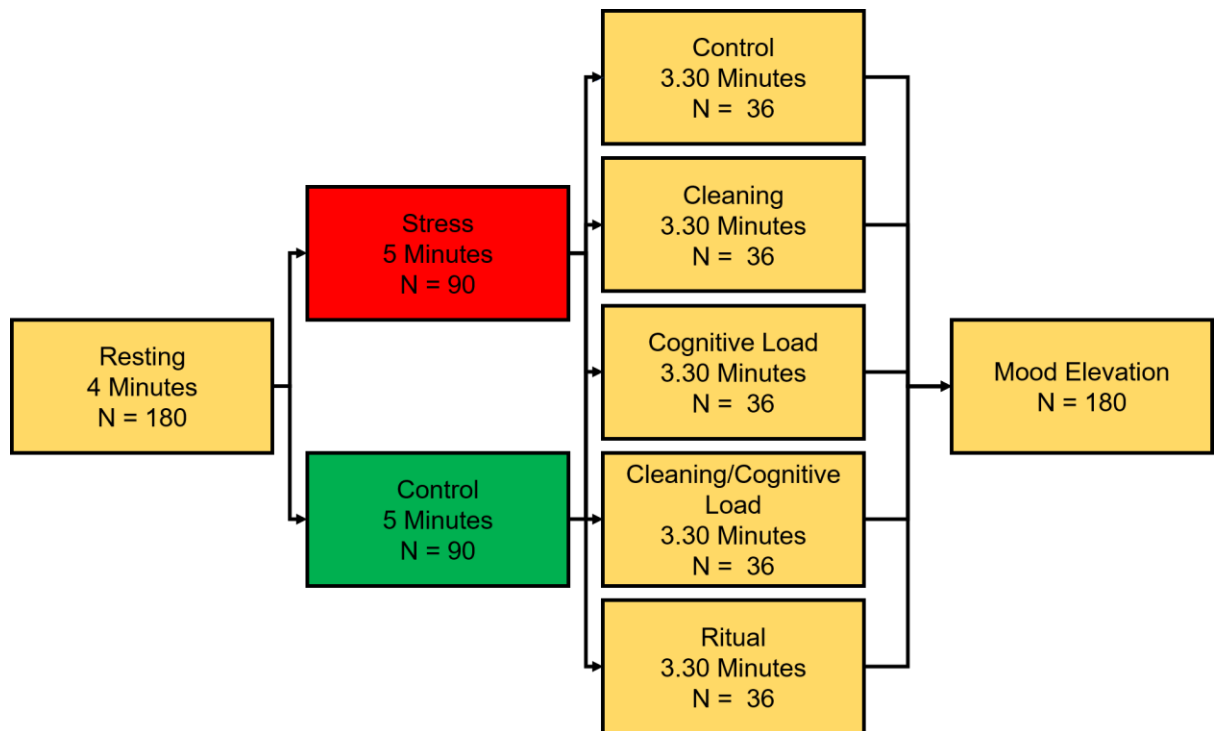


Figure 2. Flowchart and participant distribution in each block.

### 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)<sup>5</sup>.

### 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.

**Control.** Participants in this condition received an object and were asked to “Think about what this object represents to you” and “Think about what the object might mean to the

<sup>5</sup> The full material, experimental scripts, data, R scripts, and routines used for the analysis of the hypotheses are available on [osf.io/rsu9x](https://osf.io/rsu9x).

artist”. It was emphasized that the participant would not be questioned on their thoughts about the object.

### **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.

### **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<sup>6</sup>. 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.

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<sup>6</sup> Graphs that detail the results of the parallel analysis can be found in Appendix C.



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

T1		
Scales	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).<sup>7</sup> 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

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<sup>7</sup> This is a novel application of the Kinect V2. Sample code that exemplifies how data from the Kinect can be recorded (Appendix F), extracted (Appendix G), and how the RQA can be computed (Appendix H) is shown in the relevant appendices.

physiological measures were significantly impacted by our stress manipulation. (see the supplementary material for further detail)<sup>8</sup>.

### **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

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<sup>8</sup> The supplementary material of the article that was submitted for publication can be found in Appendix D.

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 control showed an increase during the cognitive load task, 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 control showed an increase during the cognitive load task, 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 ( $M = 3.64$ ) 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.<sup>9</sup>

**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

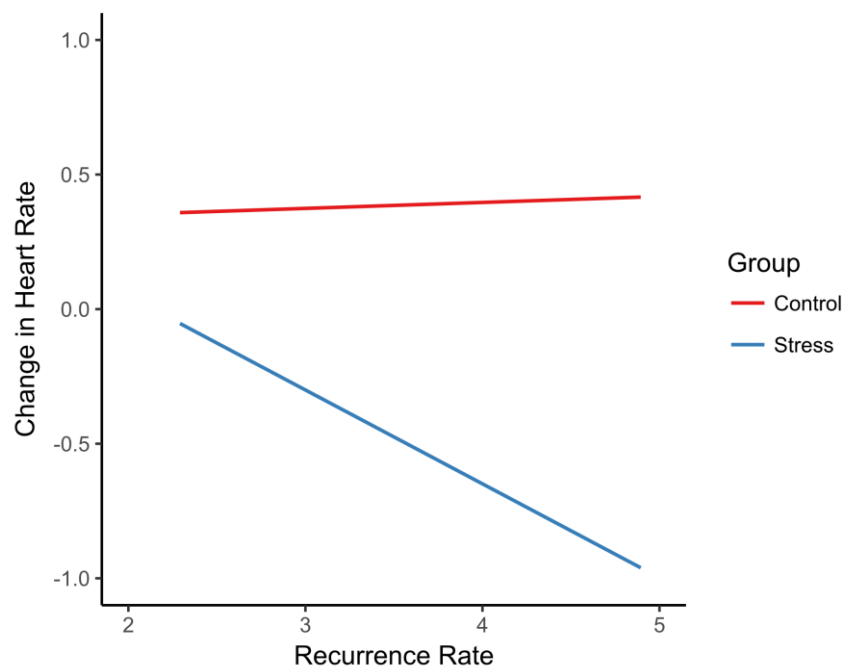
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<sup>9</sup> Additional analyses are reported in Appendix E.

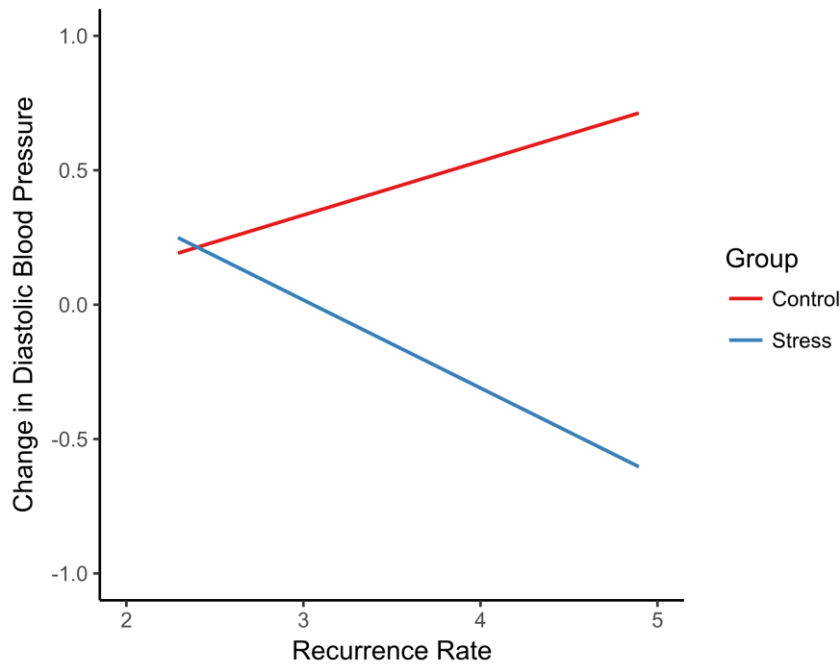


participants in the stress condition had a higher reduction in stress from time two to time three if they expressed more recurrence. This is the crucial part of our analysis.

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.



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



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

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 this analysis and the other physiological measures and cognitive anxiety in the supplementary material.<sup>10</sup>

## 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

<sup>10</sup> The relevant supplementary material can be found in Appendix D

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 hear 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.

**H6: Anxiolytic effects of ritualized behavior and combined cognitive load/ undirected movement does not differ.** This hypothesis was based on a supported fourth

hypothesis. Based on the finding that combined cognitive load/undirected movement did not impact stress significantly, we did not further investigate this hypothesis.



## **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 automatized have stress-reducing functions.

### **Findings in Relation to Repetitive Motor Tasks**

Our third hypothesis predicted that participants who took part in a 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 behavioral rigidity and determinism (Rappaport, 1993). 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 rigidity (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 rigid, 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 rigidity 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 rigidity and determinism might be instrumental in reducing individuals' stress after a stressful event. We tested this idea explicitly by examining the effect of rigidity 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 rigidity 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 rigidity in low intensity motor tasks is instrumental in reducing stress.

### **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 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 definition to experimentally create a condition that is as close as possible to a real-world ritual.

## **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 rigidity, 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 rigidity 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/fpsy.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.
- 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:10.1177/1088868317734944
- 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
- 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 (STAI). *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
- 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
- Rappaport, R. (1993). *The obvious aspects of ritual. In Ecology, Meaning, and Religion* (2nd ed., p. 272). Berkley, California: North Atlantic Books.
- 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
- 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
- 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.

## **Appendix A: The Definition of Ritual and Selected History of Ritual Research.**

Rituals and ritualistic behavior have been observed across all cultures and time-periods. Some of the oldest preserved structures and artefacts in the world are likely to have had a ritual function (Fogelin, 2007). Archaeologists uncovered a set of Neolithic temple structures on Malta suspected to be erected around 4000 BCE, predating both the great Pyramids and Stonehenge (Bonanno, Gouder, Malone, & Stoddart, 1990). These temples may have been built across multiple generations and certainly have required a substantial amount of workforce and resources. Current research on these temple structures views them as a response of Malta's inhabitants to other cultures settling in the area, responding specifically to the other cultures' diverging ritual practices (Robb, 2001).

Regardless whether this historical interpretation is correct, the fact remains that Malta's citizens of the fourth millennium BC devoted resources that could have served them in other, possibly more obviously advantageous, manners, instead of building these megalithic temples used for ritual purposes. This expenditure of resources is not a quirk of a single culture, but evidence for ritualistic activity has been found in virtually all early civilizations, from buildings, such as the great pyramid of Giza erected for Khufu in the middle of the third century BC in Egypt (O'Brien & Peavey, 2016) or the terracotta army of Qin Shi Huang dating around the late third century BC in China (Lu, Zhang, Xie, & Wang, 1988) to the abundance of grave goods from Bronze Age societies (Woodward & Hunter, 2015).

Stepping back from examining past civilizations and instead examining current cultures, rituals are still a persistent feature ranging from core institutions of societies, such as the military (Haldén & Jackson, 2016), to the fringes of society, such as organized crime (Boretz, 2010). Rituals can be accepted to be human universals; in cultures around the world individuals engage in individual or collective rituals. Regardless of creed, nation, or period

humans engaged and still engage in rituals. Bell (2006, p.91) noted: “At one time or another, almost every human activity has been done ritually or made part of a ritual.” In general, rituals are costly in materials (ritual props, ritual sites), physiological resources (e.g., extended dancing or singing), and time (for preparation and the ritual itself) (Alcorta & Sosis, 2005). Hobson, Bonk, and Inzlicht (2017) summarized this abundance of ritual practice in contrast to their costs:

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? (p.1)

Collective rituals often represent some of the most salient features of cultures. Nevertheless, rituals are still understudied. Fischer, Callander, Reddish, and Bulbulia (2013) expressed this dissonance between salience and abundance of rituals and our limited knowledge quit clearly: “The universal prominence of collective rituals, their costs, and the lack of straightforward instrumental benefits render this peculiar domain of social interaction among the most fascinating and poorly understood areas of human psychology and culture.” (p.115)

While collective rituals are often deeply intertwined with cultural context, individual rituals can also be performed without a cultural narrative, for example eating rituals by individuals (Vohs, Wang, Gino, & Norton, 2013). These individual rituals can range from personal superstitions to culturally mandated patterns of behavior of individuals, such as praying behavior. The wide conceptual spectrum of rituals ranging from individual to

collective, from ad hoc to culturally prescribed, has led to researchers struggling to find a comprehensive definition of rituals.

### **Defining Ritual for Psychological Research**

A commonly used definition of rituals, arising from anthropological research, was formulated by Rappaport (1993). He defined rituals as characterized by compulsion, rigidity, repetition, redundancy, order and boundaries, causal opaqueness, and goal demoted behavior. Sociologists approached the definition of rituals from a different track, emphasizing standardized behaviors ordered along a gradient from irrational, such as magic, to rational, such as marriages (Goody, 1961). Overall, each discipline tends to use its' own definition of what exactly constitutes a ritual. Over time, this lead to a blunting of ritual as a label, up to a point at which Boyer and Liénard (2006, p.814) remarked: “there is no clear criterion by which cultural anthropologists or other scholars of religion or classics determine that a particular type of behavior is or is not an instance of a ritual”. It seems therefore paramount to explicitly state what researchers are examining when interested in rituals. In this thesis, ritual will be defined using Rappaport’s (1993) definition presented above, because it describes ritual in terms, such as rigidity, that are operationalizable in research, without narrowing ritual down to predetermined standardized behaviors as Goody’s (1961) definition does. Furthermore, Rappaport’s definition is commonly used even outside the field of anthropology making it useful in comparing findings on rituals between different bodies of literature.

The use of Rappaport’s definition can be further supported by the agreement that laypeople show in defining which elements should be part of an efficient ritual. Legare and Souza (2012) surveyed Brazilian healing rituals (*simpatias*) for common elements. Of those common elements, detailed scripts including multiple steps, repetition, and the use of previously established symbols emerged as crucial factors that determined the perceived

effectiveness and authenticity of made up rituals. This pattern was replicated by Legare and Souza (2012) in a US sample, to whom the *simpatias* were a novel ritual. These findings partially mirror the elements established in Rappaport's (1993) definition of rituals and might form a viable approach to empirically capture cross-culturally similar ritual elements.

### **Individual and Collective Rituals.**

Whereas group rituals are often more salient due to their public performance and number of actors involved, evidence for the historical performance of individual rituals is less salient, but likely be equally abundant as group rituals (Fogelin, 2007). These individual rituals can range from simple motions and behavior before prefacing certain tasks or situations to elaborated hour-long performances. Vyse (2014) reports such an extensive ritual:

[A] former goalie for the Connecticut College hockey team prepared for each game by executing an elaborate ritual that had many of the features of a rainmaker's incantation. He began in his form room, by listening to a special song before going to the rink; in the locker room, he put on his uniform in a specific, idiosyncratic sequence; and once on the ice, he repeatedly tapped each stanchion of the goal in a rigid pattern. (Pp.98-99)

### **Persistence of Rituals as a Result of Cultural Inheritance**

While a ritual as the one performed by the unnamed hockey player has no meaning for anyone else beside the player, it seems to hold immense importance to him. Faced with this large quantity of individual rituals, collective rituals and ritual behavior, investigating the effect of rituals seems to be an endlessly fractured task. Early anthropologists approached this diversity by attempting to describe the causes and outcomes, in respect to the collective belief system, of individual rituals (e.g. Frazer, 1935). In contrast to this, Boyer and Liénard (2006; 2008) proposed that rituals are defined by similar underlying processes and effects expressed

in patterns sensible to the culture and the time. The abundance of different ritual practices could be viewed as a process of cultural inheritance as part of a cultural selection framework (Boyer & Liénard, 2006). The cultural selection framework is tied to the cultural evolution framework which sees culture as a form of exosomatic evolution, separable from genetic evolution, yet underlying similar selection mechanisms (Boyd & Richerson, 1985). To explain the persistence of rituals, they would need to fulfil a function independent of their cultural narrative.

### **Proposed Anxiolytic Effect of Rituals**

Overall, rituals might fulfil the same need in different periods and societies, but different pre-existing practices and materials are available to construct a unique ritual. One of the earliest attempts to explain the reason for ritualistic behavior stems from Malinowski's (1954) anthropological observations of fishing behaviors among the Trobriand Islanders in Melanesia in the early 1900s. Noting that the islanders performed elaborate rituals when traveling in unpredictable and dangerous ocean conditions but not when traveling in shallow, calm waters, Malinowski concluded that the islanders used rituals to reduce the anxiety induced by fishing in dangerous waters. This observation can be supplemented by the abundant observations of ritualized behavior surrounding phases of stress and anxiety, such as deaths, births, weddings, public speaking, and sports (Chesson, 2008; Norton & Gino, 2014; Schippers & Van Lange, 2006; Wrisberg & Pein, 1982).

Research on ritualistic practices in professional sport further support Malinowski's idea. Baseball players performed more superstitious rituals if they had to make a play with low chances of success, compared to when they had to make a play with high chances of success (Gmelch, 1978). Players also exhibited more superstitious, ritualistic, behavior if they were close to losing compared to if they were close to winning (Ciborowski, 1997). This



supports the notion that the pressure weighing on the individual and the anxiety it causes is one of the driving factor behind the ritualistic behavior. While anecdotal observations of the relationship between anxiety and rituals are relatively abundant in the literature, little is known about the underlying mechanism that leads to this relationship. This conceptual breadth of rituals and the previous research on it provided the rationale for the current thesis to investigate ritual through the proposed underlying mechanisms which lead to their maintenance.

### References Appendix A

- Alcorta, C. S., & Sosis, R. (2005). Ritual, emotion, and sacred symbols. *Human Nature*, 16(4), 323–359. doi:10.1007/s12110-005-1014-3
- Bell, C. (2009). *Ritual: Perspective and dimensions*. New York: Oxford University Press.
- Bonanno, A., Gouder, T., Malone, C., & Stoddart, S. (1990). Monuments in an island society: The Maltese context. *World Archaeology*, 22(2), 190–205. doi:10.1080/00438243.1990.9980140
- Boretz, A. A. (2010). *Gods, ghosts, and gangsters: Ritual violence, martial arts, and masculinity on the margins of Chinese society* (1st ed.). Honolulu, HI: University of Hawai‘i Press.
- Boyd, R., & Richerson, P. J. (1985). *Culture and the evolutionary process*. Chicago, IL: University of Chicago Press.
- 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
- Chesson, M. S. (2008). Social memory, identity, and death: An introduction. *Archeological Papers of the American Anthropological Association*, 10(1), 1–10. doi:10.1525/ap3a.2001.10.1.1
- Ciborowski, T. (1997). “Superstition” in the collegiate baseball player. *The Sport Psychologist*, 11(3), 305–317. doi:10.1123/tsp.11.3.305
- Fischer, R., Callander, R., Reddish, P., & Bulbulia, J. (2013). How do rituals affect cooperation? An experimental field study comparing nine ritual types. *Human Nature*, 24(2), 115–125. doi:10.1007/s12110-013-9167-y

- Fogelin, L. (2007). The archaeology of religious ritual. *Annual Review of Anthropology*, 36(1), 55–71. doi:10.1146/annurev.anthro.36.081406.094425
- Frazer, James George (1935). *The golden bough; a study in magic and religion*. New York, The Macmillan Company
- Goody, J. (1961). Religion and ritual: The definitional problem. *The British Journal of Sociology*, 12(2), 142. doi:10.2307/586928
- Gmelch, G. (1971). Baseball magic. *Transaction*, 2(8), 39–41.
- Haldén, P., Jackson, P., Haldén, P., & Jackson, P. (2016). *Transforming warriors: The ritual organization of military force*. New York, NY: Routledge.
- Hobson, N. M., Bonk, D., & Inzlicht, M. (2017). Rituals decrease the neural response to performance failure. *PeerJ*, 5, e3363. doi:10.7717/peerj.3363
- 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
- Liénard, P., & Boyer, P. (2006). Whence collective rituals? A cultural selection model of ritualized behavior. *American Anthropologist*, 108, 814–827. doi:10.2307/4496521
- Lu, Y., Zhang, J., Xie, J., & Wang, X. (1988). TL dating of pottery sherds and baked soil from the Xian Terracotta Army Site, Shaanxi Province, China. *International Journal of Radiation Applications and Instrumentation. Part D. Nuclear Tracks and Radiation Measurements*, 14(1), 283–286. doi:10.1016/1359-0189(88)90077-5
- 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.
- Norton, M. I., & Gino, F. (2014). Rituals alleviate grieving for loved ones, lovers, and lotteries. *Journal of Experimental Psychology: General*, 143, 266–272. doi:10.1037/a0031772
- O'Brien, J., Peavey, S., & Fuller, M. (2016). Buildings as artifacts: What are buildings in world history telling us? *The Social Studies*, 107(2), 81–87. doi:10.1080/00377996.2015.1116428
- Rappaport, R. (1993). The obvious aspects of ritual. In *Ecology, Meaning, and Religion* (2nd ed., p. 272). Berkeley, California: North Atlantic Books.
- Robb, J. (2001). Island identities: Ritual, travel and the creation of difference in neolithic malta. *European Journal of Archaeology*, 4(2), 175–202. doi:10.1177/146195710100400202
- Schippers, M. C., & Van Lange, P. A. M. (2006). The psychological benefits of superstitious rituals in top sport: A study among top sportspersons. *Journal of Applied Social Psychology*, 36(10), 2532–2553. doi:10.1111/j.0021-9029.2006.00116.x

- Vohs, K. D., Wang, Y., Gino, F., & Norton, M. I. (2013). Rituals enhance consumption. *Psychological Science*, 24(9), 1714–21. doi:10.1177/0956797613478949
- Vyse, S. A. (2014). *Believing in magic: The psychology of superstition - Updated Edition* (1st ed.). New York: Oxford University Press.
- Woodward, A., & Hunter, J. (2015). *Ritual in early bronze age grave goods: An examination of ritual and dress equipment from chalcolithic and early bronze age graves in England* (1st ed.). Oxford and Philadelphia: Oxbow Books.
- Wrisberg, C. A., & Pein, R. L. (1992). The preshot interval and free throw shooting accuracy: An exploratory investigation. *The Sport Psychologist*, 6, 14–23. doi:10.1123/tsp.6.1.14
- Yanchou, L., Jingzhao, Z., Jun, X., & Xueli, W. (1988). TL dating of pottery sherds and baked soil from the Xian Terracotta Army Site, Shaanxi Province, China. *International Journal of Radiation Applications and Instrumentation. Part D. Nuclear Tracks and Radiation Measurements*, 14(1), 283–286. doi:10.1016/1359-0189(88)90077-5

## **Appendix B: Anxiety as Multi-Component Model**

Boyer and Liénard (2006) suggested that ritualized behavior floods the working memory and therefore suppresses anxiety. It is important to note that anxiety comprises multiple components. Authors as early as Lang (1971) refuted the idea that anxiety can be represented by a singular construct. Previous research on anxiety was hampered by the unclear separation between anxiety and depression. Zerssen (1976, p.28, translated by Renner, Hock, Bergner-Koether, Laux, 2016) noted: “Our attempts to represent anxiety and depression as two different aspects of affective disturbance on two different self-report scales turned out to be infeasible, as is the case for comparable approaches.” Later research found correlations between measures of depression and anxiety as high as .80 (e.g. Clark & Watson, 1991). This can be partially attributed to measures such as the State-Trait Anxiety Inventory (Spielberger, Gorsuch, & Lushene, 1970) which included a number of items that are semantically strongly related to depression, such as “I feel blue” or “I feel like crying”.

The observation of high correlations of anxiety and depression formed the starting point for the development of the tripartite model of anxiety and depression by Clark and Watson (1991). This model conceptualized anxiety as physiological hyperarousal and depression as anhedonia, both linked through a shared factor of general distress. While the tripartite model of anxiety and depression received extensive empirical support (e.g. Mineka, Watson, & Clark, 1998), it has also been criticized for operationalizing anxiety exclusively as physiological hyperarousal. Some alternative operationalizations of anxiety, predating the formulating of the tripartite model, suggest a less narrow definition of anxiety. For example, Liebert and Morris (1967) proposed a two-component model of test anxiety, including a factor of worry and a factor of emotionality, which corresponds to physiological hyperarousal in the tripartite model. Later authors conceptualized anxiety similarly. For example, Spielberger (1972) stated in his definition of state and trait anxiety:

An anxiety state may be defined in terms of intensity of feelings of tension, apprehension, and worry that are experienced by an individual at a particular moment in time, and by heightened activity of the autonomic nervous system that accompanies these feelings. (p.6)

According to this definition anxiety, comprises two unique factors, worry and physiological arousal. This shift in the conceptualization of anxiety can also be found in recent definitions of anxiety (Kowalski, 2000):

Anxiety is an emotion characterized by heightened autonomic system activity, specifically activation of the sympathetic nervous system (i.e., increased heart rate, blood pressure, respiration, and muscle tone), subjective feelings of tension, and cognitions that involve apprehension and worry. (p.209)

This definition subdivides anxiety into two clearly separable subcomponents. A conscious cognitive component named worry, also referred to as anxious apprehension (e.g., Borkovec, Robinson, Pruzinsky, & DePree, 1983) or cognitive anxiety (Lehrer & Woolfolk, 1982), is characterized by verbal rumination and concern for the future and often accompanied by restlessness and fatigue. The second automatic physiological component named arousal, also referred to as anxious arousal, is defined by somatic reactions mainly involving the autonomic nervous system.

This conceptual differentiation of anxiety into two factors, physiological arousal and worry in recent research has allowed researchers to more clearly differentiate anxiety from depression. Renner, Hock, Bergner-Koether, and Laux (2016) compared a model of anxiety, subsuming worry and physiological arousal, and depression, subsuming anhedonia and dysthymia, against the tripartite model and other higher order models. Using item-level confirmatory factor analysis and latent class

cluster analysis they were able to establish convergent and discriminant validity of the four-factor model over the tripartite model in a representative German sample. The authors replicated their findings in a student and a clinical sample. While anxiety and depression were still found to be correlated the model was able to reliably distinguish between anxiety and depression. This research indicates that anxiety should be operationalized as a two-component structure including arousal and worry.

This distinction is further supported by findings from the field of psychological neuroscience, for example research on hemispheric asymmetry. This research found anxious apprehension was not linked to significant asymmetries, whereas activity related to anxious arousal was found to be asymmetrically located in the right hemisphere (Nitschke, Heller, Palmieri, & Miller, 1999). This indicates that the processes can be separated at a neurological level. Furthermore, recent research on resting-state functional connectivity further supported the differentiation between anxious apprehension and anxious arousal (Burdwood et al., 2016).

Overall, the previous research shows that it is paramount to not only assess cognitive measures of anxiety such as self-reports, but also autonomic responses such as physiological arousal when investigating anxiety. While the distinction between arousal and worry has clear theoretical benefits, it has often been neglected in the research on rituals. Subdividing anxiety in these components might not only provide a fuller picture of possible anxiolytic effects of rituals, but also help to explain previous conflicting findings on the interplay between cognitive load and anxiety (Nitschke, Heller, Palmieri, & Miller, 1999).

## Appendix B References

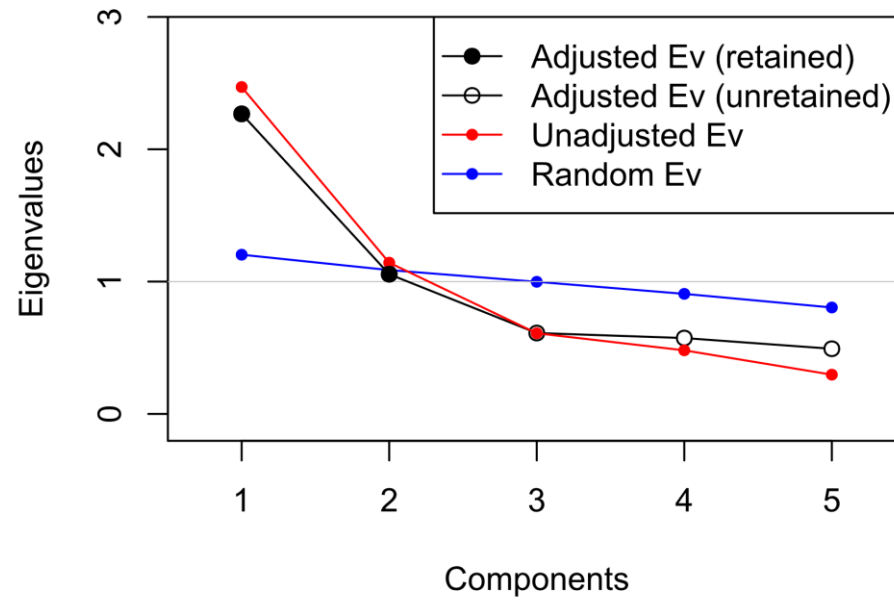
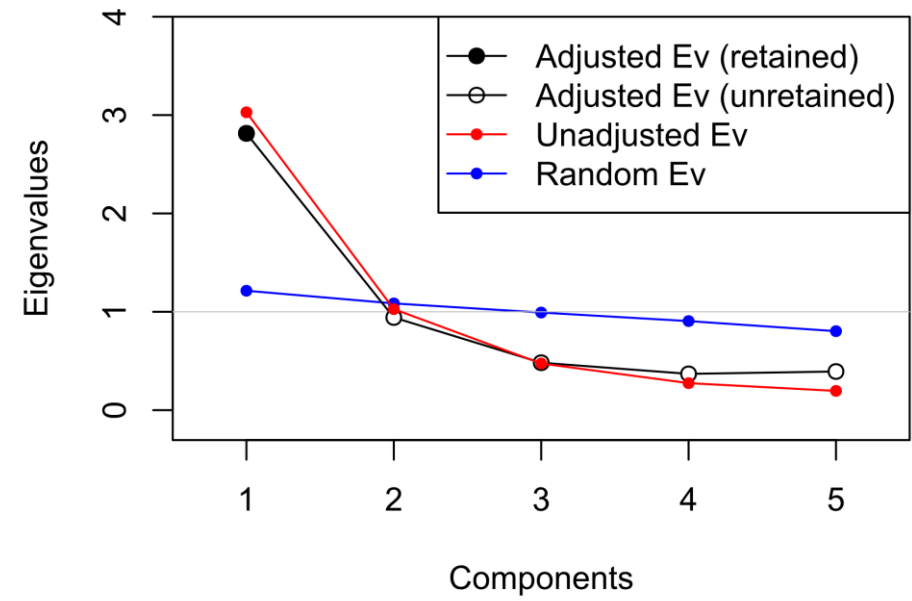
- Borkovec, T. D., Robinson, E., Pruzinsky, T., & A. DePree, J. (1983). Preliminary exploration of worry: Some characteristics and processes. *Behaviour Research and Therapy*, 21(1), 9–16. doi:10.1016/0005-7967(83)90121-3
- Boyer, P., & Liénard, P. (2006). Why ritualized behavior? Precaution systems and action parsing in developmental, pathological and cultural rituals. *The Behavioral and Brain Sciences*, 29(6), 595–613–50. doi:10.1017/S0140525X06009332
- 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
- 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
- Kowalski, R. M. (2000). Anxiety. In *Encyclopaedia of Psychology*. American Psychological Association.
- Lang, P. J. (1971). The application of physiophysiological methods to the study of psychotherapy and behavior modification. In A. E. Bergin & S. L. Garfield (Eds.), *Handbook of psychotherapy and behavior change* (pp. 75–125). New York, NY: Wiley.
- Lehrer, P. M., & Woolfolk, R. (1982). Self-report assessment of anxiety: Somatic, cognitive, and behavioral modalities. *Behavioral Assessment*, 4.
- Liebert, R. M., & Morris, L. W. (1967). Cognitive and emotional components of test Anxiety: A distinction and some initial data. *Psychological Reports*, 20(3), 975–978. doi:10.2466/pr0.1967.20.3.975
- Liénard, P., & Boyer, P. (2006). Whence collective rituals? A cultural selection model of ritualized behavior. *American Anthropologist*. Wiley American Anthropological Association. doi:10.2307/4496521
- Mineka, S., Watson, D., & Clark, L. A. (1998). Comorbidity of anxiety and unipolar mood disorders. *Annual Review of Psychology*, 49(1), 377–412. doi:10.1146/annurev.psych.49.1.377
- 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
- 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

- Spielberger, C. D., Gorsuch, R. L., & Lushene, R. E. (1970). Manual for the State-Trait Anxiety Inventory. Palo Alto, CA: Consulting Psychologists Press.
- Spielberger, C. D. (1972). *Needed research on stress and anxiety. A special report of the USOE sponsored grant study: Critical appraisal of research in the personality-emotions-motivation domain* (IBR Report No. 72-10). Washington, DC: Office of Education.
- Zerssen, D. V. (1976). *Paranoid-Depressivitäts-Skala. Depressivitäts-Skala*. Manual. Weinheim: Beltz Test.



### **Appendix C: Parallel Analysis**

The parallel analysis conducted for the measures at time one indicated that two components should be retained, these components had adjusted eigenvalues of 2.26 and 1.06 respectively. At time two the parallel analysis suggested retaining a single factor with the first factor having an eigenvalue of 2.81 and the second factor having an eigenvalue of .94. The parallel analysis as at time three suggested retaining two factors with eigenvalues of 2.50 and 1.01. At time four the parallel analysis suggested retaining two principal components with eigenvalues of 2.37 and 1.07. We show the graphs of the parallel analysis in Figure 4 to allow for an easier comparison between the separate timepoints.

**Parallel Analysis****Parallel Analysis**

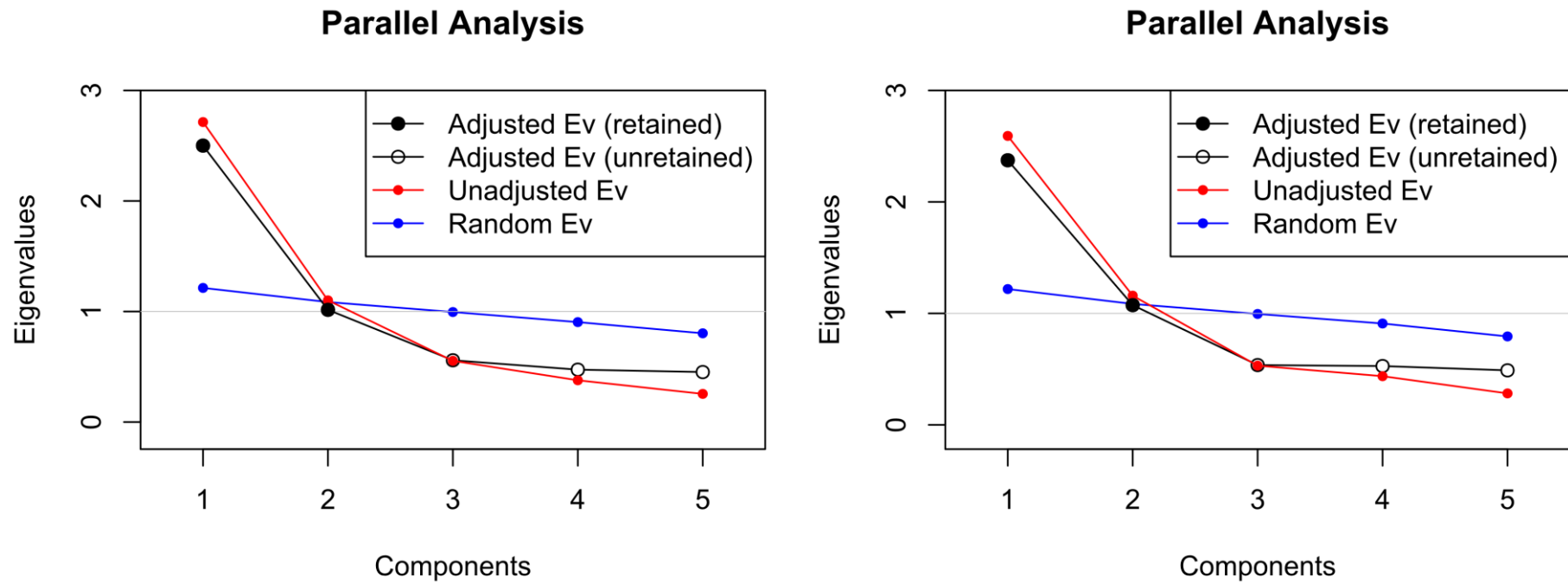


Figure 4. Adjusted scree plots visualizing the parallel analysis.

Notes. Graphs represent: Top left (Time one), Top right (Time 2), Bottom left (Time 3), Bottom right (Time 4)

Based on the parallel analysis we concluded that two factors should be retained, because the parallel analysis suggested retaining two factors at all time-points except time two, where the value was close to the recommended cutoff for principal components of eigenvalues  $> 1$ .

Bartlett's test of sphericity, confirming the overall significance of the correlation matrix, was significant at all time-points: T1 ( $\chi^2 (10) = 248.04, p < .001$ ), T2 ( $\chi^2 (10) = 447.38, p < .001$ ), T3 ( $\chi^2 (10) = 324.57, p < .001$ ), T4 ( $\chi^2 (10) = 287.29, p < .001$ ). The Kaiser-Meyer-Olkin measure of sampling adequacy indicated the strength of the relationships among variables to be adequate at all time-points: T1(KMO = .68), T2(KMO = .75), T3(KMO = .70), T4(KMO = .69).

## Appendix D: Supplementary Material

Table 2. *PANAS and State Trait Anxiety Inventory*

Please rate how applicable each adjective is to your present mood				
	Definitely Not Applicable (1)	Slightly Not Applicable (2)	Slightly Applicable (3)	Definitely Applicable (4)
Calm (1)	0	0	0	0
Tense (2)	0	0	0	0
Upset (3)	0	0	0	0
Relaxed (4)	0	0	0	0
Content (5)	0	0	0	0
Worried (6)	0	0	0	0
Passive (7)	0	0	0	0
Interested (8)	0	0	0	0
Distressed (9)	0	0	0	0
Excited (10)	0	0	0	0
Strong (11)	0	0	0	0
Guilty (12)	0	0	0	0
Scared (13)	0	0	0	0
Hostile (14)	0	0	0	0
Enthusiastic (15)	0	0	0	0
Proud (16)	0	0	0	0
Irritable (17)	0	0	0	0
Alert (18)	0	0	0	0
Ashamed (19)	0	0	0	0
Inspired (20)	0	0	0	0
Nervous (21)	0	0	0	0
Determined (22)	0	0	0	0
Attentive (23)	0	0	0	0
Jittery (24)	0	0	0	0
Active (25)	0	0	0	0
Afraid (26)	0	0	0	0

Table 3. *Mood and Anxiety Symptom Questionnaire*

Please rate how applicable each item is to you in the present:				
	Definitely Not Applicable (1)	Slightly Not Applicable (2)	Slightly Applicable (3)	Definitely Applicable (4)
Startle easily (1)	0	0	0	0
Feel faint (2)	0	0	0	0
Feel numbness or tingling in my body (3)	0	0	0	0
Have pain in my chest and body (4)	0	0	0	0
Have hot or cold spells (5)	0	0	0	0
Feel dizzy or lightheaded (6)	0	0	0	0
Am short of breath (7)	0	0	0	0
Hands are shaky (8)	0	0	0	0
Feel like I am choking (9)	0	0	0	0
Muscle twitch or tremble (10)	0	0	0	0
Am trembling or shaking (11)	0	0	0	0
Have a very dry mouth (12)	0	0	0	0
Have trouble swallowing (13)	0	0	0	0
Hands are cold or sweaty (14)	0	0	0	0

Table 4. *Penn State Worry Questionnaire*

Please rate how applicable each item is to you in the present:				
	Definitely Not Applicable (1)	Slightly Not Applicable (2)	Slightly Applicable (3)	Definitely Applicable (4)
I am currently worried about something. (1)	0	0	0	0
I just noticed that I am feeling worried. (2)	0	0	0	0
I am worried about what might be ahead. (3)	0	0	0	0
I am worried about what I might have to do next (in this study). (4)	0	0	0	0
I find it easy to dismiss worrisome thoughts. (5)	0	0	0	0
Many situations make me worry. (6)	0	0	0	0
I do not worry about things right now. (7)	0	0	0	0
My worries overwhelm me. (8)	0	0	0	0
I worry all the time. (9)	0	0	0	0
I am worried about how I did in the previous task (10) (Only displayed starting after the stress block)	0	0	0	0

Table 5. *Reliability of the measures*

	T1	T2	T3	T4
MASQ	.83/.84	.86/.86	.84/.84	.83/.83
PSWQ	.80/.81	.84/.85	.82/.83	.81/.82
PA	.82/.82	.83/.83	.88/.89	.89/.90
NA	.76/.76	.88/.89	.87/.87	.85/.85
STAI	.71/.74	.83/.85	.78/.80	.81/.82
Overall Stress	.79/.80	.88/.88	.83/.83	.81/.80

*Notes.* MASQ = Massachusetts Anxiety State Questionnaire, PSWQ = Penn State Worry Questionnaire, PA = Positive Affect, NA = Negative Affect, STA = State Trait Anxiety Inventory, Stress = General Factor of Stress; We report reliability as  $\alpha$  /  $\omega$  based on recent recommendations that urge researchers to report omega alongside alpha (McNeish, 2017).

## 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 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 tested for equality of variances between the groups and only report tests that indicated variances to be not equal. In cases, where variances were unequal we used Welch's independent sample t-test, which applies a correction to the degrees of freedom to account for unequal variances.

For self-reported stress, we found a significant within-subjects main effect of time:  $F(1, 178) = 12.3, p < .001, \eta^2 = .05$ ; a significant between subjects of stress condition:  $F(1, 178) = 19.30, p < .001, \eta^2 = .10$ ), qualified by a significant interaction of time and stress:  $F(1, 178) = 84.8, p < .001, \eta^2 = .31$ ). During the resting block, the t-test indicated no significant differences between participants in the control condition ( $M = 1.78$ ) and stress condition ( $M = 1.83$ ),  $t(178) = -0.98[-1.15, 0.05], p = .33$ ; Cohen's  $d$  was negligible:  $-0.15[-0.44, 0.14]$ .

During the stress block, the t-test indicated a significant difference on stress between participants in the control condition ( $M = 1.66$ ) and the stress condition ( $M = 2.08$ ),  $t(178) = -6.63[-0.54, -0.29], p < .001$ ; Cohen's  $d$  indicated a large effect:  $-0.99[-1.30, -0.68]$ . This indicates a successful manipulation of self-reported stress with no between-subject difference between the stress conditions at the baseline and a large difference after the stress condition was administered.

For positive affect, we found a significant within-subjects main effect of time:  $F(1, 178) = 59.47, p < .001, \eta^2 = .25$ ) and no significant between-subjects main effect of stress condition:  $F(1, 178) = 0.03, p = .86, \eta^2 = 0.00$ ). The interaction of time and stress was not



significant:  $F(1, 178) = 1.80, p = .18, \eta^2 = .01$ ). The lack of a significant interaction indicates that the stress condition was not effective in decreasing participants' positive affect compared to the control condition.

For heart rate, we found no significant within-subjects main effect of time:  $F(1, 178) = 0.00, p = 1, \eta^2 = 0.00$ ) and a significant between-subjects main effect of stress condition:  $F(1, 178) = 10.70, p < .01, \eta^2 = 0.06$ ); qualified by a significant interaction of time and stress:  $F(1, 178) = 131, p < .001, \eta^2 = .42$ ). During the resting block, participants in the control condition ( $M = 0.32$ ) and stress condition ( $M = -0.32$ ) did not significantly differ in average heart rate  $t(178) = 0.43, p = .67$ ; Cohen's  $d$  indicated a negligible effect:  $.06[-.23, .36]$ . The F test during the stress block, indicated that the variances between the stress conditions were not equal  $F(89,89) = 0.49[0.32,0.74], p < .001$ . During the stress block, there was a significant difference in heart rate between participants in the control condition ( $M = -0.47$ ) and the stress condition ( $M = .47$ ):  $t(159.05) = -7.11[-1.20, -0.68], p < .001$ ; Cohen's  $d$  indicated a large effect:  $-1.06[-1.37, -.75]$ . Overall, this indicates a successful manipulation of heart rate from the baseline by the stress condition, compared to the control condition.

For galvanic skin resistance we found no significant within-subjects main effect of time:  $F(1, 178) = 0.00, p = 1, \eta^2 = 0.00$ ) and a marginally significant between-subjects effect of stress condition:  $F(1, 178) = 3.70, p = .06, \eta^2 = 0.02$ ); qualified by a significant interaction of time and stress:  $F(1, 178) = 4.54, p < .05, \eta^2 = .03$ ). The F tests for the equality of variances indicated a significant difference of variances at time one during resting:  $F(89,89) = 0.21[0.14,0.32], p < .001$ . During the resting block, participants in the control condition ( $M = -0.04$ ) and stress condition ( $M = 0.04$ ) did not significantly differ in average galvanic skin resistance  $t(125.1) = -0.56[-.38,.21], p = .58$ ; Cohen's  $d$  was negligible:  $-.08[-.37,.21]$ . During the stress block, there was a significant difference in galvanic skin resistance between participants in the control condition ( $M = -0.32$ ) and the stress condition ( $M = 0.32$ ),  $t(178) =$

-4.54[-0.92,-0.36],  $p < .01$ ; Cohen's  $d$  was small: -.41[-.71,-.12]. This indicates that the galvanic skin resistance differed in the stress condition compared to the control.

For respiration we found no significant within-subjects main effect of time:  $F(1, 178) = 0.00, p = 1, \eta^2 = 0.00$ ), a significant between-subjects main effect of stress condition:  $F(1, 178) = 8.51, p < .01, \eta^2 = 0.05$ ), and a non-significant interaction of time and stress:  $F(1, 178) = 0.02, p = .90, \eta^2 = .00$ ). This indicates that respiratory activity was not influenced by the stress condition compared to the control condition.

For diastolic blood pressure we found no significant within-subjects main effect of time:  $F(1, 178) = 0.00, p = 1, \eta^2 = 0.00$ ); a significant between-subjects main effect of stress:  $F(1, 178) = 5.46, p < .05, \eta^2 = 0.03$ ); and qualified by a significant interaction of time and stress:  $F(1, 178) = 38.3, p < .001, \eta^2 = .18$ ). During the resting block, participants in the stress condition ( $M = -0.004$ ) and control condition ( $M = 0.004$ ) did not significantly differ in average diastolic blood pressure  $t(178) = 0.06[-0.29,0.30], p = .96$ ; Cohen's  $d$  was negligible: .01[-.29,.30]. During the stress block, there was a significant difference in diastolic blood pressure between participants in the control condition ( $M = -0.32$ ) and the stress condition ( $M = 0.32$ ),  $t(178) = -4.54[-0.92,-0.36], p < .001$ ; Cohen's  $d$  indicated a medium effect size: -.68[-.98,-.37]. This indicates an overall successful manipulation of stress as indicated by diastolic blood pressure in the stress condition compared to the control.

For systolic blood pressure we found no significant within-subjects main effect of time:  $F(1, 178) = 0.00, p = 1, \eta^2 = 0.00$ ) and no significant between-subjects main effect of stress condition:  $F(1, 178) = 0.30, p = .58, \eta^2 = 0.002$ ); qualified by a significant interaction of time and stress:  $F(1, 178) = 70.0, p < .001, \eta^2 = .28$ ). During the resting block, participants in the control condition ( $M = 0.14$ ) and in the stress condition ( $M = -0.14$ ) did not significantly differ in average systolic blood pressure:  $t(178) = 1.85[-0.02,0.57], p = .07$ ;

Cohen's  $d$  indicated a small effect size: .27[-.02,.57]. The F test during the stress block, indicated that the variances between the stress conditions were not equal:  $F(89,89) = 0.58[0.38,0.88]$ ,  $p < .05$ . During the stress block, there was a significant difference in systolic blood pressure between participants in the control condition ( $M = -0.21$ ) and the stress condition ( $M = 0.21$ ):  $t(166.4) = -2.94$ ,  $p < .01$ ; Cohen's  $d$  indicated a small effect size: -.44[-.74,-.14]. Overall, this indicates a successful manipulation of stress as indicated by the systolic blood pressure measure. We show the results of the analyses in Figures 5 to 7.

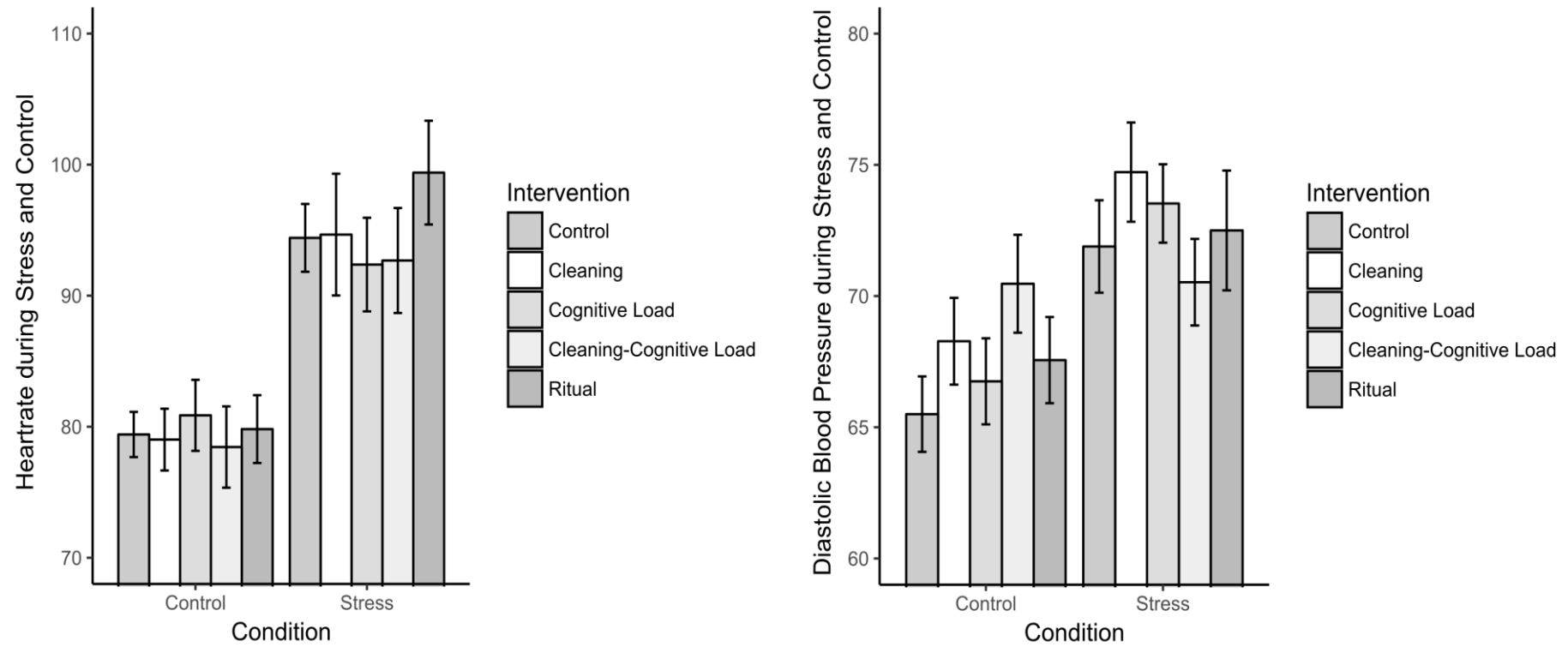


Figure 5. Measurements means in stress and control condition for the separate interventions.

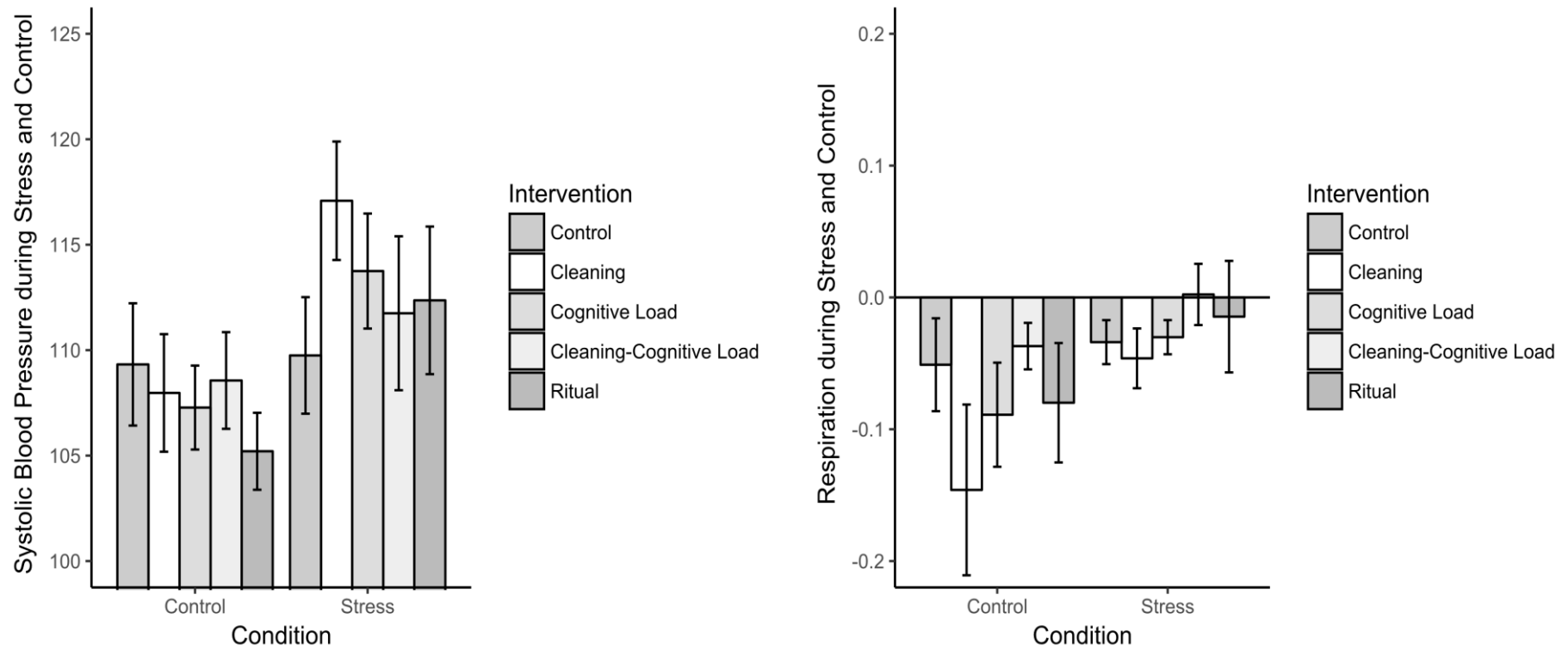


Figure 6. Measurements means in stress and control condition for the separate interventions.

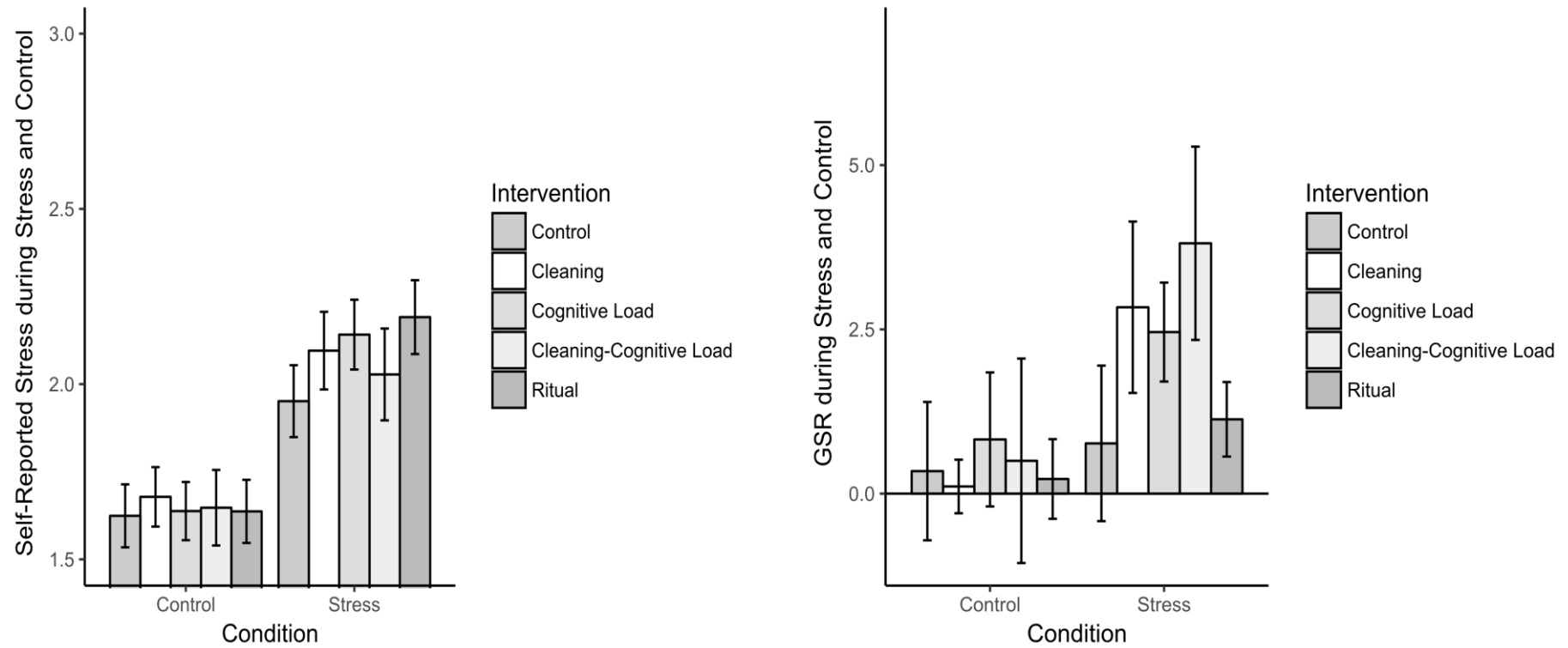


Figure 7. Measurements means in stress and control condition for the separate interventions.

Table 6. Regressions testing the effect of recurrent movement for the individual dependent variables

Heart rate				
	Control	Model 1	Model 2	Model 3
Intercept	-.05 [-.23,.14]	1.13** [.41,1.85]	.01* [.31,1.49]	.34 [-.45,1.13]
T2 Heartrate	.78*** [.61,.94]	.77*** [.61,.92]	.95*** [.81,1.09]	.91*** [.77,1.05]
Recurrence	—	-.35** [-.56,-.014]	-.15 [-.34,0.31]	.02 [-.22,.27]
Stress condition	—	—	-.85*** [-1.81,-.52]	.44 [-.85,1.73]
Recurrence * Stress condition	—	—	—	-.37 <sup>†</sup> [-.73,-.01]
	F(1,34) = 62.41, p < .001	F(2,33) = 41.69, p < .001	F(3,32) = 49.67, p < .001	F(4,31) = 40.41, p < .001
Explained variance	.65	.72	.82	.84
$\Delta R^2$	-	.06	.10	.02
Diastolic Blood Pressure				
Intercept	-.06 [-.25,.12]	.52 [-.24,1.30]	.38 [-.33,1.09]	-.41 [-1.43,.60]
T2 Blood Pressure	.83*** [.65,1.00]	.83*** [.66,1.00]	.95*** [.77,1.12]	.84*** [.65,1.03]
Recurrence	—	-.18 [-.40,.04]	-.05 [-.27,.17]	.20 [-.11,.52]
Stress condition	—	—	-.60* [-.98,-.22]	1.27 [-.51,3.04]
Recurrence * Stress condition	—	—	—	-.53 <sup>†</sup> [-1.02,-.04]
	F(1,34) = 65.15, p < .001	F(2,33) = 34.22, p < .001	F(3,32) = 29.38, p < .001	F(4,31) = 24.48, p < .001
Explained variance	.66	.67	.73	.76
$\Delta R^2$	-	.01	.06	.03
Systolic Blood Pressure				
Intercept	-.04 [-.18,.10]	-.37 [-.98,.24]	-.47 [-1.05,.11]	-.30 [-1.13,.52]
T2 Blood Pressure	.86*** [.73,1.00]	.86*** [.72,.99]	.93*** [.79,1.07]	.94*** [.80,1.09]
Recurrence	—	.10 [-.08,.27]	.18 <sup>†</sup> [.01,.36]	.13 [-.13,.39]
Stress condition	—	—	-.41* [-.71,.36]	-.79 [-2.14,.57]
Recurrence * Stress condition	—	—	—	.11 [-.27,.49]
	F(1,34) = 117.7, p < .001	F(2,33) = 59.05, p < .001	F(3,31) = 46.04, p < .001	F(4,31) = 33.77, p < .001
Explained variance	.78	.78	.81	.81
$\Delta R^2$	-	.00	.03	.00
GSR				

Intercept	-.07 [-.23,.08]	.17 [-.50,.83]	.19 [-.79,.87]	.24 [-.72,1.20]
T2 GSR	.94*** [.78,1.10]	.94*** [.78,1.10]	.93*** [.75,1.10]	.93*** [.75,1.11]
Recurrence	—	-.07 [-.26,.12]	-.10 [-.30,.12]	-.11 [-.41,.19]
Stress condition	—	—	.08 [-.27,.43]	-.04 [-1.55,1.46]
Recurrence * Stress condition	—	—	—	.04 [-.39,.47]
	F(1,34) = 99.45, p < .001	F(2,33) = 49.04, p < .001	F(3,32) = 31.90, p < .001	F(4,31) = 23.20, p < .001
Explained variance	.75	.75	.75	.75
$\Delta R^2$	-	.00	.00	.00
Stress				
Intercept	.42** [.19,.66]	.57** [.24,.91]	.46* [.09,.84]	.47 <sup>†</sup> [.00,.95]
T2 Stress	.68*** [.56,.80]	.68*** [.56,.80]	.72*** [.58,.86]	.72*** [.57,.87]
Recurrence	—	-.04 [-.11,.03]	-.02 [-.10,.05]	-.03 [-.14,.08]
Stress condition	—	—	-.09 [-.22,.04]	-.11 [-.64,.41]
Recurrence * Stress condition	—	—	—	.01 [-.14,.16]
	F(1,34) = 89.92, p < .001	F(2,33) = 45.71, p < .001	F(3,32) = 31.10, p < .001	F(4,31) = 22.60, p < .001
Explained variance	.73	.73	.74	.74
$\Delta R^2$	-	.00	.01	.00

Notes. \*\*\* $p < .001$ , \*\* $p < .01$ , \* $p < .05$ , <sup>†</sup> $p < .01$ .



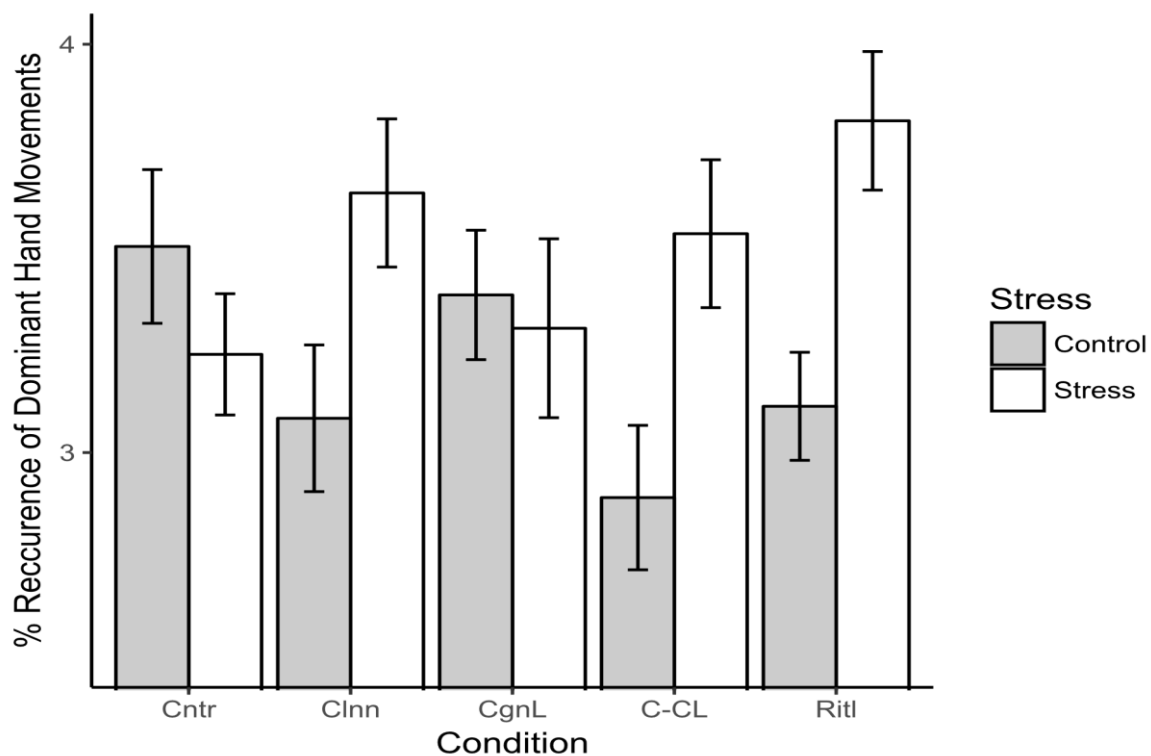
## Appendix E: Recurrence and Determinism across all Interventions

We explored the difference in recurrence and determinism between stress and control group further by comparing recurrence in the stress and control condition for all interventions to explore whether this pattern would replicate across the other interventions. We performed a univariate ANOVA with dominant hand recurrence as dependent variable and stress condition, intervention, and their interaction as independent variables. We would expect that participants who performed a condition that required movement (undirect cleaning task, undirected cleaning with cognitive load, ritualistic cleaning task) would show more recurrence and rigidity if they were assigned to the stressor task.

As described in the main text, we found a significant main effect of stress condition on dominant hand recurrence:  $F(1, 167) = 7.48, p < .01, \eta_p^2 = .04$ . Intervention had no significant main effect:  $F(4, 167) = 0.44, p = .78, \eta_p^2 = .01$ . These two main effects were qualified by a significant interaction between stress condition and intervention:  $F(4, 167) = 3.19, p < .05, \eta_p^2 = .07$ .

We followed this analysis up with individual t-tests for each of the separate interventions comparing the stress group against the control group. As could be expected for the control intervention task (which involved watching neutral photos), there was no significant difference between the scores of recurrence in the control ( $M = 3.50$ ) and stress ( $M = 3.24$ ) conditions:  $t(33) = 1.11[-.022, -.075], p = .28$ ; Cohen's  $d$  indicated a small effect ( $-0.37 [-1.07, .32]$ ). In the cognitive load intervention, there was no significant difference between the scores of recurrence in the control ( $M = 3.39$ ) and stress ( $M = 3.30$ ) conditions:  $t(34) = 0.30[-0.47, 0.63], p = .76$ ; Cohen's  $d$  indicated a negligible effect ( $-0.10 [-0.77, 0.58]$ ). In the combined cognitive load/ cleaning condition there was a significant difference between the scores of recurrence in the control ( $M = 2.93$ ) and stress ( $M = 3.54$ ) conditions:

$t(33) = -2.45[-1.12, -0.10]$ ,  $p = .02$ ; Cohen's  $d$  indicated a large effect ( $0.83[0.11, 1.55]$ ). In the ritual condition there was a significant difference between the scores of recurrence in the control ( $M = 3.11$ ) and stress ( $M = 3.81$ ) conditions:  $t(33) = -3.22[-1.14, -0.26]$ ,  $p < .01$ ; Cohen's  $d$  indicated a large effect ( $1.09[0.35, 1.83]$ ). We found a difference in recurrence between stress and control groups in the hypothesized direction in all conditions that required movement (the undirected cleaning task, the undirected cleaning with cognitive load task, the ritual task) We present the results for this analysis in Figure 8. The results confirmed our expectations that participants in the stress condition would show higher behavioral recurrence if the task had movement components.



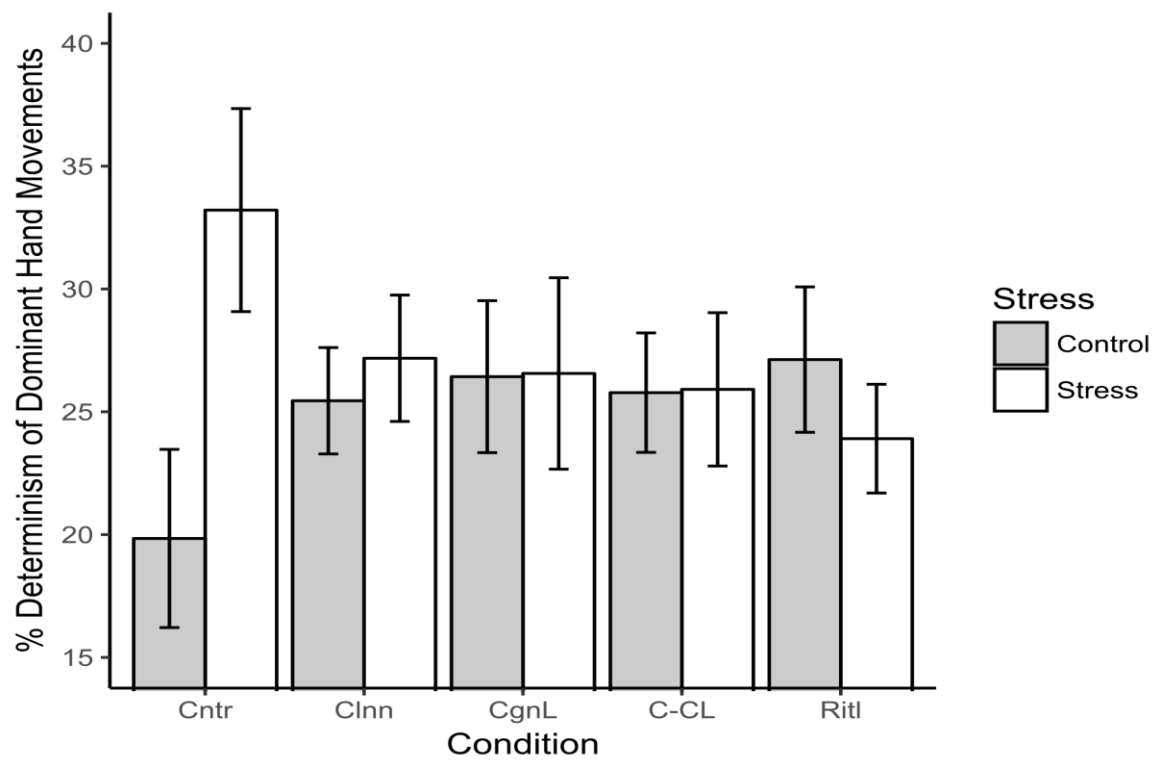
*Figure 8.* Means of dominant hand recurrence during interventions separate for stress and control condition.

*Notes.* Cntr = Control, Clnn = Cleaning, CgnL = Cognitive Load, C-CL = Cleaning and Cognitive Load, Ritl = Ritual.

We conducted a univariate ANOVA with dominant hand determinism as dependent variable and stress condition, intervention, and their interaction as independent variable. We expected a difference in determinism between stressed and control participants in tasks that required movement (as above, the undirected cleaning, cleaning with cognitive load and ritual cleaning task), based on the findings of Lang et al. (2015). We found no significant main effect of stress condition on dominant hand determinism:  $F(1, 167) = 1.51, p = .22, \eta_p^2 = .01$ . Intervention had no significant main effect:  $F(4, 167) = 0.06, p = .99, \eta_p^2 = .001$ . These two main effects were qualified by a marginally significant interaction between stress condition and intervention:  $F(4, 167) = 2.12, p = .08, \eta_p^2 = .05$ .

We followed up this analysis with individual t-tests for each of the separate interventions comparing the stress group against the control group. In the control condition there was a significant difference between the scores of determinism in the control ( $M = 19.84$ ) and stress ( $M = 33.21$ ) conditions:  $t(33) = -2.42 [-24.61, -2.13], p < .05$ ; Cohen's  $d$  indicated a large effect ( $0.82 [0.11, 1.54]$ ). As is shown in Figure 6, in the stress condition, participants showed higher determinism during the control task (watching neutral photos) than in the no-stress control condition. In the cognitive load condition there was no significant difference between the scores of determinism in the control ( $M = 26.43$ ) and stress ( $M = 26.56$ ) conditions:  $t(34) = -0.03[-10.24, 9.98], p = .98$ ; Cohen's  $d$  indicated a negligible effect ( $0.01 [-0.67, 0.69]$ ). In the combined cognitive load/ cleaning intervention there was no significant difference between the scores of determinism in the control ( $M = 25.81$ ) and stress ( $M = 25.91$ ) conditions:  $t(33) = -0.03[-8.05, 7.84], p = .98$ ; Cohen's  $d$  indicated a negligible effect ( $0.01 [-0.68, 0.70]$ ). In the ritual intervention there was no significant difference between the scores of determinism in the control ( $M = 27.12$ ) and stress ( $M = 23.91$ )

conditions:  $t(33) = 0.88[-4.25, 10.68]$ ,  $p = .39$ ; Cohen's  $d$  indicated a small effect size 0.30  $[-0.40, 0.99]$ ). We show the results of this analysis in Figure 9.



*Figure 9.* Means of dominant hand determinism during interventions separate for stress and control condition.

*Notes.* Cntr = Control, Clnn = Cleaning, CgnL = Cognitive Load, C-CL = Cleaning and Cognitive Load, Ritl = Ritual.

These findings overall indicate that in our sample, in contrast to the findings of Lang et al. (2015) dominant hand determinism was not significantly impacted by stress, except for the control intervention. This is an unexpected finding, since participants in the control intervention were not required to perform movements. This might indicate higher levels of fidgeting among stressed individuals when watching neutral photos. Since we did not find similar effects in the other conditions, we do not want to overinterpret these patterns.

## Appendix F: Recording Movement using MATLAB and the Kinect V2

The thesis measured movement using an unobtrusive method. Since this is a novel form for motion capture, the code is reproduced here to allow other researchers to use this approach. The code below allows for the recording of participants joint positions using the Kinect V2. The script outputs a number of files to allow for prolonged recording on lower powered machines. The files can be subsequently joined in MATLAB by appending them sequential. The only change necessary between participants is to adapt the sting 'Part1\_depth\_' to the appropriate participant number.

```
% Create depth kinect videoinput objects.
depthVid = videoinput('kinect',2);

set(depthVid,'Timeout',Inf);

% Set 'EnableBodyTracking' to on, so that the depth sensor will
% return body tracking metadata along with the depth frame.
depthSource = getselectedsource(depthVid);
depthSource.EnableBodyTracking = 'on';

% Acquire 500 depth frames for each call
% Continue acquiring until Timeout
framesPerTrig = 500;
depthVid.FramesPerTrigger = framesPerTrig;
depthVid.TriggerRepeat = 30;

% Start the depth and color acquisition objects.
% This begins acquisition, but does not start logging of acquired data.
pause(5);
start(depthVid);

% Get images and metadata from the color and depth device objects.
i=0;
while (i <= depthVid.TriggerRepeat )
    fprintf('In running loop, iteration %i\n', i);
    depthFile = strcat('Part1_depth_', num2str(i), '.mat' );
    i=i+1;
    fprintf('Going to get depth data\n');
    [~, ~, metadata] = getdata(depthVid);
    fprintf('Going to save depth file\n');
    save(depthFile, 'metadata');
end
fprintf('Completed running loop, total iterations %i\n', i);
stop(depthVid);
```

## Appendix G: MATLAB Script to extract Movement Data from a Kinect V2

This code uses a participant's metadata.mat file generated during the recording process. After loading the appropriate file for the participant it checks each of the six available participant recording slots for a participant present and extracts the x,y,z positions for each available joint, for each time point.

```
%load('Metadata.mat');
test=metadata;
[lr,lc]=size(test);
bodytracked=[];
All=zeros(1,83); %All Data column 1 frame...
%Allr=1; %All row count
ii=1;
%if tracking_signal==1
for i=1:lr % i can also be frame
    % check which body switch it was recorded
    tracking_signal=0;
    body_index=0;
    for iii=1:6 % 6 possible body tracked option
        if test(i).IsBodyTracked(iii)==1
            %bodytracked(i)=test(i).IsBodyTracked(iii);
            %joints{i}=test(i).JointPositions(:, :, iii);
            tracking_signal=1;
            body_index=iii;
            break;
        end
    end
    if body_index>0 && body_index<=6 && tracking_signal==1
        % set which body tracked
        bodytracked(i)=test(i).IsBodyTracked(body_index); % get what frame
        has body tracked
        joints{i}=test(i).JointPositions(:, :, body_index); % get joint
        positions
        if bodytracked(i)==1
            filtered_joints{ii}=joints{i};
            [jrl,jcl]=size(filtered_joints{ii});
            Alltemp=[body_index test(i).AbsTime test(i).FrameNumber];
            for iv=1:jrl % loop into each joints x,y,z (1,2,3 in index)
                % Frame x y z ....
                Alltemp=[Alltemp ...
                    filtered_joints{ii}(iv,1) ...
                    filtered_joints{ii}(iv,2) ...
                    filtered_joints{ii}(iv,3) ...
                ];
            end
            All=[All;Alltemp];
            ii=ii+1;
        end
    end
end
end
filename = 'participant1.xlsx';
xlswrite(filename,All);
clear;
```

## Appendix H: Computing the RQA parameters using R

The following code shows the final step in converting the recordings of the Kinect V2 to RQA results using R. The code is commented to highlight the most important steps. We recommend copying the code into an appropriate IDE for ease of reading.

```
# This section load the required packages into the R working environment.
library(crqa); library(tidyverse); library(reshape2); library(tseriesChaos);
library(gridExtra); library(openxlsx)
# Set working drive to edited excel Kinect outputs.
setwd()

List <- list() # This initializes an empty list cutting down on processing time
# The following for loop iterates over each participants file and extracts X, Y, and Z
movement combining them in accordance with the procedure of Lang et al. (2015) to a
general vector of movement.
for(k in 57:180)
{
  ## This increases the file name to load one participant file after each other
  part.file(k)
  a <- 1
  b <-9
  i <- 0
  repeat
  {
    if(i< 25)
    {
      file.dimension(rqafile, "XM")
      b <- b+3
      a <- a+1
      i <- i+1
    }
    else break
  }
  a <- 1
  b <-10
  i <- 0
  repeat
  {
    if(i< 25)
    {
      file.dimension(rqafile, "YM")
      b <- b+3
      a <- a+1
      i <- i+1
    }
    else break
  }
```

```

}
a <- 1
b <- 11
i <- 0
repeat
{
  if(i < 25)
  {
    file.dimension(rqafile, "ZM")
    b <- b+3
    a <- a+1
    i <- i+1
  }
  else break
}
i <- 1
repeat {
  if(i < 25){
    XM <- paste("XM", i, sep = "")
    YM <- paste("YM", i, sep = "")
    ZM <- paste("ZM", i, sep = "")
    rqafile[[paste('AM',i, sep="")] <- rowMeans(subset(rqafile,
                                                    select = c(XM, YM,ZM)),
                                                    na.rm = TRUE)

    rqafile <- na.omit(rqafile)
    i <- i+1
  }
  else break
}
# This section drops the first 10 and last 15 seconds of each recording to reduce movement
# artefacts due to participant either starting or finishing the task.
rqafile <- head(rqafile, -300)
rqafile <- tail(rqafile, -450)
#This section sets the joint variable of interest.
ts1 <- rqafile$"AM8"
# This section sets the general RQA parameters used to find the ideal parameters; a good
# review about those can be found in Marwan, Carmen, Thiel, and Kurths, (2007).
mlpar = list(lgM = 10, radiusspan = 1000, radiussample = 10, normalize = 0, rescale = 1,
minddiagline = 2,
              minvertline = 2, tw = 0, whiteline = FALSE, recpt = FALSE, fnnpercent = 10,
typeami = "maxlag")
optpar <- optimizeParam(ts1,ts1,mlpar); optpar
r <- optpar$radius
d <- optpar$delay
m <- optpar$emddim
#Set parameters for each k loop overriding the old values
delay = d; embed = m ; rescale = 1; radius = r;
normalize = 1; minvertline = 2; mindiagline = 2; whiteline = FALSE;
recpt = FALSE; tw = 0
#Run the actual RQA analysis with the derived parameters.

```



```
ans = crqa(ts1, ts1, delay, embed, rescale, radius, normalize, minvertline, mindiagline, tw,
whiteline, recpt)
##This section puts the output of each participants analysis in a new row of a list.
List[[length(List)+1]] <- ans[1:9]
##This should increase K by 1 per loop
k <- k+ 1

}
##Get all list results as matrix and extract parameters writing it to a csv file for later analysis.
output <- matrix(unlist(List), ncol = 9, byrow = TRUE)
write.table(output, "Joint.csv")
```

### Appendix I: R Packages used in the Thesis

Table 7. *R packages used in the current thesis.*

Package	Version	Purpose:
crqa	1.0.6	To compute the RQA results and determine the optimal parameters.
tidyverse	1.2.1	To organize the code and piping.
reshape2	1.4.2	To organize data for plotting.
tseriesChaos	0.1-13	To analyse nonlinear time series.
xlsx	0.5.7	To import and export Excel data.
psych	1.7.8	To compute principal components.
car	2.1-5	To recode and rename data.
jmv	0.8.1.11	To compute the repeated measures ANOVAs
lme4	1.1-14	To compute all regression models.
stats	3.4.3	To compute descriptive statistics and model comparison ANOVAs
paran	1.5.1	To compute the parallel analysis.
ggplot2	2.2.1	To plot results.
effsize	0.7.1	To determine Cohens's d.
Rmisc	1.5	To organize data for plotting.
sjPlot	2.4.0	To plot interaction.