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The effect of movement-focused and breath-focused yoga practice on stress parameters and sustained attention: A randomized controlled pilot study

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ABSTRACT

Yoga-based practices (YBP) typically involve a combination of movement sequences, conscious regulation of the breath, and techniques to engage attention. However, little is known about whether effects of YBP result from the synergistic combination of these components, or whether a subset may yield similar effects. In this study we compared the effect of a movement-focused practice and a breath-focused practice on stress parameters (perceived stress and salivary cortisol) and sustained attention (response inhibition) in yoga naïve university students. While participants of both programs showed a reduction in perceived stress and salivary cortisol, only the breath-focused group showed improvements in sustained attention. In addition, improvement in sustained attention was correlated with reduction in perceived stress but not with reduction in salivary cortisol. We discuss these findings in the context of a theoretical framework outlining bottom-up neurophysiological and top-down neurocognitive mechanisms hypothesized to be engaged by YBP.

1. Introduction

1.1. Growing interest in research on yoga-based practices (YBP)

Over the past decades yoga-based practices (YBP) have been sparking continually growing interest within the scientific community, with a rapidly increasing number of studies investigating their effects on physiological, neural, and behavioral measures (Gard, Noggle, Park, Vago, & Wilson, 2014). In fact, in healthy populations YBP have been shown to elicit measurable changes in cardiovascular indices (Papp, Lindfors, Storck, & Wandell, 2013), stress hormones (Rocha et al., 2012), inflammatory markers (Streeter et al., 2007), brain structure (Villemure, Ceko, Cotton, & Bushnell, 2015), brain function (Gard et al., 2015), body awareness (David, Fiori, & Aglioti, 2014), perceived stress (Gard et al., 2012), visual attention (Telles, Nagarathna, & Nagendra, 1995), memory

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(Gothe, Pontifex, Hillman, & McAuley, 2013), and executive functioning (Gard, Taquet et al., 2014). It is less well known, however, which components of YBP are driving these observed effects. YBP typically involve a combination of specific postures or movement sequences, conscious regulation of the breath, and various techniques to promote attention (Schmalzl, Powers, & Henje Blom, 2015), but so far few, if any, studies have directly attempted to deconstruct the role of these different component parts. It therefore remains unclear to which extent physiological, neural, and behavioral changes are driven by the movement, breath or attention components, and whether the effect of these components is additive or synergistic in nature (Payne & Crane-Godreau, 2013).

1.2. The effect of YBP on perceived stress and cortisol in healthy populations

Accumulating experimental and clinical research demonstrates that YBP are effective for stress reduction, and self-report measures of stress and related constructs are frequently used outcome measures to document these effects (Riley & Park, 2015). For example, self-reported perceived stress was assessed alongside other psychological outcome measures in participants of a four months long residential yoga program involving physical postures, breathing practices and meditation. (Gard et al., 2012). Attendees had lower scores on a 10-item version of the Perceived Stress Scale (PSS) (Cohen, Kamarack, & Mermelstein, 1983) compared to a control group of individuals not participating in the program. The results were statistically demonstrated to be mediated by increased levels of mindfulness and self-compassion, and interpreted according to existing theories of how mindfulness affects well-being (Shahar, Britton, Sbarra, Figueredo, & Bootzin, 2011). Similarly, a study with military populations participating in a 6-months Hatha Yoga program (Rocha et al., 2012), exhibited reduced self-reported levels of stress accompanying the reduced physiological stress parameters (i.e. salivary cortisol).

One of the primary stress response mediators in humans is the hypothalamo–pituitary–adrenal (HPA) axis. In short, environmental or psychological events perceived as stressful initiate an HPA axis response provoking a cascade of physiological events that ultimately result in the release of the steroid hormone cortisol from the adrenal gland (Nicolson, 2008). Cortisol is routinely used as a biomarker of stress, and the diurnal pattern of hormone secretion can provide clues about HPA axis regulation (Hellhammer, Wüst, & Kudielka, 2009). In humans, cortisol levels commonly peak shortly after awakening and then progressively decrease throughout the day (Levine, Zagoory-Sharon, Feldman, Lewis, & Weller, 2007). A systematic review of randomized control trials on the effect of YBP on physiological stress parameters provides preliminary evidence to suggest that yoga may efficiently promote HPA axis regulation (Pascoe & Bauer, 2015; Pascoe, Thompson, & Ski, 2017). The results of individual studies specifically targeting healthy individuals, however, are varied. One of the above-mentioned studies (Rocha et al., 2012) compared the effects of 6-months of yoga or physical exercise on salivary cortisol levels in a group of military populations. Participants assigned to the yoga group had significantly lower levels of cortisol at the end of the program, but since the analyses were based on a single sample both pre and post intervention, they need to be interpreted with caution. Another study investigated the effects of an 8-week Hatha Yoga and compassion meditation program on salivary cortisol and self-reported levels of anxiety and depression in familial caregivers of patients with Alzheimer's disease (Danucalov et al., 2013). Compared to a passive control group, the yoga group exhibited a significantly reduced cortisol awakening response (CAR) (a typically observed increase in cortisol during the first 30–40 min after awakening), as well as lower levels of stress, anxiety and depression. Unfortunately, neither of these studies described the yoga protocol in enough detail to inform specific hypotheses about the mechanism that may have driven the physiological changes. As for negative findings, one study conducted pre-post assessments of salivary cortisol and various self-report measures in healthy adults participating in ten classes of either Iyengar Yoga, mindfulness involving body-scan meditation, or "brain wave vibration training" (a type of meditative exercises (Bowden, Gaudry, An, & Gruzelier, 2012). Two saliva samples were taken for each participant within a four-hour window both pre and post intervention. While all three programs yielded improved self-report measures of stress and mindfulness, no effects on salivary cortisol were observed. Another study compared the effects of six months of restorative yoga and stretching classes on salivary cortisol and psychosocial outcome measures (Corey et al., 2014). At the end of the program, CAR as well as bedtime cortisol were more reduced in the stretching group compared to the yoga group. Interestingly, post-hoc analyses revealed that changes in cortisol were correlated with ratings of increased perceived social support, possibly driven by weekly group discussions that were part of the stretching but not the yoga protocol. The authors proposed that incorporating aspects of social support may be a crucial factor in promoting HPA regulation.

Psychological and endocrine stress responses are often assumed to represent indicators of the same construct, and hence generally expected to co-vary (Hellhammer et al., 2009). This hypothesis is corroborated on a neuroanatomical level by close links between the HPA axis and brain structures involved in mediating subjective psychological stress responses, in particular the ventral right prefrontal cortex (RPFC) (Wang et al., 2005). The analysis of psycho-endocrine covariance in studies using a variety of stressors, self-report measures, and populations has, however, yielded largely inconsistent and often negative results (Oswald, Mathena, & Wand, 2004). Substantial variation within theoretical conceptions of what constitutes stress as well as foci underlying commonly used questionnaires, are both likely to contribute to the lack of consistent findings of correlation between neuroendocrine factors and psychological stress responses.

1.3. The effects of YBP on attention healthy in populations

Only a few studies have directly investigated the impact of YBP on attention and executive functioning in healthy populations, but they nonetheless suggest that yoga may be helpful for improving aspects of attentional functioning.

One group evaluated changes in visual attention associated with a ten-day yoga program involving physical postures, breathing exercises, meditation, visual focusing exercises as well as the study of yoga philosophy. By the end of the days, participants had a bigger change in their flicker frequency detection rates compared to a control group not participating in the program (Telles et al., 1995). In another study, yoga practitioners had faster reaction times on a visual color discrimination task compared to a group of non-practitioners, suggesting that yoga practice may improve alertness and visuo-spatial attention (Narayana, 2009). A further study comparing school children participating in a 1-week program of either yoga (involving postures, breathing exercises, mantra recitation and meditation), or physical exercise (consisting of standing and sitting exercises, jogging, bending and mild weightlifting) (Manjunath & Telles, 2001) found that problem solving ability, as measured by number of moves in the Tower of London task (Shallice, 1982), improved more with the yoga practice. Taken together, these studies suggest that yoga practice may impact attention via bottom-up attentional functions involved in visual discrimination, as well as top-down attentional allocation employed in problem solving. However, many of the yoga protocols are insufficiently described and lack the necessary control conditions to allow strong conclusions about which aspects of the yoga programs drove the reported effects.

1.4. Training of sustained attention

Given that the ability to remain vigilant over time is crucial for several everyday activities, it is of interest to investigate the potential for specific training regimes to improve sustained attention. Controlled studies on sustained attention using tasks requiring target-discrimination consistently demonstrate a decline in performance over time, a phenomenon known as vigilance decrement (Parasuraman, 1986). Moreover, when target discrimination is perceptually difficult, this decline manifests as a decrease in perceptual sensitivity across the task sessions (Green & Swets, 1966). Theories of sustained attention propose that the vigilance decrement reflects the consumption of executive resources, which are depleted as attention is maintained over time (MacLean et al., 2010).

Some insights on how attention training can impact vigilance come from the meditation research literature. One of the studies (MacLean et al., 2010) investigated the effects of 3-month intense Shamatha meditation practice (Wallace, 1999) on sustained visual attention. 60 experienced meditators were randomly assigned to either a meditation retreat involving 6–10 h of meditation per day, or a waitlist control group. Both pre-, mid-, and post-training participants performed a 32-minute computerized continuous performance task (CPT) (MacLean et al., 2009), requiring them to discriminate the length of individually presented lines, and selectively respond to target lines that were slightly shorter. Following the meditation training, participants showed improved visual discrimination thresholds, as well as overall improved discrimination accuracy over the course of the task. The authors proposed that training-related improvements in visual perception may reduce the attentional resources required to discriminate line length, and consequently increase the attentional resources available for the maintenance of sustained visual attention. A related study with the same cohort of meditation practitioners (Sahdra et al., 2011) investigated whether improved sustained visual attention may be related to improvements in adapted functioning. The authors used a response inhibition task (RIT) which was slightly different from the CPT described above (MacLean et al., 2010). Participants were still asked to discriminate between the length of visually presented lines, but in this version they had to selectively withhold their response from the short target. Given the specific characteristic of inhibiting responses to target stimuli, the RIT is hypothesized to more directly target self-regulation over and above sustained visual attention. Adaptive socioemotional functioning (AF) was operationalized as a single latent factor underlying several self-report measures of personality traits, mindfulness, resilience, emotion regulation and psychological well-being. The documented improvement on the RIT task following the meditation retreat persisted several years after completion of the training (Zanesco, King, Maclean, & Saron, 2018), and dynamic models showed that these improvements also positively influenced change in AF over time.

A third study (Zanesco, King, Maclean, & Saron, 2013) investigated training related changes in response inhibition and associated phenomenal awareness of task engagement, following 1-month of intensive Vipassana meditation (Goldstein & Kornfield, 2001). An experimental group engaging in thirteen 45-minute meditation sessions per day, was compared to a control group matched for demographic variables as well as estimated lifetime meditation experience, which did not undergo any training. Testing took place on the first and last morning of the retreat, and participants were administered the RIT described above (Sahdra et al., 2011) as well as self-report measures of felt concentration, effort and motivation. Meditation training improved performance on the RIT in terms of both overall accuracy and more consistent reaction times over the course of the task, suggesting fewer fluctuations in goal directed attention. In addition, regression analyses showed that self-reported levels of concentration were a consistent predictor of objectively measured sustained attention performance. Hence, the study supports the view that different types of meditation training can facilitate efficient management of attentional resources, (Pascoe, Thompson, Jenkins, & Ski, 2017), and that this improvement can be accompanied by experiential changes in attentional stability

1.5. Specific aims of the current study

The main aims of the current study were to investigate: (a) whether YBP can be effective for promoting changes in perceived stress, physiological stress parameters and sustained attention in novice practitioners; (b) which components of YBP might be driving potential changes in these outcome measures; (c) whether changes in stress parameters are correlated with changes in attention. To address these questions we compared the effects of two 8-week programs involving YBP either with or without an active movement component respectively. This experimental design allowed us to examine the extent to which potential changes in stress parameters and attentional control are driven by the synergistic effect of movement, breath and attention, versus breath and attention alone.

2. Methods

2.1. Participants

The target population for our study consisted of yoga naïve young adults. Inclusion criteria were an age range of 18–35, never having attended a formal yoga class, willingness to attend yoga classes twice a week for an 8-week period, to complete baseline and post-program assessments, and to be randomly assigned to one of two experimental groups. Exclusion criteria included pregnancy and a history of diagnosed attention disorders. Participants were primarily recruited via flyers posted around University of California San Diego (UCSD) campus, and electronically distributed via UCSD online platforms. Following a preliminary phone screen to confirm eligibility, 65 participants were enrolled in the study and completed the baseline assessment, before being assigned to one of two experimental groups – a “Movement” group and a “Breath” group (see details below) via stratified random assignment matched for age, sex as well as handedness as it has been shown that handedness can influence perceptual and attentional processes during rapid serial visual presentation (Śmigasiewicz, Liebrand, Landmesser, & Verleger, 2017). 41 of these participants completed the 8-week program and post-intervention assessment. One participant was removed from data analyses for having chance-level performance on the attention task during the second assessment. The reported data are therefore on a final group of 40 participants (Movement: 22; Breath: 18). The study was approved by the UCSD Institutional Review Board (#140305X), and all participants provided written informed consent prior to enrolment.

2.2. Yoga program

We designed a movement-focused and a breath-focused yoga program (see details below). For each type of practice we developed an 8-week program that consisted of two 45-minute classes per week led by a certified instructor. Both programs began with a basic sequence taught during weeks 1–2, which was then gradually modified as participants progressed in their practice during weeks 3–4, 5–6, and 7–8. To avoid instructor-driven effects, both experimental groups were led in equal parts by one of two yoga instructors.

2.2.1. Led yoga classes

2.2.1.1. Movement group. The movement-focused practice was based on the traditional Ashtanga Vinyasa system (Jois, 1999), and adapted to be suitable for novices. The Ashtanga Vinyasa system consists of structured movement sequences and postures that are coupled with rhythmic breathing as well as specifically directed gaze. That is, each movement is performed to a specific rhythm of inhales and exhales, while the gaze is fixated to a selected body part or point in space. In the context of led classes, precise verbal instructions are continuously given for the movement, breath, as well as gaze components. During weeks 1–2, the movement-focused practice sessions primarily consisted of sun salutations (taught to the participants in an incremental fashion), and during the subsequent weeks additional standing and seated postures were gradually introduced. All practice sessions ended with a gentle cool down sequence, and a final supine resting pose. Throughout the practice sessions, participants were instructed to engage in “ujjayi breath” (Brown & Gerbarg, 2005), a slow and rhythmic breath performed through the nostrils with concurrent narrowing of the throat passage which creates a soft and soothing sound. Dynamic movement sequences were performed to a rhythm of even inhalations and exhalations, and static postures were held for five full breaths. Instructions for directed gaze were given with the aim to train the participants to avoid eye movements to potentially distracting stimuli in the visual environment. Synchronization of movement, breath and gaze was emphasized throughout. A detailed outline of the 8-week movement-focused yoga program is provided in the supplementary material.

2.2.1.2. Breath group. The breath-focused practice consisted of seated breathing exercises performed in conjunction with directed gaze. As for the movement-focused practice, the basic breathing technique consisted of ujjayi breath. To better match the complexity of the movement-focused practice however, participants were instructed a series of variations of the breath instead of merely a slow and steady rhythm of even inhalations and exhalations. The variations included visualizing the breath moving up and down the spine, directing the breath to specific parts of the body (e.g. expanding the front, side, or back of the ribcage during inhalations), short breath retentions between inhalations and exhalations, and alternate nostril breathing. Similar to the movement-focused practice, the sequence of breathing exercises gradually increased in complexity over the course of the 8 weeks. All sessions ended with a supine breathing sequence, and a final supine resting pose. Instructions for directed gaze were again given to train the participants to avoid eye movements to any distracting stimuli in the visual environment. A detailed outline of the 8-week breath-focused yoga program is provided in the supplementary material.

2.2.2. Home practice

In addition to the led yoga classes, participants were provided with videos to assist them with a daily home practice. The home practice sessions were 15–20 min long and consisted of subsets of the movement and breathing sequences taught during the led classes. To match the incremental progress of the led classes, participants were provided with selective home practice videos for weeks 1–2, 3–4, 5–6, and 7–8 respectively. The videos featured the same two instructors that taught the led classes and were uploaded to a password-protected website from which participants could access them via computer or other mobile devices. Participants were encouraged to do their home practice on days on which there was no led class. Each week of the program participants were given a practice log aimed at monitoring their attendance and amount of home practice. On the practice log participants were also asked to indicate whether they had been experiencing any physical, emotional, perceptual, or cognitive changes as a result of the practice. Apart from temporary muscle affecting a few participants, no adverse effects were reported.

2.2.2.1. *Movement group*

The home practice sessions for the movement group consisted of subsets of the led movement-focused classes. All practice sessions ended with a supine resting pose. Specific verbal instructions were provided for the movement, breath and gaze components.

2.2.2.2. *Breath group*

The home practice sessions for the breath group consisted of subsets of the led breath-focused classes. All practice sessions ended with a supine resting pose. Specific verbal instructions were provided for the breath and gaze components.

2.3. *Assessments*

Assessments took place in the week immediately before and after the 8-week yoga programs. The assessments included self-report questionnaires and a computerized attention task. In addition, participants were provided a take-home kit for salivary cortisol collection, which took place on a separate day.

2.3.1. *Demographics*

Demographic information was documented for all participants included age, gender, ethnicity, handedness, height and weight. A summary of the demographic information for the set of participants that completed the program and both pre and post assessment is reported in Table 1.

Table 1
Demographics. Summary of demographic information for the set of participants who completed the program and assessments.

	Movement	Breath
N	22	18
Age	24.91 (SD 5.99)	23.94 (SD 5.41)
Gender	12 Female, 10 Male	11 Female, 7 Male
Handedness	19 Right, 3 Left	15 Right, 3 Left
BMI	24.38 (SD 3.68)	23.65 (SD 5.36)

2.3.2. *Practice time*

Overall practice time was documented via class attendance sheets and home practice logs.

2.3.3. *Perceived stress*

Subjectively experienced levels of stress were assessed with the short version of the Perceived Stress Scale (PSS) (Cohen et al., 1983). It consists of 10 items scored on a scale from 1 to 5 (1 = never; 5 = very often). Half of the items are reverse-scored and the total score is recorded.

2.3.4. *Salivary cortisol*

Salivary cortisol was collected on the Sunday prior to the baseline assessment and following the post assessment respectively. Participants were given take home kits containing labeled collection tubes with salivettes, and a detailed instruction sheet outlining the timing and methods of saliva collection. Collection times used for analyses in this study were at 7:00 am (waking), and then at 3 further time points divided by 3-hour intervals. Participants received a text message reminder 10 min prior to each of these times and were specifically instructed to not eat a major meal within 60 min of sample collection, to not drink any alcohol the night before or during the day of saliva collection, to not smoke within 60 min of sample collection, to rinse their mouth thoroughly with water 10 min before collection, and to keep the collection tubes refrigerated until handing them in to the study assistant within 2–4 days of collection. The samples were then stored in a dedicated freezer space at −80 °C, and collectively analyzed after the post-intervention samples were collected. Free cortisol in saliva was determined by commercial ELISA (R&D Systems – https://www.rndsystems.com). Inter- and intra-assay variability was < 5% and 10%, respectively. Sensitivity was approximately 0.007 µg/dL.

2.3.5. *Response inhibition task (RIT)*

Sustained attention was assessed with a computerized response inhibition task (RIT) (Zanesco et al., 2013), which involves performing subtle visual discriminations over a prolonged period of time (~45 mins). The RIT was presented on IBM Thinkpad T-40 laptops using Presentation Software (Neurobehavioral Systems, http://neurobs.com). The distance between participants' eyes and the laptop monitor was fixed at 57 cm by having participants place the bridge of their nose at one end of a 57 cm string that was attached at the other end to the center of the laptop screen.

Immediately prior to the actual RIT, participants underwent a visual stimulus thresholding procedure (~10 mins), used to determine the length of a target stimulus (i.e. a vertical short line) at which an individual achieves ~75% accuracy in discriminating the target from a set-length stimulus (i.e. a vertical long line). Participants were asked to fixate on a small yellow dot at the center of a black background, while vertical gray lines were displayed one at a time for 150 ms each. A dotted visual mask was presented 100 ms before and 100 ms after the vertical line. The interstimulus interval (ISI) varied between 1550 and 2150 ms so as to minimize any response advantage due to the predictability of the stimulus. Participants were instructed to press the left mouse button as quickly as possible when a long line was displayed (70% of stimuli), and to withhold the button press when a target short line was displayed (30% of stimuli). Auditory feedback about response accuracy was provided via SONY MDR-V150 headphones. The length (in pixels) of the short line stimulus was adjusted in accordance with parameter estimation through sequential testing (PEST) (Taylor & Creelman, 1967) until a participant's accuracy reached 75% for a given line length. This line length was then implemented in the RIT to equate the threshold of task difficulty across individuals.

The RIT followed after a 3-minute break and consisted of 8 contiguous 4-minute blocks of 120 trials (960 trials total). The stimulus-adjoining transient mask pattern during the RIT accounted for cues drawing attention toward luminance contrast changes associated with the transient display. Otherwise, the task was procedurally the same as the PEST procedure, with participants being instructed to withhold mouse clicks whenever they detected a short line target. During the RIT task however, short lines constituted only 10% of all stimuli (96 trials), and there was no auditory feedback. We would like to note that in order to determine any potential changes in visual threshold over time, as well as to keep the overall duration of the task the same, the PEST procedure was performed at both the baseline and post-intervention assessments. However, each participant's baseline threshold was used during their post-intervention RIT assessment to match the task demands across assessment times.

2.4. Data analyses

2.4.1. Practice time

We conducted independent *T*-tests to assess differences in practice times between the two groups.

2.4.2. Perceived stress

We conducted a repeated-measures analysis of variance (ANOVA) to assess potential changes in perceived levels of stress by the end of the yoga programs.

2.4.3. Salivary cortisol

For each participant, the sum of the linear area-under-the-curve (AUC) value was calculated for 4 cortisol samples collected at equal time intervals (~3 h apart) over the course of a day in the week prior and following the yoga programs. The linear AUC was computed by summing the average between each sample point multiplied by 1 (the time unit of the first sample divided by the time unit of the second sample was always identical). We then conducted a repeated-measures ANOVA potential differences in how the groups' cortisol AUC changed by the end of the yoga programs.

2.4.4. Response inhibition task (RIT)

A non-parametric estimate of perceptual sensitivity called *A* (Zhang & Mueller, 2005) was calculated to quantify response inhibition accuracy. *A* incorporates both hits (successful inhibition of a response to a short line target stimulus) and false alarms (FA) (withholding of a response to a long line non-target stimulus). *A* ranges between .5 (chance-level accuracy) and 1 (perfect accuracy) in discriminating targets and non-targets. The consistency in the speed with which participants responded to non-target stimuli was quantified by a calculation of the reaction time coefficient of variability (RTCV). The RTCV is the standard deviation of the reaction time (RT) divided by the mean of the RT to long line non-target stimuli. Greater response variability is considered a marker of mind-wandering (Seli, Cheyne, & Smilek, 2013), and a reduced RTCV is associated with better overall performance on the RIT task (Zanesco et al., 2013). For each participant, both *A* and RTCV were calculated for the overall task and for each of the 8 4-minute blocks of 120 trials (12 targets, 108 non-targets) at both assessment times. We compared practice-related changes in the overall group average *A* and RTCV before and after the yoga programs. We further examined group-related changes in the trajectory of *A* and RTCV performance across the 8-blocks blocks using mixed effects multi-level models (MLM) to discern whether the groups' patterns of sustained attention and response inhibition over the 32-minute period differed from before to after the yoga programs.

2.4.5. Correlations

We investigated the correlation between the observed changes in perceived stress, salivary cortisol, and sustained attention. We first computed the change in PSS score, cortisol AUC, and the two main RIT measures of interest (*A* and RTCV) from pre to post assessment. We then correlated the change values using a .05 significance criterion and Holm-Bonferroni correction. The main analyses of interest were the change correlation between perceived stress and salivary cortisol, and the change correlations between each of the two stress-related outcome measures and the RIT measures. Correlation analyses were assessed among the entire participant group as well as for the Movement and Breath groups individually.

2.4.6. Effect sizes

For analyses of variance (ANOVA) effect sizes are reported as partial eta-squared (η^2) values calculated with simple means using the R package heplots (Fox & Friendly, 2018). For multi-level models (MLM) effect sizes are reported as coefficient of determination (R^2) values describing the amount of variability within the model associated with the significant effect. The R package r2glmm (Jaeger, 2017) was implemented using the Kenward-Roger method for calculating a semi-partial R^2 for each fixed effect in the model.

Reported R^2 values were computed as the proportion of semi-partial R^2 associated with the reported effect out of the total R^2 ascribed to the full model.

3. Results

Results are reported for analyses conducted on the subset of participants (N = 40) who completed all 8 weeks of the yoga program and both assessments (Movement = 22, Breath = 18).

3.1. Practice time

Practice times for each group were as follows. Led class hours: Movement group $M = 11.64$, $SD = 2.92$; Breath group $M = 10.44$, $SD = 3.54$. Home practice hours: Movement group $M = 13.68$, $SD = 8.21$; Breath group $M = 18.44$, $SD = 14.60$. Total hours: Movement group $M = 25.32$, $SD = 9.06$; Breath group $M = 28.89$, $SD = 13.76$. Independent samples *T*-tests used to compare practice times showed no significant differences between the two groups for led class hours ($t = 1.146$, $p = .250$), home practice hours ($t = 1.234$, $p = .201$) or total hours ($t = .946$, $p = .331$).

3.2. Perceived stress

Repeated-measures ANOVA with group and assessment time included as independent factors, and PSS values as a dependent factor, was used to assess differences in perceived levels of stress by the end of the yoga programs. There was a main effect of assessment time ($F(1,38) = 46.557$, $p < .01$, partial $\eta^2 = .07$) showing perceived stress decreased in both groups by the end of the yoga programs (Movement: - 3.68, Breath: - 3.11). There was no main effect of group, nor a significant interaction (Fig. 1).

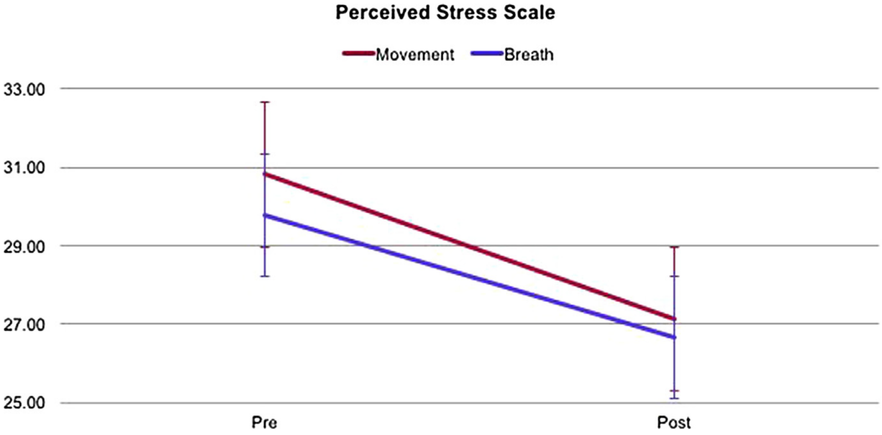

Fig. 1. Perceived Stress Scale (PSS). Pre and post scores on the Perceived Stress Scale (PSS) for the two experimental groups. Pre: Movement group $M = 30.82$, $SD = 6.74$; Breath group $M = 29.78$, $SD = 6.34$; Post: Movement group $M = 27.14$, $SD = 5.40$; Breath group $M = 26.67$, $SD = 7.50$. ANOVA (group x time) – Main effect: time ($p < .01$). Error bars represent SDs.

3.3. Salivary cortisol

Repeated-measures ANOVA with group and assessment time included as independent factors, and summed cortisol AUC as a dependent factor, was used to assess differences in the groups by the end of the yoga programs. There was a main effect of assessment time ($F(1,38) = 27.205$, $p < .01$, partial $\eta^2 = .25$) showing cortisol decreased in both groups by the end of the yoga programs (Movement: -3.7, Breath: -6.1). There was no main effect of group, nor a significant interaction (Fig. 2).

3.4. Response inhibition task (RIT)

3.4.1. Discrimination

The PEST visual discrimination thresholding procedure was completed immediately prior to the RIT at both data collection time points. To match the task demands across assessment times however, the baseline PEST threshold values were implemented in the RIT at both the pre and post assessments. Neither of the two types of yoga practice was expected to affect the PEST threshold per se, but possible changes from baseline to post-program were tested using a repeated-measures ANOVA with between-subject group (Movement, Breath) and within-subject assessment time (pre, post) as independent variables. There was a main effect of assessment time ($F(1,38) = 6.231$, $p = .017$, partial $\eta^2 = .141$), indicating that at post-intervention both groups were able to reach 75% accuracy at a larger visual angle (i.e. when viewing more difficult targets). There was no main effect of group, or interaction between

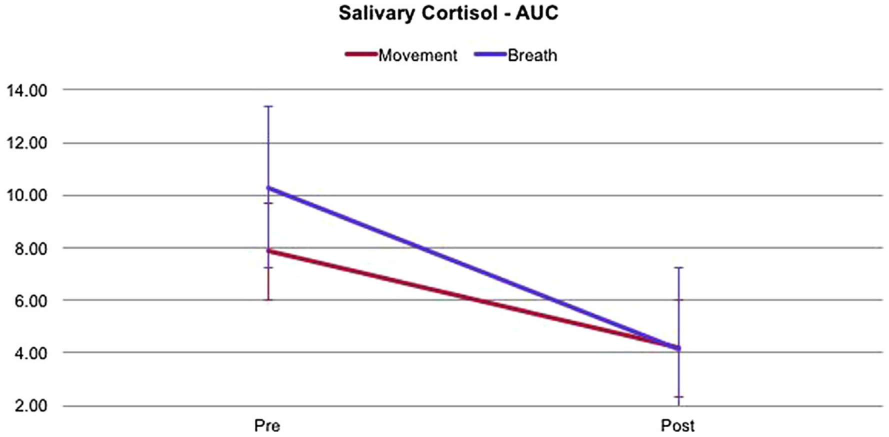

Fig. 2. Cortisol AUC. Pre and post cortisol values for the two experimental groups expressed as the sum of the linear area under the curve (AUC). Pre: Movement group $M = 7.86$, $SD = 5.27$; Breath group $M = 10.29$, $SD = 5.83$; Post: Movement group $M = 4.19$, $SD = 2.45$; Breath group $M = 4.16$, $SD = 1.85$. ANOVA (group x time) – Main effect: time ($p < .01$). Error bars represent SDs.

group and assessment time. The improvements in visual discrimination from baseline to post-program could be practice effects or potential influence of the overall intervention setting. Absence of a main group effect indicates that target line lengths were not meaningfully different across groups at the beginning or the end of the program.

3.4.2. Perceptual sensitivity (A)

Independent samples *T*-tests were used to assess baseline differences among participants in the two experimental groups on the *A* measure of perceptual sensitivity to targets during the RIT task. The groups did not differ in the overall *A* measure of perceptual sensitivity (F (1,38) = 2.019, $p = .163$) before the yoga program.

Mixed multi-level models (MLM) were generated using the nlme R package version 3.1-126 (Pinheiro, Bates, DebRoy, Sakar, & Team, 2016) to assess group-related changes in perceptual sensitivity to targets (*A*) before and after the yoga programs. Multi-level modeling is advantageous here because variability due to inherent differences among individual participants can be included as a random factor, which allows for a more controlled comparison of group-level effects. Parameter estimates in these models represent the difference in predicted variable (i.e. *A* or RTCV) with a unit of increase of a given predictor (i.e. group or assessment time) keeping all other predictors constant. Changes in overall performance irrespective of block-by-block fluctuations were interpreted from type III fixed effects of a model including training group (1 = Movement, 2 = Breath) and assessment time (1 = pre, 2 = post), which were modeled as class factors. There was a marginal main effect of assessment time (F (1,598) = 3.228, $p = .073$, $R^2 = .077$) showing *A* tended to increase by .014 by the post-program assessment time. Importantly, there was a significant and large interaction effect between group and assessment time (F (1,598) = 15.136, $p < .01$, $R^2 = 243$) showing the groups' *A* changed in opposite directions. The Movement groups average *A* decreased by .013 whereas the Breath group's *A* increased by .046 (Fig. 3). These finding suggest overall perceptual sensitivity was improved by the breath-focused yoga practice, but not the movement-focused practice. Parameter estimates for this model are reported in Table 2.

An additional model with group, assessment time, and block as fixed factors was used to further examine changes in *A* among groups over the 4-minute blocks of the 32-minute sessions, to determine if the within-session trajectory of sustained attention differed in relation to the type of practice. In addition to being included as a fixed factor, block (Block 1 = 0, Block 8 = 7) was included as a random factor because block-to-block *A* measures the slope of performance across the session and it is expected to vary randomly across individuals. On overall *A* performance we observed an effect of block, (F (1, 594) = 69.23, $p < .001$, $R^2 = .035$), a trend towards significance for assessment time, (F (1, 594) = 3.621, $p = .058$, $R^2 = .020$), but no effect of group (F (1, 594) = 0.237, $p = .63$). There were no significant two-way interactions between assessment time, and group. Importantly, however, there was a three-way interaction between block, assessment time, and group (F (1, 594) = 5.042, $p = .025$, $R^2 = .040$) showing that changes in vigilance decrement over the 32-minute session were significantly different between the two groups after the yoga program. In the Breath group, *A* declined by −.013 ($p < .001$, 95% CI [−0.02, −0.006]) each 4-minute block before the yoga program. The *A* decrement was −.008 at the post-assessment, but this change in slope was not significant ($\beta = .005$, p = .242, 95% CI [−0.004, 0.014]). In the Movement group, *A* declined by −.011 ($p = .002$, 95% CI [−0.017, −0.004]) each 4-minute block before the yoga program. The *A′* decrement was −.019 at the post-assessment, and this change in slope was significant ($\beta = -.009$, p = .036, 95% CI [−0.017, −0.001]) (Fig. 4). These findings suggest that at the post-assessment the groups' vigilance changed differently. The Breath group participant's vigilance decrement was maintained, whereas in the Movement group participants it actually increased. Parameter estimates this model are reported in Table 3.

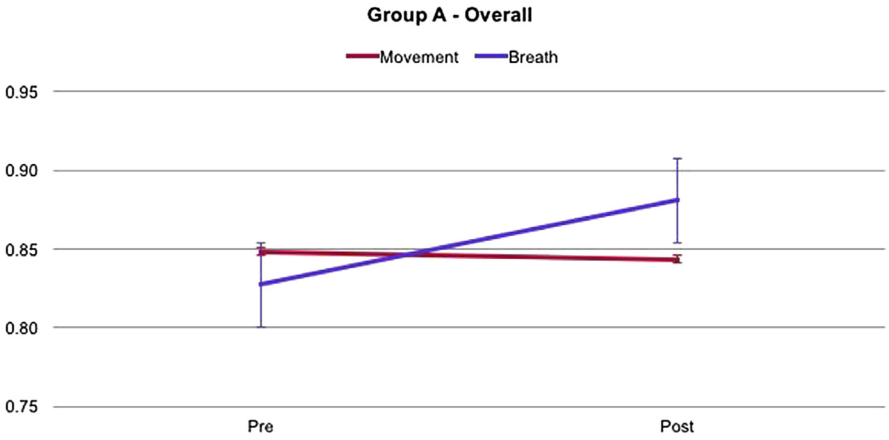

Fig. 3. A overall performance. Pre and post *A* overall performance for the two experimental groups. Pre: Movement group *M* = 0.85, *SD* = 0.06; Breath group *M* = 0.83, *SD* = 0.08; Post: Movement group *M* = 0.84, *SD* = 0.08; Breath group *M* = 0.88, *SD* = 0.06. MLM (group x time). Marginal main effect: time (*p* = .07); 2-way interaction: group x time (*p* < .01). Error bars represent SDs.

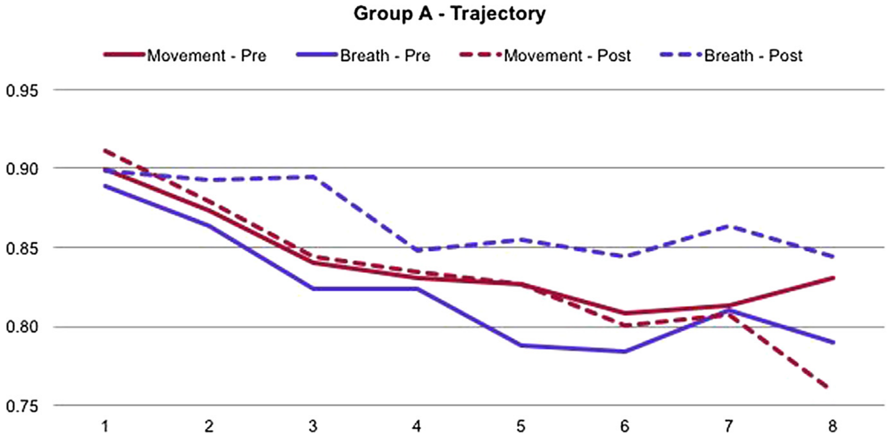

Fig. 4. A trajectory. Pre and post *A* trajectory for the two experimental groups. Pre: Movement – block # 1 *M* = 0.90, *SD* = 0.07; block # 2 *M* = 0.87, *SD* = 0.07; block # 3 *M* = 0.84, *SD* = 0.10; block # 4 *M* = 0.83, *SD* = 0.10; block # 5 *M* = 0.83, *SD* = 0.10; block # 6 *M* = 0.81, *SD* = 0.10; block # 7 *M* = 0.81, *SD* = 0.15; block # 8 *M* = 0.83, *SD* = 0.08; Breath – block # 1 *M* = 0.89, *SD* = 0.06; block # 2 *M* = 0.86, *SD* = 0.06; block # 3 *M* = 0.82, *SD* = 0.13; block # 4 *M* = 0.82, *SD* = 0.11; block # 5 *M* = 0.79, *SD* = 0.14; block # 6 *M* = 0.78, *SD* = 0.16; block # 7 *M* = 0.81, *SD* = 0.13; block # 8 *M* = 0.79, *SD* = 0.11. Post: Movement – block # 1 *M* = 0.91, *SD* = 0.05; block # 2 *M* = 0.88, *SD* = 0.08; block # 3 *M* = 0.84, *SD* = 0.10; block # 4 *M* = 0.83, *SD* = 0.12; block # 5 *M* = 0.83, *SD* = 0.12; block # 6 *M* = 0.80, *SD* = 0.15; block # 7 *M* = 0.81, *SD* = 0.12; block # 8 *M* = 0.76, *SD* = 0.14; Breath – block # 1 *M* = 0.90, *SD* = 0.11; block # 2 *M* = 0.89, *SD* = 0.06; block # 3 *M* = 0.89, *SD* = 0.10; block # 4 *M* = 0.85, *SD* = 0.12; block # 5 *M* = 0.86, *SD* = 0.12; block # 6 *M* = 0.84, *SD* = 0.13; block # 7 *M* = 0.86, *SD* = 0.11; block # 8 *M* = 0.84, *SD* = 0.14. MLM (group x time x block) – Main effect: block (*p* < .01); Marginal main effect: time (*p* = .08); 3-way interaction: group x time x block (*p* < .05).

3.4.3. Response variability (RTCV)

We also assessed group-related changes in consistency of RT to non-target stimuli (RTCV).

Independent samples *t*-tests found that at baseline there were no differences among participants in the two experimental groups on the overall RTCV measure of response variability (F (1,38) = −.193, p = .848).

A MLM with group and assessment time as fixed factors and participant as a random factor predicting RTCV found no main effects of group or assessment time independently, but there was a significant interaction (F (1,598) = 17.0813, p < .01, R^2 = .280) which showed the response stability in the group changed in opposite directions. The Breath group decreased in RTCV (−.025 ± .103), whereas the Movement group's RTCV increased (.025 ± .109) (Fig. 5). Parameter estimates for the reported models are presented in Table 2.

To more closely examine changes in RTCV among groups across blocks of the 32-minute sessions, we examined an additional model with group, assessment time and block as fixed factors, and block also set as a random factor within individuals. This model described the group differences in within-session trajectory of response variability. In RTCV we observed a large significant effect of block (*F* (1, 594) = 67.265, *p* < .001, R^2 = .080), no effect of assessment time (*F* (1, 594) = 0.204, *p* = .652), and no effect of

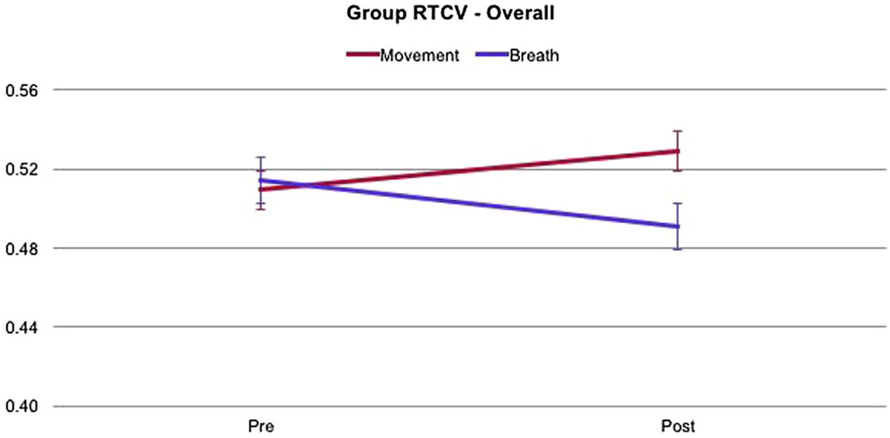

Fig. 5. RTCV overall performance. Pre and post RTCV overall performance for the two experimental groups. Pre: Movement group *M* = 0.51, *SD* = 0.07; Breath group *M* = 0.51, *SD* = 0.08; Post: Movement group *M* = 0.53, *SD* = 0.08; Breath group *M* = 0.49, *SD* = 0.08. MLM (group x time) – 2-way interaction: group x time ($p < .01$). Error bars represent SDs.

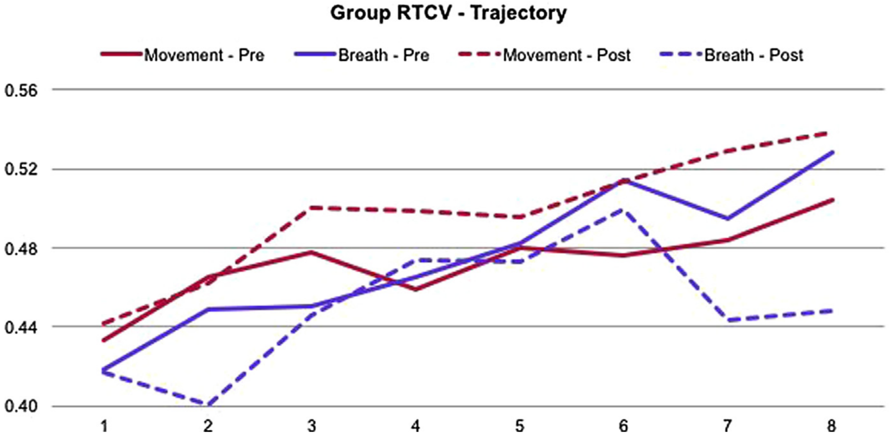

Fig. 6. RTCV trajectory. Pre and post RTCV trajectory for the two experimental groups. Pre: Movement – block # 1 *M* = 0.43, *SD* = 0.07; block # 2 *M* = 0.47, *SD* = 0.09; block # 3 *M* = 0.48, *SD* = 0.08; block # 4 *M* = 0.46, *SD* = 0.09; block # 5 *M* = 0.48, *SD* = 0.08; block # 6 *M* = 0.48, *SD* = 0.07; block # 7 *M* = 0.48, *SD* = 0.08; block # 8 *M* = 0.50, *SD* = 0.12; Breath – block # 1 *M* = 0.42, *SD* = 0.05; block # 2 *M* = 0.45, *SD* = 0.08; block # 3 *M* = 0.45, *SD* = 0.09; block # 4 *M* = 0.47, *SD* = 0.09; block # 5 *M* = 0.48, *SD* = 0.12; block # 6 *M* = 0.51, *SD* = 0.13; block # 7 *M* = 0.49, *SD* = 0.10; block # 8 *M* = 0.53, *SD* = 0.16. Post: Movement – block # 1 *M* = 0.44, *SD* = 0.07; block # 2 *M* = 0.46, *SD* = 0.08; block # 3 *M* = 0.50, *SD* = 0.11; block # 4 *M* = 0.50, *SD* = 0.11; block # 5 *M* = 0.50, *SD* = 0.09; block # 6 *M* = 0.51, *SD* = 0.10; block # 7 *M* = 0.53, *SD* = 0.12; block # 8 *M* = 0.54, *SD* = 0.13; Breath – block # 1 *M* = 0.42, *SD* = 0.06; block # 2 *M* = 0.40, *SD* = 0.04; block # 3 *M* = 0.45, *SD* = 0.08; block # 4 *M* = 0.47, *SD* = 0.12; block # 5 *M* = 0.47, *SD* = 0.13; block # 6 *M* = 0.50, *SD* = 0.16; block # 7 *M* = 0.44, *SD* = 0.09; block # 8 *M* = 0.45, *SD* = 0.06. MLM (group x time x block) – Main effect: block ($p < .01$); 3-way interaction: group x time x block ($p < .05$).

group (F (1, 38) = .985, p = .327). We observed no two-way interactions assessment time, and group. Importantly, however, we observed a small significant three-way interaction between block, assessment time, and group, (F (1, 594) = 6.403, p = .012, R^2 = .057), showing that changes in RT variability over blocks were significantly different between groups after the yoga program. In the Breath group, RTCV increased by .014 ($p < .001$, 95% CI [0.008, 0.021]) each 4-minute block at the baseline assessment. The increase in RCTV over blocks was .007 at the post-assessment, and this change in slope was significant ($\beta = -.007$, $p = .038$, 95% CI [−0.014, −0.001]). In the Movement group, RTCV increased by .007 (p = .018, 95% CI [0.001, 0.013]) each 4-minute block at the baseline assessment. This increase in variability over blocks was .013 at the post-assessment, but this increase was not significant (β = .005, p = .101, 95% CI [−0.001, 0.012]) (Fig. 6). These findings suggest that in the Breath group participants the increase in RTCV over each 4-minute block of the task was reduced at the post-assessment, whereas the in the Movement group participants the increase in RTCV over blocks was unchanged. Parameter estimates for the reported models are presented in Tables 2 and 3.

Table 2

MLM parameter estimates – group × time. Parameter estimate outcomes from a multi-level regression model using group (Movement or Breath) and time (pre or post) to predict overall *A′* and RTCV.

MLM parameter estimates	A		RTCV	
	Estimate	SE	Estimate	SE
Intercept	0.85	0.02***	0.45	0.02***
Group - Breath	−0.08	0.03*	0.05	0.03
Time - Pre	−0.01	0.01	0.03	0.01**
Group - Breath * Time	0.06	0.02***	−0.05	0.01***
AIC	−1071.33		−1334.14	
BIC	−1044.60		−1307.41	
Log Likelihood	541.66		673.07	
Number of Observations	640		640	
Number of Groups	40		40	

* p < .05.
** p < .01.
*** p < .001.

Table 3

MLM parameter estimates – group × time × block. Parameter estimate outcomes from a multi-level regression model using group (Movement or Breath), time (pre or post) and block to predict the within-session trajectory of *A′* and RTCV.

MLM parameter estimates	A		RTCV	
	Estimate	SE	Estimate	SE
Intercept	0.86	0.04***	0.44	0.03***
Group - Breath	0.00	0.05	−0.04	0.05
Timepoint - Pre	0.03	0.02	0.00	0.02
Block	0.00	0.01	0.00	0.01
Group - Breath * Time	0.00	0.03	0.01	0.03
Group - Breath * Block	−0.02	0.01	0.02	0.01*
Time * Block	−0.01	0.00*	0.01	0.00
Group - Breath * Time * Block	0.01	0.01*	−0.01	0.01*
AIC	−1097.06		−1355.60	
BIC	−1052.58		−1311.12	
Log Likelihood	558.53		687.80	
Number of Observations	640		640	
Number of Groups	40		40	

** p < .01.
* p < .05.
*** p < .001.

3.5. Correlations

3.5.1. Correlation between perceived stress and cortisol

There was no statistically significant correlation between the change in perceived stress and the change in cortisol AUC for the group of participants as a whole ($r = -0.284$, $p = .161$) and for the Movement group ($r = -0.172$, $p = .609$), but a significant negative correlation for the Breath group ($r = -0.377$, $p = .009$). Hence, in the Breath group decreases in perceived stress were correlated with increases in cortisol AUC.

3.5.2. Correlation between perceived stress and RIT parameters

For the group of participants as a whole, there was no significant correlation between the change in perceived stress and the change in *A* ($r = -0.186$, $p = .150$), but there was a significant correlation between the change in perceived stress and the change in RTCV ($r = 0.283$, $p = .049$). For the Movement group, there was no significant correlation between the change in perceived stress and the change in *A* ($r = -0.182$, $p = .268$) or RTCV ($r = 0.048$, $p = .786$). For the Breath group, there was a non-significant negative correlation between the change in perceived stress and the change in *A* ($r = -0.191$, $p = .65$), and a significant correlation between the change in perceived stress and the change in RTCV ($r = 0.555$, $p < .001$). Hence, in the Breath group participants decreases in perceived stress were correlated with decreases in RTCV.

3.5.3. Correlation between cortisol and RIT parameters

For the group of participants as a whole, there was no significant correlation between the change in cortisol AUC and the change in A ($r = -0.039$, $p = .925$) or RTCV ($r = -0.176$, $p = .221$). For the Movement group, there was also no significant correlation between the change in cortisol AUC and the change in A ($r = 0.012$, $p = .628$) or RTCV ($r = 0.161$, $p = .262$)). For the Breath group, there was no significant negative correlation between the change in cortisol AUC and the change in A ($r = -0.081$, $p = .896$), but a significant negative correlation between the change in cortisol and the change in RTCV ($r = -0.619$, $p < .001$). Hence, increases in cortisol were related to reductions in RTCV.

4. Discussion

4.1. Summary of results

Both the Movement and Breath intervention groups showed reduced levels of perceived stress as well as salivary cortisol after the 8-week program. As for the sustained attention task, the breath-focused yoga practice more effectively fostered the maintenance of perceptual sensitivity and response time consistency over an extended sitting. There was no correlation between the reductions in perceived stress and the reductions in cortisol from pre to post assessment. Perceived levels of stress were, however, correlated with performance on the sustained attention task. In contrast, there was no significant correlation between the reduction in cortisol and improvement in any of the sustained attention task parameters. Taken together, our findings indicate that the breath-focused yoga program more effectively promoted improved ability to sustain attention for a prolonged duration under demanding circumstances. In addition, they suggest that reduced perceived stress, but not cortisol, was a supporting factor for the improvements in attention.

4.2. Conclusions to our research questions

In the current study we set out to investigate: (a) whether YBP can be effective for promoting changes in perceived stress, physiological stress parameters and sustained attention in novice practitioners; (b) which components of YBP might be driving potential changes in these outcome measures; (c) whether changes stress parameters were correlated with changes in attention. We will now discuss our findings with respect to these questions.

4.2.1. Can YBP be effective for promoting changes in perceived stress, physiological stress parameters and sustained attention in novice practitioners?

Our results show that eight weeks of YBP can elicit measurable changes in perceived stress, salivary cortisol and sustained attention in novice practitioners. However, while we observed a reduction in perceived stress and salivary cortisol in both experimental groups, only the group of participants assigned to the breath-focused yoga practice showed improvements in sustained attention. Our finding of reduced perceived stress as measured with the PSS is in line with previous studies documenting self-reported stress reduction following a 4-month long residential yoga program (Gard et al., 2012). The findings of reduced diurnal salivary cortisol were also consistent with previous work documenting similar results in a 6-months of yoga program (Rocha et al., 2012). It needs to be noted that cortisol levels can be highly fluctuating, and that sample collection should ideally occur over several days (Hellhammer et al., 2009). Given logistical imitations we were only able to collect samples on a single day pre and post intervention which represents a limitation of our study. Future studies assessing both perceived stress and salivary cortisol over several consecutive days will be informative to further clarify the impact of YBP and the relationship between experiential and physiological stress parameters. Finally, the findings of improved sustained attention in the Breath group in terms of both target discrimination accuracy and response time variability corroborated with previous studies with expert meditation practitioners in a retreat setting (MacLean et al., 2010; Sahdra et al., 2011; Zanesco et al., 2013).

4.2.2. Which components of YBP are driving changes in stress parameters and sustained attention?

The common as well as differential results observed in the Movement and Breath groups respectively, provide an interesting context for the formulation of hypotheses about which components of YBP are likely to have primarily contributed to the changes in stress parameters and attention.

As described in the methods section, the experimental groups primarily differed in regard to the inclusion of an active movement component, while being matched as closely as possible in terms of the breath and attention components. The fact that changes in perceived stress and salivary cortisol were observed in both groups, indicates that the movement component was not necessary for driving stress reduction. Based on previous literature documenting the physiological benefits of slow and rhythmic breathing (Brown & Gerbarg, 2005), it can be assumed that the breath regulation employed in both types practices was a key component underlying the reduction of stress parameters. The absence of a significant difference between the groups however, does not allow us to draw any strong conclusions as to the causal role of the breath and / or the attention component for stress reduction. It cannot be ruled out that a social bonding effect brought about by taking part in a group activity for several weeks might have played a role, especially as far as perceived stress is concerned. Future studies adding a third experimental arm consisting of a passive control group participating in some form of group activity not involving any of the active components of YBP, could shed light on this fact.

The following hypotheses are proposed to account for the finding that sustained attention improved only in the breath group. First, the pacing of the breath was somewhat slower in the breath-focused practice compared to the movement-focused practice.

While the Movement group was instructed to engage in ujjayi breath with a consistent rhythm of inhales and exhales accompanying the movement sequences throughout the duration of each practice session, the Breath group engaged in a series of variations of ujjayi breath that included more slowly paced breathing as well as short breath retentions between inhalations and exhalations. Hence, the average pace of inhales and exhales for the Breath group across the practice sessions was slower than that of the Movement group. In the absence of objective breath monitoring devices we are not able to provide a precise quantification of breath rate, but estimated average ranges based on the program outlines were 6–8 breaths per minute for the movement-focused practice, and 3–5 breaths per minute for the breath-focused practice. Studies documenting the benefits of slow and rhythmic breathing consistently report that they are facilitated by breathing rates at or below six breaths per minute (Sovik, 2000). Although speculative, we hypothesize that the impact on self-regulatory and attentional mechanisms that are positively impacted by parasympathetic dominance may also be maximized in the context of the lower breath rate.

Second, while both the movement-focused and the breath-focused practice included directed gaze to promote attentional focus, the overall gaze direction was more stable in the breath-focused practice. That is, in the movement-focused practice the point of focus changed much more frequently than during the breath-focused practice. During static postures the gaze was focused on the same spot for a maximum of five consecutive breaths, and for dynamic movement sequences the point of focus mostly changes with each breath to enable the synchronization of movement, breath, and gaze. During the breath-focused practice on the other hand, the gaze was focused on the same spot for the entire duration of each individual breathing exercise and hence for several minutes. The type of gaze control of the breath-focused practice was therefore much more similar to the one employed in the RIT which requires steady focus to the same location of the computer screen for a prolonged period of time, and therefore more likely to transfer to the assessment context.

Third, a further aspect that might explain the results favoring the breath-focused practice is the higher degree of complexity of the movement-focused practice for novice practitioners. Learning new movement sequences, while contemporarily following instructions for breath regulation and gaze direction is attentionally demanding, and although taught in an incremental fashion the more complex practice might not have allowed the participants to foster the type of single focused attention required for our outcome measure of interest. We do not intend to claim that the movement component has a negative impact on attentional control. It is likely however, that the duration of the program was insufficient for allowing novices to get to the point of mastering the integration of movement, breath and attention to an extent that may promote a true synergistic effect. In future studies it would be of interest to investigate whether a longer program might lead to different results favoring a practice with an active movement component.

4.2.3. *Is there a correlation between changes stress parameters and sustained attention?*

While we observed a significant reduction in both perceived stress and salivary cortisol, the reduction in these two parameters was not correlated. In fact, the only significant correlation we found was a negative correlation between the change in perceived stress and the change salivary cortisol in the Breath group. This result indicates that at least some of the Breath group participants who indicated more reduction in perceived stress actually showed less reduction in cortisol or vice versa. The inconsistency of psycho-endocrine covariance in the context of stress parameters has been noted in previous work using a variety of stressors, self-report measures, and populations (Oswald et al., 2004). Our study therefore corroborates the notion that self-report and physiological parameters of stress do not always reflect the same construct, and that a reduced physiological stress response does not always translate into less perceived stress.

In terms of the correlation between stress parameters and attention, our results indicate that perceived stress but not salivary cortisol may have impacted performance on the RIT. Specifically, we found that reduced perceived stress was correlated with reduced response time variability across all participants, and additionally with increased perceptual sensitivity in the Breath group. These results are consistent with previous research suggesting that one's ability to sustain attention decreases with increased perceived stress (Hancock, 1989), and that with prolonged attentional demands under stressful situations both accuracy and response speed become increasingly variable (Hockey, 1986). In contrast, we did not find any indication that reduced cortisol correlated with improved performance on the RIT. As for the correlation between stress parameters the only correlation we found was negative, in this case between the change in cortisol and the change in RTCV in the Breath group. This result indicates that at least some of the Breath group participants who showed more reduction in cortisol had actually more response variability during the RIT or vice versa. Further studies investigating the link between stress physiology and sustained attention will be of interest to shed light on the potential implications of this finding.

4.3. *Potential neurophysiological and neurocognitive mechanisms underlying the observed results*

4.3.1. *Bottom-up neurophysiological mechanisms*

There are a number of bottom-up physiological mechanisms that can be hypothesized to underlie the observed results of reduced stress parameters as well as improved attention, most of which are likely to be facilitated primarily by the breath component.

Slow and rhythmic breathing has been shown to promote parasympathetic dominance (Sovik, 2000), facilitating stress regulation (Sharma, 2014) as well as cognitive control (Sharma et al., 2014). One of the main mechanisms through which slow breathing is proposed to impact autonomic regulation is by promoting vagal tone (Porges, 2001). The vagus nerve is one of the key components of autonomic regulation (Porges, 1995), with its afferent fibers communicating peripheral information about bodily states to the brain, and its efferent fibers providing parasympathetic innervation to most visceral organs as well as striated muscles of the face, head and neck (Berthoud & Neuhuber, 2000). Vagal tone is reflected by the variability of the inter-beat intervals of the heart or heart rate variability (HRV) (Porges, 2001), and especially mirrored by the HRV within the frequency of respiration or respiratory sinus arrhythmia (RSA) (Calabrese, Perrault, Dinh, Eberhard, & Benchetrit, 2000). Consequently, there is an interaction between breathing frequency and HRV as well as vagal tone, with slower breathing rates promoting an increase of both these indices (Bernardi, Gabutti, Porta, & Spicuzza, 2001). Moreover, the described ujjayi breath employed in both types of practice involves contraction of laryngeal muscles, which are hypothesized to additionally stimulate somatosensory vagal afferents to the brain (Brown & Gerbarg, 2005) and in turn further promote improved autonomic regulation (Calabrese et al., 2000). Alternate nostril breathing, which was employed in the breath-focused practice, has also been associated with measurable psychophysiological effects. These include again increased parasympathetic nervous system activity as measured by heart rate parameters (Sinha, Deepak, & Gusain, 2013), as well as changes in auditory evoked potential which are of cognitive processes required for sustained attention (Telles, Singh, & Puthige, 2013).

While vagal tone is predominantly impacted by slow and rhythmic breathing (Brown & Gerbarg, 2005), the movement component of YBP is likely to play an important role in promoting vagal afference as well. For example, many yoga poses emphasize abdominal tone through interior muscle activation, which additionally promotes peripheral vagal stimulation and afference (Ritter, Ritter, & Barnes, 1992). In addition, they often enhance the depth of the breath (e.g. via active expansions/contractions of the rib cage during back/forward bends), potentially furthering its effects. In our study we did not observe any additional benefit from the movement component. As mentioned above, we assert that this is likely due to the added complexity to the practice that provided a challenge for novice practitioners, preventing them to fully integrate the movement and breath components.

4.3.2. Top-down neurocognitive mechanisms

A central characteristic of YBP is the direction of attention toward bodily sensations. Much of our current knowledge about the neural correlates of body-focused attention is based on studies of body-centered meditation and mindfulness practices, which have reported both structural and functional changes in brain areas involved in processing bodily information. A meta-analysis of structural brain changes associated with meditation practices (Fox et al., 2014) found these to be particularly consistent in the insular cortex, primary and secondary sensorimotor cortices, and the anterior precuneus, which are involved in interoceptive awareness, the processing of tactile and proprioceptive sensations, and higher-order body awareness respectively. A meta-analysis of functional brain changes associated with meditation practices (Fox et al., 2016) also reported changes in several areas that process bodily signals, such as parietal areas involved in spatial and somatosensory processing, the right supramarginal gyrus, and again the insular cortex. There is preliminary evidence that YBP may also be associated with structural and functional changes in brain areas involved the processing of bodily sensations. Findings include increased gray matter volume in the insula, cingulate cortex, medial prefrontal cortex, inferior and superior parietal lobule, and cerebellar regions (Froeliger, Garland, & McClernon, 2012; Villemure, Ceko, Cotton, & Bushnell, 2014), as well as increased intra-insular white matter connectivity (Villemure et al., 2014) in advanced yoga practitioners compared to controls.

Of particular interest to our finding of improved sustained attention, it has been proposed that body-focused attention can elicit changes in brain dynamics that enhance signal-to-noise ratio in attentional processing across different modalities (Kerr, Sacchet, Lazar, Moore, & Jones, 2013). Specifically, it has been proposed that somatically focused practices enhance attentional control of the 7–14 Hz alpha rhythm, which is said to play a crucial role for regulating input and signal-to-noise ratio not only for sensory cortices, but across the neocortex (Kerr et al., 2011). The tangible nature of somatic information and feedback is thought to make it an efficient tool for learning how to modulate the alpha rhythm, so that it is then more likely to be efficiently filtered and prioritized throughout the brain. This proposal is consistent with studies on body-focused mindfulness practices showing long-term changes in prefrontal cortex activation (Davidson et al., 2003; Farb, Anderson, & Segal, 2012), as well as enhanced performance in tests of visual selective attention (Jensen, Vangkilde, Frokajer, & Hasselbach, 2012; Jha, Krompinger, & Baime, 2007).

Both practices in our study employed controlled gaze to foster attentional focus. Following on from the previous paragraph, much information about the neural process that are affected when gaze is used to train attention comes from studies investigating the relationship between gaze and self-regulation of alpha waves. For example, is known that a state of relaxed wakefulness is associated with the presence of alpha rhythm in occipital / visual brain regions (Haegens, Cousijn, Wallis, Harrison, & Nobre, 2014). While this state typically occurs with closed eyes, it has been shown that individuals can be trained to induce alpha waves while their eyes are open as long as their attention is turned inward (Green, Green, & Walters, 1979). Alpha wave production in this case is suggested to be related to a defocus and relaxation of ocular convergence, a technique that is also found in many yogic eye postures or “drishti” (Bahm, 1965).

Focused gaze towards specific body parts, with concomitant avoidance of eye movements towards distracting stimuli, has also been linked to specific neural correlates. Data from functional magnetic resonance imaging (fMRI) studies indicates that inhibiting saccades and redirecting gaze toward a target engages a frontal oculomotor network known to be involved in action inhibition and performance monitoring, which includes the medial frontal cortex, frontal and supplementary eye fields, and the striatum (Thakkar, van den Heiligenberg, Kahn, & Neggers, 2014). In addition, studies using event-related potential (ERP) have shown that gazing at a body part enhances tactile acuity (Forster & Eimer, 2005), spatial attention (Gherri & Forster, 2014), as well as activation of fronto-parietal networks representing peripersonal space (Gillmeister & Forster, 2010). Lastly, gaze control and voluntary eye movements are supported by basal ganglia (BG) circuits, which involve cortico-striatal projections from frontal and supplemental eye fields via the superior colliculus (Arsalidou, Duerden, & Taylor, 2013). These BG circuits are implicated in smooth pursuit and in the control of saccadic eye movements, particularly in terms of preventing saccadic eye movements toward distracting visual stimuli (Hikosaka, Takikawa, & Kawagoe, 2000). Given that spatial orienting through eye movements is known to be associated with the orienting of attention (Schneider & Deubel, 2002), it is likely that BG circuits play a role in fostering attentional control applied in YBP.

4.3.3. Interaction of bottom-up physiological and top-down cognitive processes promoted by YBP

Recently proposed theoretical frameworks (Gard, Noggle et al., 2014; Schmalzl et al., 2015; Sullivan et al., 2018) outline mechanistic models of how YBP may affect various aspects of self-regulation. One concept that is consistently underlined in these frameworks is the interaction between bottom-up physiological processes (primarily driven by the movement and breath components of YBP), and top-down cognitive processes (primarily driven by the attention component of YBP). Bottom-up processes including vagal afference, heart rate dynamics, endocrine mechanisms as well as sensory input, all contribute to the detection and evaluation of environmental stimuli prior to their conscious elaboration by higher brain centers (Porges, 2003). For example, vagal afferent information is mediated via the thalamus to the insula, anterior cingulate cortex and prefrontal cortex, which are involved in emotion regulation as well as in attentional control (Thayer & Sternberg, 2006). Conversely, by detecting and environmental stimuli, higher order brain centers modulate autonomic states and adaptive behaviors. For example, brain structures such as the amygdala and the prefrontal cortex, which are implicated in fear-detection, attentional mechanisms, executive function and self-regulatory behaviors (McEwen & Gianaros, 2011), are linked via the vagus nerve to the regulation of metabolic systems (Thayer & Sternberg, 2006).

By employing a rich set of both bottom-up and top-down mechanism, YBP lend themselves as an ideal method for promoting and dynamically exploring the interplay between the body's physiological stress responses and regulatory systems (Schmalzl et al., 2015). In the context of YBP, physiological stress responses may be elicited by the physical, emotional or mental challenges that arise during the practice. As they arise, both bottom-up breath-related and top-down attention-related processes are systematically employed to counteract them and reinstall a balance within the system. In addition, the movement allows for these processes to be applied in a dynamic and ecological way, which is likely to facilitate the generalization of the self-regulatory effects to everyday life situations.

5. Conclusion

In conclusion, our study shows that eight weeks of YBP can lead to measurable changes in perceived stress, salivary cortisol and sustained attention in novice practitioners. In addition, our experimental design evaluating the comparative effectiveness of two carefully designed programs, allows us to formulate informed hypotheses about which aspects of the practice are likely to have driven the results. We believe that our study sets the scene for a number of interesting future investigations. While we found the breath-focused practice to be more effective for sustained attention for example, it is possible that a different choice of outcome measures might show a different pattern of results. The breath-focused practice seems to be tailored to improve the type of single focus attention required for the RIT, but it is an open question whether the movement-focused practice would be the more efficient training method for a task requiring the integration of more multifaceted attentional demands. Another important question for future research is to assess the extent to which improved performance on attention tasks such as the one used in our study is related to improved attentional performance in everyday life. Similarly, it will be of interest to investigate whether the documented objective improvements in attention performance are also reflected by subjective experiences of increased self-regulation. One of the challenges for future studies is therefore to combine strictly controlled experimental tasks with more ecologically valid and possibly individually tailored assessments that provide a more complete picture of how individuals benefit from contemplative interventions.

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Conflict of interest statement

The authors declare no conflict of interest.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.concog.2018.07.012.

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