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How does yoga reduce stress? A clinical trial testing psychological mechanisms

Crystal L. Park[1] | Lucy Finkelstein-Fox[1] | Shane J. Sacco[2] | Tosca D. Braun[3] | Sara Lazar[4]

[1]Department of Psychological Sciences, University of Connecticut, Storrs, Connecticut, USA

[2]Department of Allied Health Sciences, University of Connecticut, Storrs, Connecticut, USA

[3]Warren Alpert Medical School of Brown University, Providence, Rhode Island, USA

[4]Department of Psychiatry, Massachusetts General Hospital, Boston, Massachusetts, USA

Correspondence
Crystal L. Park, Department of Psychological Sciences, University of Connecticut, Storrs, CT 06269, USA.
Email: crystal.park@uconn.edu

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Abstract

Yoga interventions can reduce stress, but the mechanisms underlying that stress reduction remain largely unidentified. Understanding how yoga works is essential to optimizing interventions. The present study tested five potential psychosocial mechanisms (increased mindfulness, interoceptive awareness, spiritual well-being, self-compassion and self-control) that have been proposed to explain yoga's impact on stress. Forty-two participants (62% female; 64% White) in a yoga program for stress reduction completed surveys at baseline (T1), mid-intervention (T2) and post-intervention (12 weeks; T3). We measured two aspects of stress, perceived stress and stress reactivity. Changes were assessed with paired *t*-tests; associations between changes in mechanisms were tested in residual change models. Only stress reactivity decreased, on average, from T1 to T3. Except for self-compassion, all psychosocial mechanisms increased from T1 to T3, with minimal changes from T2 to T3. Except for self-control, increases in each mechanism were strongly associated with decreases in both measures of stress between T1 and T2 and decreases in perceived stress from T1 to T3 (all p's < 0.05). Increased psychosocial resources are associated with stress reduction. Yoga interventions targeting these resources may show stronger stress reduction effects. Future research should test these linkages more rigorously using active comparison groups and larger samples.

KEYWORDS
mind-body, self-regulation, stress-reduction, yoga

1 | INTRODUCTION

Stress is a commonly experienced aversive state purported to impact the course of disease and illness at a systemic level (Cohen, Edmondson, & Kronish, 2015; Muscatell & Eisenberger, 2012). Indeed, many health conditions have been shown to directly relate to or be exacerbated by stress (e.g., migraine, gastrointestinal problems and hypertension), and even health conditions that are not overtly related to stress often have close linkages (Muscatell & Eisenberger, 2012). For example, acute pain severity is highly influenced by perceived stress (Wieland et al., 2017; Woda, Picard, & Dutheil, 2016). In addition, stress itself is widely considered to constitute a problematic health condition (Goyal et al., 2014).

Stress is one of the most commonly studied outcomes of yoga practice (Domingues, 2018), and yoga interventions targeting stress reduction have generally demonstrated favourable findings (Chong, Tsunaka, Tsang, Chan, & Cheung, 2011; Pascoe & Bauer, 2015; Pascoe, Thompson, & Ski, 2017). Indeed, randomized controlled trials of yoga conducted across varied samples, including healthy stressed individuals, employees, students, pregnant women, people in treatment for cancer and people with hypertension, arthritis, headaches and asthma, have demonstrated significant

reductions in self-reported stress (see Pascoe & Bauer, 2015, for a review).

Importantly, self-reported stress can reflect either global perceptions of psychological pressure in one's life (e.g., feeling overwhelmed, unable to keep up) or physiological arousal that leaves one overly reactive to provocations (e.g., feeling agitated, intolerant and touchy). We term these types of stress, respectively, 'perceived stress' and 'stress reactivity'. While related, these types of stress are distinct in terms of individuals' experience (Flett; Nepon, Hewitt, & Fitzgerald, 2016; Oken, Chamine, & Wakeland, 2015), consequences (Adam & Epel, 2007; Crawford & Henry, 2003) and treatment approaches (Chiesa & Serretti, 2009; Iglesias et al., 2012; Lindsay, Young, Smyth, Brown, & Creswell, 2018). Yoga research has generally focused on the former (e.g., Chong et al., 2011), but people tend to find both aspects of stress aversive and troubling (Aldwin, 2007; Cohen, Kamarck, & Mermelstein, 1983; Lovibond & Lovibond, 1995). Thus, assessing the impact of yoga on both aspects of stress may be useful, given that yoga's effects on each aspect are distinct and might act through different mechanisms of change. For example, stress reactivity may be impacted more strongly by physical posture and breathwork than would perceived stress. In turn, elements of yoga that target cognitive-affective aspects of stress appraisals, such as mindfulness, self-compassion and meditation, may exert stronger direct effects on perceived stress than on stress reactivity. However, these differences remain purely speculative in the absence of empirical research and merit formal tests.

Indeed, despite the considerable amount of research on yoga and stress, we know little about how yoga reduces stress. Until recently, researchers focused primarily on testing yoga's efficacy for improving health status across a variety of health problems and conditions, with little emphasis on cognitive-behavioural mechanisms of change. As efficacy is increasingly demonstrated in clinical trials research, understanding how yoga produces salutary effects is emerging as an important next step towards optimizing interventions offered to the public. To date, surprisingly few studies have focused on identifying the mechanisms through which yoga reduces stress (Riley & Park, 2015), and of those, most lacked adequate sample sizes, time frames and theoretical bases. However, multiple theoretical perspectives have been advanced regarding the psychological mechanisms that might underlie yoga's effects on stress (Gard, Noggle, Park, Vago, & Wilson, 2014; Kinser, Goehler, & Taylor, 2012; Streeter, Gerbarg, Saper, Ciraulo, & Brown, 2012). Among the most promising of these potential mechanisms are increased mindfulness, interoceptive awareness, self-compassion, self-control and spiritual well-being.

First, myriad studies have shown that yoga practice is positively related to mindfulness, the extent to which one practices paying attention in the present moment with intention and non-judgement (Dick, Niles, Street, DiMartino, & Mitchell, 2014). Several studies have tested whether mindfulness mediates yoga's effects on outcomes such as post-traumatic stress (PTS) symptoms, with mixed findings (e.g., Dick et al., 2014; Mehling et al., 2018), but we were not able to locate studies that specifically examined mindfulness as a mechanism of yoga's effects on stress per se.

Interoceptive awareness, the awareness of inner body sensations, including receiving, accessing and appraising signals of the body's internal states, has been suggested as a related potential mechanism of action for body-based mindfulness interventions, particularly those with a strong physical basis such as yoga (Mehling et al., 2011). Improving awareness of one's internal states may provide opportunities to engage in mind–body skills that allow yoga practitioners to consciously intervene in their own stress reduction. One clinical trial of war veterans with PTS disorder found that interoceptive awareness, along with mindfulness, corresponded with reductions in symptoms in an integrated exercise program that included some elements of yoga (Neukirch, Reid, & Shires, 2019). Again, we were unable to find any formal tests of interoceptive awareness as a mechanism of change that may predict stress reduction in a yoga intervention.

Improvement in self-compassion, or mindful self-kindness, has also been suggested to be a mechanism by which yoga reduces stress (Braun et al., 2016; Neff & Germer, 2012). Self-compassion involves being caring and compassionate towards oneself in the face of hardship or perceived inadequacy (Neff, 2003). Acting with kindness towards oneself is associated with less stress reactivity and better coping skills (Allen & Leary, 2010). We located one study that tested self-compassion as a mediator of yoga's effects on stress, a longitudinal study of 33 young adults in a 4-month residential yoga intervention program; increases in self-compassion were associated with reductions in perceived stress (Gard et al., 2012).

Self-control and spiritual well-being have also been theoretically and empirically linked to yoga practice (Gard et al., 2014; Gerbarg & Brown, 2015), but we were unable to find any studies directly testing mechanistic linkages to stress. Self-control, the capacity to consciously alter or override one's incipient responses, especially to bring them into line with one's goals or standards, is related to lower stress levels (Tangney, Baumeister, & Boone, 2004; Park, Wright, Pais, & Ray, 2016) and several studies have suggested that yoga can increase self-control (e.g., Park et al., 2017; Ramadoss & Bose, 2010). Spiritual well-being refers to one's ability to experience and integrate meaning and purpose in life through connection with oneself others, nature or a power greater than oneself (Peterman, Fitchett, Brady, Hernandez, & Cella, 2002). Copious empirical evidence links higher spiritual well-being with lower levels of stress (e.g., Park & Slattery, 2013), and several studies have demonstrated that yoga is associated with positive aspects of spirituality (Büssing, Hedtstück, Khalsa, Ostermann, & Heusser, 2012; Gaiswinkler & Unterrainer, 2016). Thus, while not directly tested to date, these pathways—self-control and spiritual well-being—may indeed explain yoga's effects on stress.

The present study set out to examine these five potential mechanisms of change (mindfulness, interoceptive awareness, self-compassion, self-control and spiritual well-being) that may be associated with the effects of a 12-week yoga intervention and subsequent stress reduction. We elected to use an intervention based on Kripalu yoga, a practice, that is, relatively high in body awareness, acceptance/self-compassion, breathwork, mental and

emotional awareness, and active postures compared to other yoga types (Park et al., 2018). Based on previous literature, we hypothesized that: (1) all five psychosocial mechanisms, as well as indicators of two different aspects of stress, would significantly improve over the course of the intervention and (2) changes in psychosocial mechanisms from pre-to mid-treatment would be associated with changes in both indicators of stress from pre-to mid-treatment and pre-to post-treatment.

2 | METHOD

2.1 | Participants and procedures

The current study comprises a secondary analysis of a parent study assessing the effects of yoga on dietary change, which will be reported elsewhere (Masked for review, under review). Recruitment from two sites in the Northeastern US—an urban medical school in MA and a rural public university in CT—began in April 2015 and final assessments were completed in October 2016. Recruitment ads for a stress reduction program were posted via public transit and direct mail and online advertisements. Study candidates completed a web survey and phone screen, and for those remaining eligible, an in-person screening appointment where they provided written informed consent. Final eligibility was then confirmed following completion of the Mini International Neuropsychiatric Interview (MINI; Sheehan et al., 1998), the Eating Disorders module from the Structured Clinical Interview DSM-IV (SCID; First, Spitzer, Gibbon, & Williams, 1995) and a body mass index (BMI) assessment. Participants were required to be between 23 and 67 years of age and to be seeking stress reduction.

Exclusion criteria, based on the parent study, encompassed an exercise regimen of more than 180 min per week (based on Haskell et al., 2007), consumption of five or more servings of fruits and vegetables, current diagnosis of psychiatric illness or prior eating disorder diagnosis as determined by the MINI or SCID eating disorders module, significant prior meditation or yoga experience (defined as ≥12 classes in last 3 years or more than 20 classes in lifetime), medications that altered appetite and medical conditions that would limit the ability to exercise or do yoga. These stringent criteria resulted in a large number of individuals failing to screen in (e.g., due to high scores on current health behaviours). Following screening, 117 volunteers provided informed consent, of whom 84 were randomized. Participant flow is shown in Figure 1.

Participants were randomized with equal allocation ratio into one of three home practice groups for the program duration: 'low practice' (10 min/day 6 days per week), 'medium practice' (40 min/day 3 days per week and 10 min/day 3 days a week) and 'high practice' (40 min/day 6 days per week). The parent study was conservatively powered on an *N* of 135 participants to detect significant differences in change between home practice groups. In light of the present study's focus on covariance between stress and potential mechanisms over the course of the yoga program, the analyses reported here were collapsed across randomization groups to preserve statistical power.

Following initial baseline assessment (T1), this study included two additional assessment points: at 8 weeks (T2; mid-treatment) and at 12 weeks (T3; post-treatment). Participants were remunerated up to $100 for completing study assessments and received the yoga program for free. The study protocol was approved by both sites' Institutional Review Boards and monitored by Westat. The protocol is registered in Clinicaltrials.gov (NCT02098018).

2.2 | Yoga intervention

The Kripalu yoga intervention integrated yoga practice with yoga philosophy pertinent to self- and affect-regulation to decrease physiological arousal and enhance well-being. Participants learned how to monitor and modulate mental, emotional and physiological responses moment-to-moment through in-class experiential exercises and prescribed home yoga practice. The intervention was 12 weeks in length and consisted of two consecutive segments. The first segment was a manualized 8-week intervention designed to serve as an introduction to mindful yoga that was initially created and piloted by the Kripalu Center for Yoga. The intervention was slightly modified for use with a high-stress population. Each of the eight once-weekly, 2-h sessions included 100–115 min of yoga practice (meditation, breathing exercises, postures and relaxation) and 25–30 min of theory/philosophy. The second segment began at the ninth week, comprised 4 weeks of 90 min, once-weekly sessions of yoga practice (no didactic content), and concluded at 12 weeks. Participants who completed nine or more sessions from the first and/or second segment of the yoga intervention were considered to have received the full 'dose' of the intervention and were categorized as compliant to the study protocol. Treatment compliance had no bearing on the analyses reported here; all participants who completed post-treatment assessments were retained for analyses (see Section 2.5).

2.3 | Measures

2.3.1 | Perceived stress and stress reactivity

Perceived stress and stress reactivity were assessed, respectively, with a measure tapping into global psychological appraisals of one's life as overwhelmingly stressful (the Perceived Stress Scale; PSS; Cohen & Williamson, 1988) and a measure tapping descriptions of oneself as stress-reactive (stress subscale of the Depression Anxiety Stress Scale; DASS-21; Lovibond & Lovibond, 1995). The PSS contains 10 items, rated from 0 (never) to 3 (very often), asked of the stem, 'In the last month, how often have you…' A sample item is 'found that you could not cope with all the things you had to do?' Higher sum scores indicate higher levels of overall perceived stress. The PSS has good reliability and validity (Cohen & Williamson, 1988). The PSS is designed to measure subjective perceptions of stress

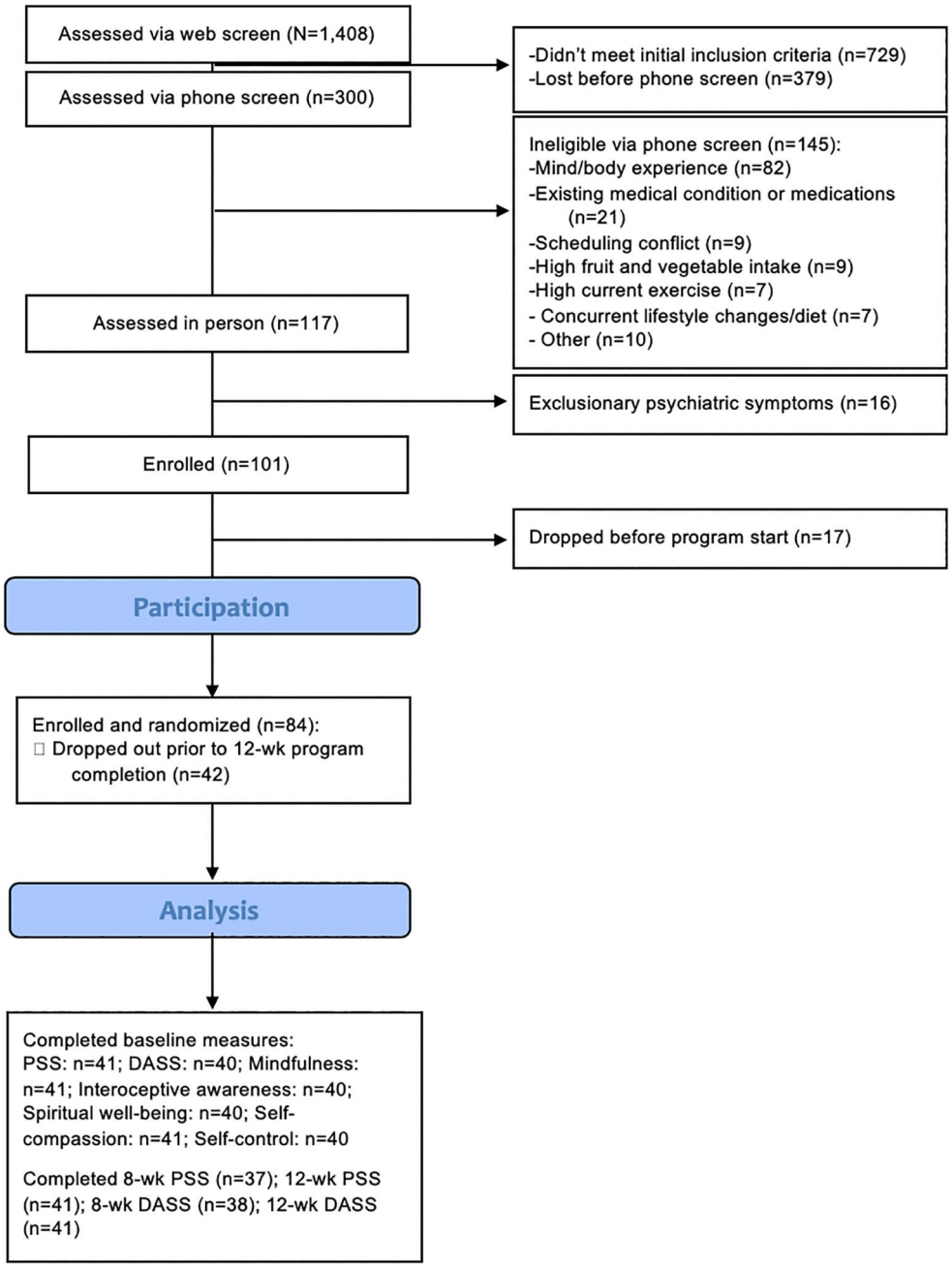

FIGURE 1 Participant Flow (CONSORT Diagram)

depending on changes in environmental stressors and coping resources (Cohen & Williamson, 1988); thus, no standardized clinical cut-offs exist for this measure. Within the present study, alphas for the PSS were 0.90, 0.93 and 0.91, at T1, T2 and T3, respectively. The DASS-21 stress subscale consists of 7 of the 21 items of the DASS-21 scale and assesses stress in terms of stress reactivity and arousal (e.g., 'touchy', 'agitated' and 'difficult to relax'). Items are rated from 0 (did not apply to me at all) to 3 (applied to me very much or most of the time); higher sum scores indicate higher levels of stress. Clinical cut-offs for stress scores on the DASS were developed by its authors, including normal (0–14), mild (15–18), moderate (19–25), severe (26–33) and extremely severe (34+; Lovibond & Lovibond, 1995). The DASS subscales have good reliability and validity (Lovibond & Lovibond, 1995). Within the present study, alphas for the DASS stress subscale were 0.83, 0.85 and 0.88, at T1, T2 and T3, respectively.

2.3.2 | Mindfulness

Mindfulness was assessed with the 24-item Five-Facet Mindfulness Questionnaire, short form (FFMQ-SF; Bohlmeijer, ten Klooster, Fledderus, Veehof, & Baer, 2011), a revision of the original 39-item FFMQ (Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006). The

FFMQ taps into five domains of mindfulness (acting with awareness, describing, observing, non-reacting and non-judging) and produces a global score. A sample item is 'I watch my feelings without getting carried away by them'. Item responses range from 1 (never or very rarely true) to 5 (very often or always true); higher average scores indicate greater mindfulness. The FFMQ global score has demonstrated good validity and reliability (Bohlmeijer et al., 2011). In the present study, alphas were 0.88, 0.89 and 0.90, at T1, T2 and T3, respectively.

2.3.3 | Interoceptive awareness

Interoceptive awareness was assessed with the 32-item Multidimensional Assessment of Interoceptive Awareness Scale (MAIA; Mehling et al., 2012). A sample item is 'When I am tense I notice where the tension is located in my body'. Item responses range from 1 (Never) to 5 (Always). Higher scores indicate more interoceptive awareness. The MAIA's global domain, used in the present study, sums eight subscales (noticing, not distracting, not worrying, attention regulation, emotional awareness, self-regulation, body listening and trusting). The MAIA global scale demonstrates good internal consistency (Mehling et al., 2012). In the present study, alpha was 0.93, 0.94 and 0.93 at T1, T2 and T3, respectively.

2.3.4 | Spiritual well-being

Spiritual well-being was assessed with the 12-item Functional Assessment of Chronic Illness Therapy—Spiritual Well-Being (FACIT-Sp; Peterman et al., 2002). A sample item is 'I feel a sense of purpose in my life'. Item responses range from 0 (not at all) to 4 (very much), with higher sum scores indicating greater spiritual well-being. The FACIT-Sp generates subscales for meaning, peace and faith and an overall score, the latter of which was used in the present study. The validation study indicated good internal consistency for the overall scale (Peterman et al., 2002). Within the present study, alphas were 0.83, 0.86 and 0.88, at T1, T2 and T3, respectively.

2.3.5 | Self-compassion

Self-compassion was assessed with the 12-item Self-Compassion Scale, Short Form (SCS-SF; Raes, Pommier, Neff, & Van Gucht, 2011), a revision of the original 26-item SCS (Neff, 2003). A sample item is 'When I'm going through a very hard time, I give myself the caring and tenderness I need'. Item responses range from 1 (almost never) to 5 (almost always), with higher scores indicating greater self-compassion. The SCS generates six subscales (self-kindness, self-judgement, common humanity, isolation, mindfulness and over-identification) and a global score, the latter used in the present study. The SCS-SF demonstrated good internal consistency for the global scale in the validation study (Raes et al., 2011). Within the present study, alphas were 0.89, 0.87 and 0.82, at T1, T2 and T3, respectively.

2.3.6 | Self-control

Self-control was assessed with the 10-item Brief Self-Control Scale (BSCS; Tangey et al., 2004). A sample item is 'I wish I had more self-discipline' (reverse scored). Items are rated from 1 (not at all like me) to 5 (very much like me) and summed; higher scores indicate higher self-control. The BSCS produces two subscales and an overall score, the latter reported here. The BSCS has demonstrated adequate reliability and validity (Tangey et al., 2004). Within the present study, alphas were 0.78, 0.86 and 0.88, at T1, T2 and T3, respectively.

2.4 | Recruitment and retention

At study start, a total of 84 participants attended at least one intervention session and elected to proceed with study participation. Those who did not complete T3 assessments ($n = 42$) evidenced no significant variance on baseline demographics or study variables relative to intervention completers ($n = 42$; p's > 0.11). Information on attendance and study attrition and completion rates are detailed in Figure 1.

2.5 | Data analysis

Descriptive statistics were conducted to describe demographics and study variables at all timepoints; when available, clinical cut-offs were used to interpret magnitude of study variables. Paired *t*-tests were conducted to determine if study variables differed between T1 and T2, T2 and T3 and T1 and T3; effect sizes were calculated using Cohen's *d* to describe standardized magnitudes of change between timepoints. Study variables were inter-correlated using Pearson's *r* to determine if any meaningful relationships existed at T1. Research site (i.e., rural vs. urban) and cohort (i.e., time of year that the intervention was completed) were also examined as potential covariates to study variable at T1 by conducting a series of analysis of variables. Correlational analyses were carried out to test primary mechanism of change hypotheses (e.g., Gibbons et al., 2009; Parschau et al., 2012). For each mechanism and stress measure, standardized residuals were obtained by regressing observed endpoints on baseline scores (e.g., T2 PSS scores were regressed on T1 PSS scores). Standardized residuals of mechanisms and stress measures were correlated using Pearson's *r*; correlations were compared between stress measures using *Z*-tests. Standardized residuals of mechanisms were also inter-correlated using Pearson's *r* to determine if any meaningful relationships existed between mechanisms of change. Missing data within those who completed T3 assessments were negligible (1–2 missing values, ≤5 for few variables), and thus

TABLE 1 Participant characteristics and estimated differences between timepoints

	T1 ($n = 42$)	T2	T3	T1–T2		T2–T3		T1–T3	
	%/M (SD)	M (SD)	M (SD)	*d*	*t* (*p*)	*d*	*t* (*p*)	*d*	*t* (*p*)
Gender (% female)	61.9	-	-	-	-	-	-	-	-
Race (% White)	64.3	-	-	-	-	-	-	-	-
Ethnicity (% Hispanic/Latino)	9.5	-	-	-	-	-	-	-	-
Age	41.0 (14.2)	-	-	-	-	-	-	-	-
Body mass index (kg/m^2)	25.2 (4.9)	-	-	-	-	-	-	-	-
Perceived stress (PSS)	18.5 (6.8)	18.3 (8.1)	17.1 (7.1)	0.06	−0.43 (0.67)	0.17	−1.37 (0.18)	0.20	−1.52 (0.14)
Stress reactivity (DASS)	15.2 (9.3)	13.5 (8.9)	12.0 (9.2)	0.20	−1.35 (0.19)	0.14	−0.80 (0.43)	0.37	**−2.16 (0.04)**
Mindfulness (FFMQ-SF)	3.4 (0.5)	3.5 (0.5)	3.6 (0.5)	0.11	0.87 (0.39)	0.21	**2.05 (0.05)**	0.29	**2.36 (0.02)**
Interoceptive awareness (MAIA)	2.3 (0.7)	3.0 (0.7)	3.0 (0.7)	1.01	**6.28 (<0.001)**	<0.01	0.02 (0.98)	0.98	**4.98 (<0.001)**
Spiritual well-being (FACIT-Sp)	26.6 (7.8)	29.1 (8.9)	29.7 (8.6)	0.30	**2.08 (0.05)**	0.04	2.43 (0.75)	0.41	**3.22 (0.003)**
Self-compassion (SCS-SF)	3.2 (0.8)	3.3 (0.7)	3.4 (0.6)	0.12	0.91 (0.37)	0.16	1.24 (0.22)	0.28	1.92 (0.06)
Self-control (BSCS)	43.6 (8.1)	45.5 (9.0)	46.1 (8.6)	0.24	1.91 (0.07)	0.02	0.27 (0.79)	0.29	**2.12 (0.04)**

Note: Bolded values indicate $p < 0.05$.

Abbreviations: BSCS, Brief Self-Control Scale; DASS, Depression Anxiety Stress Scale; FACIT-Sp, Functional Assessment of Chronic Illness Therapy—Spiritual Well-Being; FFMQ-SF, Five-Facet Mindfulness Questionnaire, short form; MAIA, Multi-dimensional Assessment of Interoceptive Awareness Scale; PSS, Perceived Stress Scale; SCS-SF, Self-Compassion Scale-Short Form.

list-wise deletion was utilized. Alpha for two-sided tests was set to 0.05. All analyses were conducted in IBM SPSS Statistics for Windows, Version 26.0.

3 | RESULTS

3.1 | Descriptive information

Descriptive statistics and change in all study variables are outlined in Table 1.

3.1.1 | Demographics

Participants who completed the intervention were predominantly female (61.9%; $n = 26$) were an average age of 41.0 years old (SD = 14.2) and had an average baseline BMI of 25.2 (overweight; SD = 4.9). A majority of participants were White (64.3%; $n = 27$), with fewer being Asian (11.9%; $n = 5$), biracial (11.9%; $n = 5$), or reporting another race (4.8%; $n = 2$) or not reporting race (7.1%; $n = 3$). Few participants were Hispanic/Latino (9.5%; $n = 4$). Over half of participants had a graduate degree (50.0%; $n = 21$) or a 4-year undergraduate degree (33.3%; $n = 14$), and fewer had a 2-year undergraduate degree (11.9%; $n = 5$), some college completion (2.4%; $n = 1$), or a high school diploma (2.4%; $n = 1$). Most participants were either currently married (47.6%; $n = 20$) or never married (40.5%; $n = 17$); few participants were divorced (7.1%; $n = 3$) or separated (2.4%; $n = 1$).

3.1.2 | Stress

As measured by the DASS, stress reactivity was mild to moderate at T1 and remained similar between T1 and T2 and between T2 and T3. However, decreases in stress reactivity were moderate from T1 to T3. Perceived stress as measured by the PSS declined over timepoints, but these small effect sizes were not statistically significant.

3.1.3 | Mechanisms

Mindfulness was similar at T1 and T2 and increased slightly between T2 and T3 and between T1 and T3. Interoceptive awareness greatly increased from T1 to T2 and remained similar between T2 and T3; increases between T1 and T3 were large and similar to the observed increases between T1 and T2. Spiritual well-being increased with only small effect sizes from T1 to T2 and remained similar between T2 and T3; increase between T1 and T3 were moderate. Self-compassion remained statistically unchanged at T1, T2 and T3. Self-control also remained similar at T1, T2 and T3, with a small statistically significant increase from T1 to T3.

3.1.4 | Differences in study variables by research site and cohort

Regarding differences in study variables between research site and cohort, only baseline self-control differed by research site, in that the rural site ($M = 46.5$, SD = 8.5) reported significantly greater

self-control than the urban site ($M = 39.6$, SD = 5.7), F (1,39) = 8.5, $p = 0.006$. No study variables differed by cohort.

3.2 | Cross-sectional correlations among mechanisms and stress at baseline

3.2.1 | Intercorrelation of mechanisms with stress

Stress reactivity and perceived stress (as measured by DASS-21 and PSS, respectively) were strongly correlated at T1 ($r = 0.72$, $p < 0.001$). Higher perceived stress was related to lower levels of most psychosocial mechanisms: mindfulness ($r = -0.59$, $p < 0.001$), spiritual well-being ($r = -0.47$, $p = 0.002$), self-compassion ($r = -0.63$, $p < 0.001$) and self-control ($r = -0.45$, $p = 0.004$), but was not significantly related to interoceptive awareness ($p = 0.24$). Associations with stress reactivity were similar for mindfulness ($r = -0.42$, $p = 0.007$), self-compassion ($r = -0.47$, $p = 0.002$) and self-control ($r = -0.33$, $p = 0.04$), but stress reactivity was not significantly related to interoceptive awareness or spiritual well-being at T1 (p's > 0.10).

3.2.2 | Intercorrelation of mechanisms

Mindfulness was positively associated with spiritual well-being ($r = 0.58$, $p < 0.001$), self-compassion ($r = 0.77$, $p < 0.001$) and self-control at T1 ($r = 0.50$, $p = 0.001$). Spiritual well-being was also positively associated with self-compassion ($r = 0.54$, $p < 0.001$) and self-control ($r = 0.38$, $p = 0.02$). Self-compassion was positively correlated with self-control ($r = 0.43$, $p = 0.005$). Interoceptive awareness was only marginally positively related to self-compassion ($r = 0.31$, $p = 0.052$). No other relationships were statistically significant (p's > 0.14).

3.3 | Intercorrelation of residual change in mechanisms and stress

3.3.1 | Intercorrelation of changes in mechanisms

As shown in Table 2, many inter-correlations between residual changes in mechanisms from T1 to T2 were noted: increases in self-compassion were associated with increases in mindfulness, interoceptive awareness and spiritual well-being. Increases in spiritual well-being also correlated with increases in self-control. Increases in mindfulness and interoceptive awareness were marginally positively associated ($p = 0.053$).

3.3.2 | Intercorrelation of changes in stress

As shown in Table 3, decreases in perceived stress were strongly associated with decreases in stress reactivity from T1 to T2, T2 to T3 and T1 to T3. Decreases in perceived stress from T1 to T3 were also strongly associated with decreases in stress reactivity from T2 to T3, and vice versa, decreases in stress reactivity from T1 to T3 were strongly associated with decreases in perceived stress from T2 to T3. Residual changes in neither stress measure from T1 to T2 were associated with changes in the other from T2 to T3 or T1 to T3.

TABLE 2 Inter-correlations between residual changes in psychosocial mechanisms from T1 to T2

T1–T2	1	2	3	4
1. Mindfulness (FFMQ-SF)	1.00	-	-	-
2. Interoceptive awareness (MAIA)	0.33	1.00	-	-
3. Spiritual well-being (FACIT-Sp)	0.17	0.26	1.00	-
4. Self-compassion (SCS-SF)	**0.55****	**0.45****	**0.34***	1.00
5. Self-control (BSCS)	0.30	0.12	**0.33***	0.09

Note: Bolded values indicate $p < 0.05$.

Abbreviations: BSCS, Brief Self-Control Scale; FACIT-Sp, Functional Assessment of Chronic Illness Therapy—Spiritual Well-Being; FFMQ-SF, Five-Facet Mindfulness Questionnaire, short form; MAIA, Multidimensional Assessment of Interoceptive Awareness Scale; SCS-SF, Self-Compassion Scale-short form.

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

TABLE 3 Inter-correlations between residual changes in stress

	Stress reactivity (DASS)		
Perceived stress (PSS)	T1–T2	T2–T3	T1–T3
T1–T2	**0.60*****	0.11	0.30
T2–T3	−0.09	**0.52****	**0.48****
T1–T3	0.30	**0.49****	**0.60*****

Note: Bolded values indicate $p < 0.05$.

Abbreviations: DASS, Depression Anxiety Stress Scale; PSS, Perceived Stress Scale.

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

3.3.3 | Intercorrelation of changes in mechanisms with changes in stress

As shown in Table 4, residual increases from T1 to T2 in all psychosocial mechanisms except self-control were significantly associated with residual decreases in both stress reactivity and global perceived stress from T1 to T2. The correlation between T1–T2 residual change in spiritual well-being and T1–T2 change in stress was greater for perceived stress than for stress reactivity. Residual changes in mechanisms from T1 to T2 were not associated with residual changes in stress reactivity or perceived stress from T2 to T3. For perceived stress, associations between T1 to T2 changes in mechanisms and T1 to T3 changes in stress followed the same pattern of statistical significance as did correlations with T1 to T2 changes in perceived stress (i.e., all residual change scores were

TABLE 4 Associations between post-intervention changes in PSS and DASS and changes in proposed mechanisms

	T1–T2			T2–T3			T1–T3		
T1–T2	PSS	DASS	PSS versus DASS *Z*-score (*p*)	PSS	DASS	PSS versus DASS *Z*-score (*p*)	PSS	DASS	PSS versus DASS *Z*-score (*p*)
Mindfulness (FFMQ-SF)	**−0.45****	**−0.40***	−0.4 (0.70)	−0.17	−0.03	−0.9 (0.37)	**−0.42***	−0.13	**−2.1 (0.04)***
Interoceptive awareness (MAIA)	**−0.41***	**−0.42****	0.1 (0.92)	−0.14	−0.16	0.2 (0.87)	**−0.38***	−0.32	−0.4 (0.66)
Spiritual well-being (FACIT-Sp)	**−0.63*****	**−0.38***	**−2.1 (0.03)***	0.02	−0.02	0.3 (0.77)	**−0.38***	−0.12	−1.9 (0.06)
Self-compassion (SCS-SF)	**−0.64*****	**−0.73*****	0.9 (0.35)	−0.07	−0.18	0.7 (0.47)	**−0.50****	**−0.40***	−0.8 (0.45)
Self-control (BSCS)	−0.25	−0.16	−0.6 (0.53)	−0.06	0.05	−0.7 (0.49)	−0.13	0.08	−1.5 (0.14)

Note: Bolded values indicate $p < 0.05$.

Abbreviations: BSCS, Brief Self-Control Scale; DASS, Depression Anxiety Stress Scale; PSS, Perceived Stress Scale; FACIT-Sp, Functional Assessment of Chronic Illness Therapy—Spiritual Well-Being; FFMQ-SF, Five-Facet Mindfulness Questionnaire, short form; MAIA, Multi-dimensional Assessment of Interoceptive Awareness Scale; SCS-SF, Self-Compassion Scale-short form.

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

significantly associated, excepting self-control). In contrast, only T1 to T2 change in self-compassion was significantly associated with T1–T3 change in stress reactivity. The correlations between T1–T2 residual change in mindfulness and T1–T3 change in stress were greater for perceived stress than for stress reactivity.

4 | DISCUSSION

These results advance yoga intervention research by providing essential information on psychological mechanisms through which yoga practice may reduce perceived stress. Most importantly, we demonstrate the usefulness of examining psychosocial mechanisms of change in a clinical trial and provide potentially fruitful direction for future research to build on the current evidence base regarding yoga and stress.

First, while stress reactivity and perceived stress are fairly strongly related, we found different patterns of yoga's effects on these two outcomes. Although both aspects of stress declined across the intervention timepoints, only the reduction in stress reactivity was statistically significant across the entire sample. Yet, generally, we found stronger associations of within-person changes in psychosocial resources with perceived stress than with stress reactivity, suggesting that cognitive/emotional aspects of stress may be most directly linked to the proposed 'active ingredients' of a yoga intervention.

Such differential findings may also be related to the type of yoga that we tested. Kripalu yoga emphasizes a self-compassionate stance towards stressful experience, such that participants are encouraged to non-judgmentally attend to and accept stressful experience while using breathwork and postures to regulate the effects of stress on well-being (Faulds, 2005). Future research might compare different yoga interventions that are optimized more for reactivity or perceived stress to determine differential effects. For example, an intervention encouraging participants to direct attention away from stressful experience or reappraise perceptions of events as less stressful might have stronger effects on perceptions of stress than on stress reactivity. These findings also suggest that researchers should be more explicit about the type of stress that they are intent on studying and may usefully inform future systematic reviews and meta-analyses, which might find differential effects for yoga on different dimensions of stress.

Second, all of the psychological resources included here increased over the course of the intervention, as we would expect based on previous research (e.g., Büssing et al., 2012; Dick et al., 2014; DiGreeson et al., 2011; Gard et al., 2012; Mehling et al., 2018; Park et al., 2018). The exception to this general trend was self-compassion, which did not significantly increase over the course of the intervention, in contrast to prior yoga studies (e.g., Gard et al., 2012). All of these increases became larger—and several only then large enough to be statistically significant at T3—suggesting that length of practice has a meaningful influence on steady change in psychological resources. In the present study, interoceptive awareness demonstrated by far the largest effect size from pre-to post-intervention ($d = 0.98$); in contrast, mindfulness, self-compassion and self-control all demonstrated only small effect sizes (ds = 0.28, 0.28 and 0.29). Future studies will benefit from examining change in these same proposed psychosocial mechanisms following different types of yoga (e.g., Bikram, restorative), since it is likely that different practices will have very different effects on psychosocial mechanisms and change in perceived stress and stress reactivity (Park, Finkelstein-Fox, Groessl, Lee, & Elwy, 2020). Changes in psychological responses to stress (i.e., mindfulness, self-compassion and self-control) may occur on different temporal schedules or over longer periods of regular yoga practice than that involved in the present study while attention to internal states (i.e., interoceptive awareness) changes more quickly. It will be very interesting for future research to examine change in mindfulness, self-compassion and self-control after a longer period of regular yoga practice, particularly among a non-clinical sample of novice practitioners like the one included here.

Of note, the results reported here suggest that most of the hypothesized mechanisms demonstrated patterns of change concurrent with, rather than prior to, changes in stress. This finding highlights an important distinction between Kripalu yoga's utility as a stress management resource versus a standalone clinical intervention. Even a single session of yoga practice has demonstrated significant pre–post effects on positive and negative affective experience (Park et al., 2020), and regular, repeated yoga practice has been associated with positive stress-related outcomes (Gard et al., 2014; Greenberg et al., 2018). In contrast to talk-based cognitive behavioural therapies that provide explicit discussion of disordered emotion regulation abilities (Hofmann, Sawyer, Fang, & Asnaani, 2012), mechanisms of yoga interventions such as Kripalu may act much more quickly upon perceptions of acute stress by directing non-judgemental attention towards physical experience, and thus require different methods of assessing change in real time (e.g., ecological momentary assessment, measurement of affective states pre- and post-practice). Future research on yoga interventions will benefit from creative measurement of individual variation in cognitions, affect and stress reactivity.

Third, change in all of the proposed mechanisms, with the exception of self-control, closely paralleled change in stress. In general, the synchrony of the mechanisms with perceived stress was especially strong, although change in self-compassion was particularly closely related to change in stress reactivity. Despite some patterns of statistically significant associations between change in mechanisms and perceived stress contrasting non-significant associations between change in mechanisms and stress reactivity, we had low power to detect statistically significant differences in effect sizes for either stress measure. As such, the possibility of meaningfully different patterns of association between mechanisms and distinct stress outcomes warrants further examination in future research with larger sample sizes and lower drop-out rates. Still, despite our small sample size, change in two mechanisms (spiritual well-being and mindfulness) at mid-treatment had significantly stronger ties to change in perceived stress mid- and post-treatment, respectively. Thus, while a number of associations were non-significant for both stress measures, these two 'active ingredients' may be most important for interventions targeting perceived stress rather than stress reactivity. It is also possible that interventions targeting either stress measure may benefit from incorporating other potential mechanisms not measured here (e.g., physical fitness, breathwork).

Finally, by examining the associations between changes in multiple mechanisms over time, we also highlight the extent to which various psychosocial resources relate during the course of a mindful yoga intervention. For example, results suggest that self-compassion and mindfulness may change at a similar rate, whereas changes in mindfulness and self-control or spiritual well-being may follow different patterns of change across a 12-week yoga intervention. These preliminary findings may have implications for the design of larger clinical trials targeting psychosocial mechanisms of change in stress; it will be particularly interesting for future studies to test the associations between distinct but related variables such as self-compassion and interoceptive awareness over multiple timepoints to parse apart causal or lagged associations between these constructs.

Limitations of our study must be acknowledged. We do not have a control group against which we could compare our findings, although determining the extent to which stress and psychosocial resources changed over time independently of the yoga intervention would be valuable. The strongest design would be an active comparison arm that controlled for non-specific effects, but even an assessment-only group would allow ruling out temporal or seasonal effects (Park et al., 2014). Our study was also underpowered to detect longitudinal effects of smaller magnitude due to a high non-completion rate and participant scheduling difficulties; it is likely that a larger sample would have elucidated more reliable changes in both stress and psychological resources and provided more generalizable findings. Our measures were all self-report and thus liable to all the biases inherent in self-report measures (Paulhus & Vazire, 2007). Excluding individuals with a current psychiatric diagnosis may have reduced the range of stress we would have been able to measure had we not had that inclusion criterion. Furthermore, our set of psychological resources, while broad, likely leaves out other important psychological resources that may be important mechanisms of yoga's effects on stress. In addition, we tested only one type of yoga; different types of yoga may have different effects on stress and resources. Furthermore, our findings were only associative, and thus causal inferences cannot be definitively made.

Although these many limitations render our findings suggestive rather than conclusive, they provide direction for subsequent research aimed at better understanding how yoga exerts salutary effects on stress. Future research should examine each of the potential mechanisms identified in the present study, as all five showed significant increases over time and four demonstrated significant roles within the hypothesized pathways linking yoga and stress. Clinical trials to test these pathways should be fully powered and include a strong comparison condition to verify them. Testing different types of yoga with different emphases may further illuminate which aspects of yoga exert stronger effects on specific psychological resources.

These results may have clinical implications for yoga therapists as well as other healthcare providers aiming to reduce stress. Given the different patterns demonstrated in our data, therapists treating stress-related complaints might consider the different kinds of impact that psychological resources have on perceived stress and stress reactivity, which have the potential to inform treatment planning and even intervention optimization for highly stressed populations.

Although tentative, our results suggest that Kripalu yoga may have beneficial effects for positive psychological resources such as interoceptive awareness, mindfulness, spiritual well-being and self-compassion, all of which may have temporal effects on within-person change in perceived stress over time. Further, experiences of stress reactivity appear to decline significantly over the course of a mindful yoga intervention, suggesting that Kripalu yoga may be especially beneficial for individuals experiencing marked arousal and over-reactions to stress exposure. Given increasing evidence of yoga's

effects on stress, future research may build on these results to better understand the specific pathways through which different aspects and types of yoga can reduce different types of stress, ultimately leading the way to personalized yoga interventions for stress reduction.

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AUTHOR CONTRIBUTIONS

All authors contributed to the conceptualization, implementation, data interpretation, writing and editing of the paper. Shane Sacco conducted the formal data analysis.

CONFLICT OF INTEREST

The authors have declared that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available to any qualified researcher from the corresponding author, Crystal L. Park upon request.

ORCID

Crystal L. Park https://orcid.org/0000-0001-6572-7321

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