International Journal of Psychophysiology 87 (2013) 147–151

Contents lists available at SciVerse ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Do not worry, be mindful: Effects of induced worry and mindfulness on respiratory variability in a nonanxious population

Elke Vlemincx [a,*], Daniel Vigo [a,b,c], Debora Vansteenwegen [d,e], Omer Van den Bergh [a], Ilse Van Diest [a]

[a] Research Group on Health Psychology, University of Leuven, Leuven, Belgium
[b] Departamento de Docencia e Investigación, Universidad Católica Argentina, Buenos Aires, Argentina
[c] Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Buenos Aires, Argentina
[d] Psychology of Learning and Experimental Psychopathology, University of Leuven, Leuven, Belgium
[e] ISW Limits, Kessel-Lo, Belgium

ARTICLE INFO

Article history:
Received 9 July 2012
Received in revised form 28 November 2012
Accepted 9 December 2012
Available online 22 December 2012

Keywords:
Worry
Mindfulness
Respiratory variability

ABSTRACT

Generalized anxiety disorder (GAD) is characterized by chronic worry. Mindfulness-based stress reduction is thought to remediate excessive worry, because it counteracts a permanent defense state of enhanced vigilance to potential threats. The present study aimed to compare respiratory variability (RV) during worry and mindfulness. Following an 8-minute baseline, 37 healthy participants underwent 11-min worry and mindfulness inductions, in randomized order, using auditory scripts. Respiration was measured by chest and abdominal inductance belts. RV was quantified by (1) autocorrelation to assess linear breathing variability and (2) sample entropy to assess nonlinear breathing variability. Compared to baseline and mindfulness, worry showed decreased autocorrelation in all respiratory parameters and compared to mindfulness, worry showed decreased entropy in respiratory rate. These results suggest that, in contrast to mindfulness, worry is characterized by decreased respiratory stability and flexibility, and therefore worry and mindfulness seem to have countering effects on RV and respiratory regulation.

1. Introduction

A key feature of GAD is excessive worry (Andrews et al., 2010). Worry has been defined as a "chain of relatively uncontrollable, negative-affect laden thoughts and images" (Borkovec et al., 1983), involving continued hypervigilance to internal and external cues signaling future danger in order to mentally avoid the anxiously anticipated danger (Borkovec, 2002). While continuously detecting and interpreting threat, defensive fight/flight reactions are engaged in order to escape or attack the threat. Whereas acute worry may act as an adaptive defensive reaction to alarm, prompt and prepare for danger (Tallis and Eysenck, 1994), chronic worry is maladaptive. Brosschot (2010) conceptualizes worry as unconscious and conscious perseverative cognitions, characterized by repeated or chronic activation of cognitive representations of one or more psychological stressors. Because not only threat, but also mental representations of threat elicit defensive fight/flight responses, perseverative cognitions involve a prolonged state of action readiness, not only during the presence of a stressor, but also in far anticipation of the stressor, during recovery from the stressor, and during recurrent episodes of past stressors (Brosschot, 2010; Brosschot et al., 2005, 2010). Accordingly, Thayer and Lane (2000) have advanced a neurophysiological account for perseverative cognition. Whereas disinhibition of prefrontal inhibitory control allows flexible responding to threat by engaging defensive flight/fight responses and prefrontal inhibitory control dominates in the absence of threat, perseverative cognitions are marked by disrupted prefrontal inhibitory control resulting in a permanent defensive activation. Consequently, a worry state is characterized by prolonged physiological activation in the absence of stress or threat. In line with this, perseverative cognitions are associated with increased cortisol and immunoglobulin, elevated blood pressure, increased heart rate and lower heart rate variability during anticipation of stressors and during recovery from stress (for an overview see Brosschot et al., 2006). Moreover, increased autonomic activity during stress and worry is mediated by worry and duration of worry episodes, and these relations are not only found during an awake state, but also during sleep (Brosschot et al., 2010). In addition, high chronic worriers show not only a greater cardiac defense response during contextual fear rather than cued fear, but additionally show reduced respiratory sinus arrhythmia and increased respiration rate due to decreased expiratory time during rest (Delgado et al., 2009). In line with this finding, several studies have consistently demonstrated reduced parasympathetic activity to be a stable disposition in high worriers (Hofmann et al., 2005; Thayer et al., 1996; Thayer and Brosschot, 2005).

* Corresponding author at: Tiensestraat 102 Box 3726, B-3000 Leuven, Belgium. Tel.: +32 16 325994; fax: +32 16 326144.
E-mail address: elke.vlemincx@ppw.kuleuven.be (E. Vlemincx).

0167-8760/$ – see front matter
http://dx.doi.org/10.1016/j.ijpsycho.2012.12.002

Conceptually, worry shows great overlap with mindfulness, as both seem opposites on several dimensions (Borkovec, 2002; Roemer and Orsillo, 2002). Whereas worry is characterized by continued anxious anticipation of future and recurrent past events in order to cognitively avoid danger and uncertainty is not acceptable in this, mindfulness focuses on nonjudgmental openness and acceptance of present internal and external experiences as they are, by self-regulating attention towards the present (Baer, 2003; Delgado et al., 2010). Therefore, mindfulness has been proposed as a stress reduction method to remediate a permanent defense state of high vigilance to and avoidance of threat, as is worry (Borkovec, 2002; Roemer and Orsillo, 2002; Roemer et al., 2009; Delgado et al., 2010). Confirming the usefulness of mindfulness to reduce worry, mindfulness training programs significantly improved anxiety and depression symptoms in GAD, which remained at 3-month follow up (Kabat-Zinn et al., 1992) and at 3-year follow up (Miller et al., 1995). Additionally, mindfulness increases emotional comprehension and reduces worry by decreasing the number and the duration of worry episodes and decreasing worry-related anxiety and depressive symptoms (Delgado et al., 2010).

Mindfulness also seems to counter worry physiologically. Mindfulness is characterized by lower respiration rate and heart rate, higher expiration time and heart rate variability whereas worry is characterized by higher respiration rate and heart rate, lower expiration time and heart rate variability (Delgado et al., 2010). Additionally, mindfulness training specifically reduces respiration rate during rest and worry compared to progressive muscle relaxation (Delgado et al., 2010).

Given the important countering influences of mindfulness training on worry in mean respiratory variables, the present study aims to further compare respiratory variability during worry and mindfulness. Various types of respiratory variability reflect stability and flexibility in the respiratory system. A stable yet flexible respiratory system, allowing responding to occasional threats and recovery to a dynamic steady state afterwards, is characterized by both nonrandom and random variability. Nonrandom fluctuations increase system stability by varying parameters over several lags to continuously determine the system's properties (Moser et al., 2006). Random fluctuations increase system flexibility or adaptability as they represent the system's ability to flexibly respond to environment changes (Goldberger, 1996). In other words, a normal or healthy respiratory system balances nonrandom variability ensuring respiratory stability and random variability warranting respiratory flexibility. In contrast, an unstable system that is not able to recover to a steady state is characterized by excessive random or irregular breathing, whereas an inflexible system that is rigidly controlled not allowing flexible responding to perturbations is characterized by nonvariable or periodic breathing (Bruce, 1996). One way to restore a healthy balance between nonrandom and random variability is to sigh (Vlemincx et al., 2010). Sighs have not only been proposed to function as physiological resetters, but also as psychological resetters, serving as a coping mechanism during negative emotional states (Vlemincx et al., 2011, 2012).

Because worry involves persistent defensive responding in the absence of immediate danger or threat, we predict that respiration will be dominated one-sided by cognitive and affective perturbations overriding autonomic control, resulting in an inflexible and unstable respiratory system exhibiting decreased random variability and decreased nonrandom variability. In addition, we predict that the perseverative nature of worry inhibits temporary resetting and therefore no increased sigh rates will occur during this specific negative emotional state. In contrast, because mindfulness is characterized by a complex state of self-regulation and effective coping and control, we predict that respiratory regulation will reflect integrated autonomic control in the light of cognitive and affective perturbations, resulting in increased random breathing variability while maintaining nonrandom variability reflecting a flexible yet stable respiratory system.

Instructing nonanxious individuals to worry about a theme that greatly concerns them reliably induces cognitive, physiological, affective and behavioral correlates of chronic worry or GAD (Borkovec, 2002). Therefore, the present study will investigate respiratory variability during a single worry episode induced by worry instructions in a nonanxious population, and compare respiratory variability to a single mindfulness session based on focused breathing instructions.

2. Materials and methods

2.1. Participants

Thirty-seven individuals (5 men, age range 18–20) participated in the study in exchange for course credits. Participants reported to be in good health and not to suffer from any current respiratory or cardiac disease. The experiment was approved by the Ethics Committees of the Department of Psychology and of the Faculty of Medical Sciences.

2.2. Apparatus

Respiration was measured continuously by means of respiratory inductive plethysmography (RIP), using the LifeShirt System® (Vivometrics Inc., Ventura, CA; Wilhelm et al., 2003) to assess respiratory rate and relative tidal volume. Two inductance belts at the level of the ribcage and the abdomen, sewn into a LifeShirt garment, were connected to a digital processing unit, including a data storage card. Vivologic software (Vivometrics Inc., Ventura, CA) was used to edit raw respiratory data. Although respiratory plethysmography does not provide accurate absolute tidal volumes, this was of less concern since the study focused on relative changes across conditions within subjects.

2.3. Measures

2.3.1. Subjective measures

The emotional state of participants was assessed by means of 9-point self-assessment manikin (SAM) scales of valence, arousal and dominance (Bradley and Lang, 1994). For research purposes beyond the scope of this paper, relaxation was measured using the Smith Relaxation States Survey (SRSS, Smith, 2001) and social desirability was measured by the Dutch version of the Marlow-Crowne Social Desirability scale (Nederhof, 1981).

2.3.2. Mean respiratory parameters

Tidal volume (Vt), inspiratory (Ti) and expiratory time (Te), respiration rate ($RR = 60/Ti + Te$), minute ventilation ($V'E = VtxRR$) and percentage rib cage breathing (%RC) were derived from the raw respiratory signal and calculated breath-by-breath.

2.4. Procedure

Participants were individually invited to an experiment studying physiological effects of worry and focused breathing instructions. Before the experiment started, participants signed the informed consent form, the LifeShirt equipment was set up and participants were seated in a comfortable chair.

Following an 8-min baseline phase, participants underwent 11-min mindfulness and worry inductions, in randomized order. Participants were informed that during these various phases, the experimenter would leave the room, but would monitor them via cameras and microphones. During the baseline phase, participants were asked to sit quietly and silently while proper recording of all equipment was checked. The worry and mindfulness inductions consisted of auditory scripts presented through head phones, validated by and adapted from Arch and Craske (2006). Participants were instructed to listen carefully to the scripts. The mindfulness induction consisted of focused breathing instructions which were part of a mindfulness meditation exercise. Participants were instructed to focus their attention and awareness to the sensations they were experiencing, while specifically focusing on the actual sensation of breathing without thinking about it. The worry induction consisted of instructions to worry sequentially about social relations, achievement, money, safety, health and environment. Participants were instructed to worry about their primary personal worry or concern in each domain and to imagine the consequences when the worry or concern would become reality.

Following the baseline, worry and mindfulness phases, participants rated their emotional state and at the end of the experiment social desirability was assessed.

3. Data analysis

3.1. Measures of respiratory variability and sighing

Respiratory variability during the 8-min baseline period was compared to respiratory variability during the final 8-min of the 11-min mindfulness and worry inductions in order to obtain equal time intervals for all phases. Additionally, selecting the final 8 minutes of the mindfulness and worry inductions ensured that respiratory variability was assessed during a more progressed and profound state of mindfulness and worry while excluding the settling in phase. Respiratory variability during baseline, mindfulness and worry was computed for Vt, RR and V′E by both linear and nonlinear measures of variability.

Linear nonrandom variability was quantified by autocorrelation which assesses to which extent the respiratory controller is relying on recent past information to produce the current breath (Busha and Stella, 2002; Wysocki et al., 2006). To quantify this "short-term memory," the autocorrelation coefficient was calculated at one breath lag (AR, the correlation of the breath string during each phase with itself, shifted one breath lag) (Tobin et al., 1995).

Random breathing variability was quantified by the nonlinear variability index sample entropy (SampEn). Briefly, SampEn is the logarithmic probability that breathing sequences that are close to each other will remain close to each other in subsequent incremental comparisons. Regular sequences will result in lower SampEn values whereas random behavior is associated with larger SampEn values (Richman and Moorman, 2000). SampEn is a variant of Approximate Entropy (ApEn) with some statistical advantages since it does not count self-matches in the calculation. In addition, it is more appropriate for short length time series and has greater relative consistency (Richman and Moorman, 2000). Two parameters must be fixed a priori: m, the length of the sequence used in the comparison (usually, $m = 2$) and r, the threshold for accepting similarity between sequences (usually, $0.1 < r < 0.25$). However, usually suggested values for r may lead to biased results, and different r values should be considered (Chen et al., 2005). For this study we found that $r = 0.5$ leads to the maximum differentiation capability between states.

Finally, sigh rate during baseline, mindfulness and worry was calculated as the number of breaths within each phase with Vt at least twice as large as mean Vt during each phase.

3.2. Analysis

SAM ratings, mean respiratory parameters and respiratory variability measures were subjected to a repeated measures analysis with one within-subject variable "phase" distinguishing baseline, mindfulness and worry. Post hoc Tukey contrasts were tested to compare dependent variables between baseline, mindfulness and worry. To control for possible carryover effects of negative emotional states in the condition in which worry was induced before mindfulness, the variable order (worry-mindfulness vs. mindfulness-worry) was analyzed as an additional between-subject variable. Because main effects of order (all $F(1,35) < .90$, ns) and order by phase interaction effects (all $F(2,35) < 3.05$, ns) were not significant and did not change the results, only the analysis including phase effects only is reported.

4. Results

4.1. Subjective measures

Significant phase effects were found for valence ($F(2,72) = 45.76$, $p < .0001$, $\eta_p^2 = .56$), arousal ($F(2,72) = 18.50$, $p < .0001$, $\eta_p^2 = .34$) and dominance ($F(2,72) = 10.43$, $p < .01$, $\eta_p^2 = .22$). Post hoc contrasts revealed that worry elicited more unpleasantness, more arousal and less dominance compared to baseline ($p < .01$, $p < .05$, $p < .01$, respectively) and mindfulness (all $p < .01$). Mindfulness elicited lower arousal compared to baseline ($p < .01$).

4.2. Mean respiratory parameters

Except for V′E ($F(2,72) = 1.33$, ns), phase effects are found for all mean respiratory variables: Vt ($F(2,72) = 10.83$, $p < .0001$, $\eta_p^2 = .23$), RR ($F(2,72) = 6.16$, $p < .01$, $\eta_p^2 = .15$), Ti ($F(2,72) = 16.33$, $p < .0001$, $\eta_p^2 = .31$), Te ($F(2,72) = 3.50$, $p < .05$, $\eta_p^2 = .09$), %RC ($F(2,72) = 5.13$, $p < .01$, $\eta_p^2 = .12$). Post hoc Tukey comparisons show that Vt is significantly decreased during worry compared to baseline ($p < .01$) and mindfulness ($p < .01$), whereas RR is significantly increased during worry compared to baseline ($p < .01$) and mindfulness ($p < .05$). Ti and Te are significantly decreased during worry compared to baseline ($p < .01$, $p < .05$, respectively), and Ti is significantly decreased during worry compared to mindfulness ($p < .01$). These results suggest that worry is characterized by shallow, rapid breathing. No differences in %RC are found between baseline and worry, but %RC is significantly lower during mindfulness compared to baseline and worry ($p < .01$), suggesting that abdominal breathing increases during mindfulness.

4.3. Measures of respiratory variability

AR measures show significant phase effects for AR(Vt) ($F(2,72) = 14.14$, $p < .0001$, $\eta_p^2 = .28$), AR(RR) ($F(2,72) = 8.34$, $p < .01$, $\eta_p^2 = .19$) and AR(V′E) ($F(2,72) = 9.24$, $p < .01$, $\eta_p^2 = .20$) (Fig. 1). Tukey comparisons show decreased AR during worry compared to baseline and mindfulness for Vt, RR and V′E (all $p < .01$). No differences in AR are found between mindfulness and baseline. These results suggest that worry is specifically characterized by decreased linearly correlated variability in all respiratory parameters, whereas mindfulness cannot be distinguished from baseline based on linear variability measures.

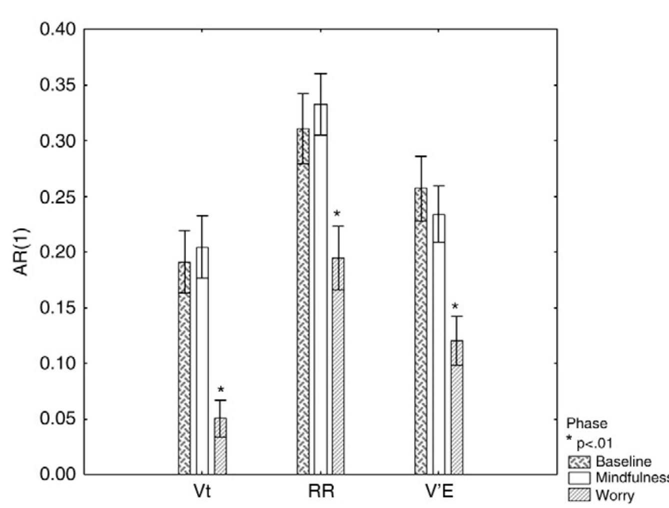

Fig. 1. Autocorrelation (AR(1)) as a measure of linearly correlated variability of tidal volume (Vt), respiratory rate (RR) and minute ventilation (V′E) during worry, mindfulness and baseline.

SampEn measures show significant phase effects for SampEn (Vt) ($F(2,72)=4.55$, $p<.05$, $\eta_p^2=0.11$) and SampEn (RR) ($F(2,72)=3.39$, $p<.05$, $\eta_p^2=0.09$), with no significant phase effects for SampEn (V′E). Tukey comparisons show decreased SampEn (Vt) during mindfulness ($p<.05$) and worry ($p<.05$) compared to baseline, and increased SampEn (RR) during mindfulness ($p<.05$) compared to worry. These results suggest that worry is specifically characterized by decreased nonlinear variability in Vt and RR, while mindfulness shows decreased nonlinear variability in Vt but increased nonlinear variability in RR.

For sigh rate, no significant phase effects are found ($F(2,72)=1.82$, ns).

5. Discussion

The present study compared respiratory variability measures during single episodes of experimentally induced worry and mindfulness in nonanxious individuals. Importantly, various measures of respiratory variability significantly distinguished between worry and mindfulness. Compared to mindfulness and baseline, worry was characterized by decreased linearly correlated variability in all respiratory parameters, suggesting a loss of "short-term respiratory memory" or reduced breathing stability during worry. Compared to worry, mindfulness showed higher nonlinear variability in respiratory rate, suggesting higher breathing flexibility during mindfulness than during worry. No differences in sigh rate were found between worry, mindfulness and baseline.

These results are in line with our hypotheses. Worry is characterized by a fight or flight state that uncontrollably persists, despite the unlikelihood of actual threat or danger. Respiratory responses during such maladaptive defense reaction are driven predominantly by behavioral, cognitive and affective inputs, such as behavioral and cognitive avoidance and anxious anticipation, and do not match with required metabolic needs which do not require change as no threat or danger is actually present. As a result, control processes are decoupled as their outcomes diverge and control systems, such as the respiratory system, become rigid and unstable. In contrast, mindfulness comprises complex cognitive (attentive), affective (nonjudgmental) and behavioral (acceptance) interactions with matching metabolic requirements. As a result, control processes are complexly integrated allowing control systems, such as the respiratory system, to be flexible and stable. In sum, these findings suggest that worry and mindfulness are opposites on the dimension of respiratory regulation: whereas worry is associated with decreased autocorrelation and decreased nonlinear variability representing an unstable and rigid respiratory system, mindfulness is associated with a stable yet flexible respiratory system reflected by high autocorrelation and nonlinear respiratory variability.

The current results are also consistent with the extensively replicated finding that heart rate variability is an important marker of worry, and maybe also of mindfulness. Whereas decreased heart rate variability is typical of worry indicating deficient prefrontal inhibitory control resulting in prolonged activation in the absence of threat or danger (Hofmann et al., 2005; Thayer et al., 1996; Thayer and Brosschot, 2005), mindfulness states induce increased heart rate variability (Delgado et al., 2010) indicating flexibility and adaptability in physiological functioning. This is in line with the present findings that worry elicits decreased autocorrelation and decreased nonlinear breathing, consistent with an unstable and rigid system and an active respiratory fight/flight response focusing rigidly on potential threats and dangers when these are very unlikely; while mindfulness entails high autocorrelation and nonlinear breathing variability consistent with high stability and flexibility in the respiratory system.

Given the conceptual overlap between worry and mindfulness, and chronic worry being the key feature in GAD, mindfulness components may add significantly to the treatment of GAD. Among the various anxiety disorders, treatment of GAD appears to be the most challenging, because the object of fear in GAD is diffuse and transient. Chronic worry involves nonspecific catastrophizing about a broad range of unlikely negative events in order to avoid these negative events (behavioral avoidance) and the distress they may cause (experiential avoidance) (Roemer and Orsillo, 2002). Therefore, a potential successful treatment needs to focus on exposure to worrisome cues and behavioral and experiential nonavoidance or engagement. Mindfulness potentially may be a good candidate, because it consists of focusing attention to the present and accepting present internal and external experiences without judgment (Roemer and Orsillo, 2002; Delgado et al., 2010). Roemer and Orsillo (2002) have proposed an acceptance based behavior therapy for GAD that includes mindfulness techniques. They have shown that this treatment reduces depression, anxiety and fear reports, experiential avoidance and severity of GAD posttreatment, at 3-month follow up (Roemer and Orsillo, 2007), and at 9-month follow up (Roemer et al., 2008). Additionally, this acceptance based treatment protocol increases acceptance of internal experiences and uncertainty, perceived control, emotion regulation and active engagement, compared to a waitlist control group at 3- and 9-month follow up (Treanor et al., 2011).

Grossman et al. (2004) performed a meta-analysis showing substantial effect sizes of mindfulness-based stress reduction programs for both nonclinical and clinical purposes, among which anxiety reduction, despite the limited number of qualified studies. However the specificity of these effects to mindfulness remain unclear and although various mechanisms of mindfulness techniques have been proposed (Baer, 2003), the potential mechanisms by which it may remediate anxiety and worry remain to be investigated (Rubia, 2009). In addition, the efficacy of mindfulness training for chronic worry or GAD through respiratory effects depends on the causal effects of dysregulation of the respiratory system on chronic health outcomes, for which evidence so far is scarce (Guazzi et al., 2007; Wysocki et al., 2006).

Although the main findings of the present study are in line with current theories on worry and mindfulness, some of the results need some further clarification. First, although the effects of worry and mindfulness on linear respiratory variability are consistent for all respiratory parameters, the effects on nonlinear variability appear to be parameter specific. Nonlinear variability only differentiates mindfulness from worry in the respiratory rate parameter, showing higher nonlinear variability in respiratory rate during mindfulness compared to worry. This finding is in line with the specificity of differential responses in respiratory timing during cognitive tasks (Evans et al., 2009). Several studies indicate that, among respiratory parameters, specifically respiratory time can change markedly upon stimulation of higher structures (Homma and Masaoka, 2008; Masaoka et al., 2005), and therefore differentiate between mindfulness and worry. In addition, results show that both worry and mindfulness, compared to baseline, show decreased nonlinear variability in the respiratory volume parameter. This result could be explained by the common task characteristics of the specific mindfulness and worry tasks used in this study, which both consist of focused attention to auditory instructions and some level of imagery.

Second, the finding that worry is associated with both decreased nonlinear respiratory variability and decreased autocorrelation may seem odd, since mostly high autocorrelation values are associated with low entropy or chaos values (Busha and Stella, 2002). However, low levels of chaotic oscillations may be associated with the loss of autocorrelation, as found in dynamic models for irregular neural spiking (Baier et al., 2000).

Finally, some limitations of the present study need to be acknowledged. First, an evenly distributed sample of males and females could possibly reveal gender differences in respiratory effects of mindfulness and worry. Second, the current findings are limited to single session investigations of worry and mindfulness and so, the effects of chronic worry and mindfulness training need further research. Third, the present study results are limited to the effects of instructed mindfulness and worry in a nonanxious population, and therefore the implications of mindfulness training on chronic worry and GAD need to be examined further. Fourth, the current study was limited to respiratory measures and the present subjective ratings did not sufficiently assess various worry and mindfulness dimensions to examine which cognitive, affective, behavioral or other physiological factors characterize worry and mindfulness and therefore could account for the effectiveness of mindfulness training in chronic worry or GAD. Future research could focus on unraveling which mechanisms underlie reductions in worry and anxiety by mindfulness training. Overall, the present findings suggest that the countering respiratory effects of worry and mindfulness may be an interesting link to explore in the context of anxiety disorders such as GAD.

Acknowledgments

This research was partially funded by IWT (Flemish government agency for Innovation by Science and Technology) through the SME innovation project 080785 of ISW Limits. Elke Vlemincx is a Postdoctoral Fellow of the Research Foundation — Flanders (FWO). Daniel Vigo is supported by a grant from the Agencia Nacional de Promoción Científica y Tecnológica, Argentina (ANPCyT) (PICT 2010-1465). The authors thank Paulien Haesen for assisting with the data collection.

References

Andrews, G., Hobbs, M.J., Borkovec, T.D., Beesdo, K., Craske, M.G., Heimberg, R.G., Rapee, R.M., Ruscio, A.M., Stanley, M.A., 2010. Generalized worry disorder: a review of DSM-IV generalized anxiety disorder and options for DSM-V. Depression and Anxiety 27, 134–147.

Arch, J.J., Craske, M.G., 2006. Mechanisms of mindfulness: emotion regulation following a focused breathing induction. Behaviour Research and Therapy 44, 1849–1858.

Baer, R.A., 2003. Mindfulness training as a clinical intervention: a conceptual and empirical review. Clinical Psychology: Science and Practice 10, 125–143.

Baier, G., Escalera Santos, G.J., Perales, H., Rivera, M., Müller, M., Leder, R., Parmananda, P., 2000. Self-exciting chaos as a dynamic model for irregular neural spiking. Physical review. E, Statistical physics, plasmas, fluids, and related interdisciplinary topics 62 (6), R7579–R7582.

Borkovec, T.D., 2002. Life in the future versus life in the present. Clinical Psychology: Science and Practice 9, 76–80.

Borkovec, T.D., Robinson, E., Pruzinsky, T., Depree, J.A., 1983. Preliminary exploration of worry: some characteristics and processes. Behaviour Research and Therapy 21, 9–16.

Bradley, M.M., Lang, P.J., 1994. Measuring emotion: the self-assessment manikin and the semantic differential. Journal of Behavior Therapy and Experimental Psychiatry 25, 49–59.

Brosschot, J.F., 2010. Markers of chronic stress: prolonged physiological activation and (un)conscious perseverative cognition. Neuroscience and Biobehavioral Reviews 35, 46–50.

Brosschot, J.F., Pieper, S., Thayer, J.F., 2005. Expanding stress theory: prolonged activation and perseverative cognition. Psychoneuroendocrinology 30, 1043–1049.

Brosschot, J.F., Gerin, W., Thayer, J.F., 2006. The perseverative cognition hypothesis: a review of worry, prolonged stress-related physiological activation, and health. Journal of Psychosomatic Research 60, 113–124.

Brosschot, J.F., Verkuil, B., Thayer, J.F., 2010. Conscious and unconscious perseverative cognition: is a large part of prolonged physiological activity due to unconscious stress? Journal of Psychosomatic Research 69, 407–416.

Bruce, E.N., 1996. Temporal variations in the breathing pattern. Journal of Applied Physiology 80 (4), 1079–1087.

Busha, B.F., Stella, M.H., 2002. State and chemical drive modulate respiratory variability. Journal of Applied Physiology 93, 685–696.

Chen, X., Solomon, I., Chon, K., 2005. Comparison of the use of approximate entropy and sample entropy: applications to neural respiratory signal. Conference proceedings: Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society 4, 4212–4215.

Delgado, L.C., Guerra, P., Perakakis, P., Mata, J.L., Pérez, M.N., Vila, J., 2009. Psychophysiological correlates of chronic worry: cued versus non-cued fear reaction. International Journal of Psychophysiology 74, 280–287.

Delgado, L.C., Guerra, P., Perakakis, P., Vera, M.N., del Paso, G.R., Vila, J., 2010. Treating chronic worry: psychological and physiological effects of a training programme based on mindfulness. Behaviour Research and Therapy 48, 873–882.

Evans, K.C., Dougherty, D.D., Schmid, A.M., Scannell, E., McCallister, A., Benson, H., Dusek, J.A., Lazar, S.W., 2009. Modulation of spontaneous breathing via limbic/paralimbic-bulbar circuitry: an event-related fMRI study. NeuroImage 47 (3), 961–971.

Goldberger, A.L., 1996. Non-linear dynamics for clinicians: chaos theory, fractals and complexity at the bedside. Lancet 347, 1312–1314.

Grossman, P., Niemann, L., Schmidt, S., Walach, H., 2004. Mindfulness-based stress reduction and health benefits: a meta-analysis. Journal of Psychosomatic Research 57, 35–43.

Guazzi, M., Raimondo, R., Vicenzi, M., Arena, R., Proserpio, C., Sarzi Braga, S., Pedretti, R., 2007. Exercise oscillatory ventilation may predict sudden cardiac death in heart failure patients. Journal of the American College of Cardiology 50 (4), 299–308.

Hofmann, S.G., Moscovitch, D.A., Litz, B.T., Kim, H.J., Davis, L.J., Pizzagalli, D.A., 2005. The worried mind: autonomic and prefrontal activation during worry. Emotion 5, 464–475.

Homma, I., Masaoka, Y., 2008. Breathing rhythms and emotions. Experimental Physiology 93 (9), 1011–1021.

Kabat-Zinn, J., Massion, A.O., Kristeller, J., Peterson, L.G., Fletcher, K.E., Pbert, L., Lenderking, W.R., Santorelli, S.F., 1992. Effectiveness of a meditation-based stress reduction program in the treatment of anxiety disorders. The American Journal of Psychiatry 149, 936–943.

Masaoka, Y., Koiway, N., Homma, I., 2005. Inspiratory phase-locked alpha oscillation in human olfaction: source generators estimated by a dipole tracing method. The Journal of Physiology 566 (3), 979–997.

Miller, J.J., Fletcher, K., Kabat-Zinn, J., 1995. Three-year follow-up and clinical implications of a mindfulness meditation-based stress reduction intervention in the treatment of anxiety disorders. General Hospital Psychiatry 17, 192–200.

Moser, M., Frühwirth, M., Penter, R., Winker, R., 2006. Why life oscillates: from a topographical towards a functional chronobiology. Cancer Causes & Control 17 (4), 591–599.

Nederhof, A.J., 1981. Beter Onderzoek: Bestrijding van foutenbronnen in sociaal-wetenschappelijk onderzoek. VUGA-Uitgeverij, s Gravenhage.

Richman, J.S., Moorman, J.R., 2000. Physiological time-series analysis using approximate entropy and sample entropy. American Journal of Physiology. Heart and Circulatory Physiology 278 (6), 2039–2049.

Roemer, L., Orsillo, S.M., 2002. Expanding our conceptualization of and treatment for generalized anxiety disorder: integrating mindfulness/acceptance-based approaches with existing cognitive behavioral models. Clinical Psychology: Science and Practice 9, 54–68.

Roemer, L., Orsillo, S.M., 2007. An open trial for an acceptance-based behavior therapy for generalized anxiety disorder. Behavior Therapy 38, 72–85.

Roemer, L., Orsillo, S.M., Salters-Pedneault, K., 2008. Efficacy of an acceptance-based behavior therapy for generalized anxiety disorder: evaluation in a randomized controlled trial. Journal of Consulting and Clinical Psychology 76 (6), 1083–1089.

Roemer, L., Lee, J.K., Salters-Pedneault, K., Erisman, S.M., Orsillo, S.M., Mennin, D.S., 2009. Mindfulness and emotion regulation difficulties in Generalized Anxiety Disorder: preliminary evidence for independent and overlapping contributions. Behavior Therapy 40, 142–154.

Rubia, K., 2009. The neurobiology of meditation and its clinical effectiveness in psychiatric disorders. Biological Psychology 82, 1–11.

Smith, J.C., 2001. Advances in ABC relaxation: Application and inventories. Springer Publishing Company, New York, NY.

Tallis, F., Eysenck, M.W., 1994. Worry: mechanisms and modulating influences. Behavioural and Cognitive Psychotherapy 22, 37–56.

Thayer, J.F., Brosschot, J.F., 2005. Psychosomatics and psychopathology: looking up and down from the brain. Psychoneuroendocrinology 30 (10), 1050–1058.

Thayer, J.F., Lane, R.D., 2000. A model of neurovisceral integration in emotion regulation and dysregulation. Journal of Affective Disorders 61, 201–216.

Thayer, J.F., Friedman, B.H., Borkovec, T.D., 1996. Autonomic characteristics of generalized anxiety disorder and worry. Biological Psychiatry 39, 255–266.

Tobin, M.J., Yang, K.L., Jubran, A., Lodato, R.F., 1995. Interrelationship of breath components in neighboring breaths of normal eupneic subjects. American Journal of Respiratory and Critical Care Medicine 152, 1967–1976.

Treanor, M., Erisman, S.M., Salters-Pedneault, K., Roemer, L., Orsillo, S.M., 2011. Acceptance-based behavioural therapy for GAD: effects on outcomes from three theoretical models. Depression and Anxiety 28, 127–136.

Vlemincx, E., Van Diest, I., Lehrer, P.M., Aubert, A.E., Van den Bergh, O., 2010. Respiratory variability preceding and following sighs: a resetter hypothesis. Biological Psychology 84, 82–87.

Vlemincx, E., Taelman, J., De Peuter, S., Van Diest, I., Van den Bergh, O., 2011. Sigh rate and respiratory variability during mental load and sustained attention. Psychophysiology 84 (1), 117–120.

Vlemincx, E., Van Diest, I., Van den Bergh, O., 2012. A sigh following sustained attention and mental stress: effects on respiratory variability. Physiology & Behavior 107, 1–6.

Wilhelm, F.H., Roth, W.T., Sackner, M.A., 2003. The LifeShirt: an advanced system for ambulatory measurement of respiratory and cardiac function. Behavior Modification 27, 671–691.

Wysocki, M., Cracco, C., Teixeira, A., Biostat, Msci, Mercat, A., Diehl, J.-L., Lefort, Y., Derenne, J.-P., Similowski, T., 2006. Reduced breathing variability as a predictor of unsuccessful patient separation from mechanical ventilation. Critical Care Medicine 34 (8), 2076–2083.