Influence of a single slow-paced breathing session on cardiac vagal activity in athletes

Abstract

Introduction: Slow-paced breathing (SPB) is a well-known relaxation technique in athletes, which has also the potential to help optimize addiction treatments based on its effects on the autonomic nervous system. Specifically, these effects directly impact cardiac vagal activity (CVA), the activity of the vagus nerve regulating cardiac functioning. The effects of long-term SPB interventions on CVA have already received some attention, however, the effects of a single SPB session on CVA still require further investigation. Consequently, the aim of this study was to investigate the effects of SPB on CVA during, immediately after, and 60min after a single SPB session. **Methodology:** Twenty-four athletes were involved in a within-subject design, with two conditions: slow-paced breathing (at 6 cycles per minutes) and a control condition watching an emotionally neutral TV documentary while breathing at a spontaneous breathing rate. CVA was derived from heart rate variability measurement and indexed via the root mean square of successive differences, RMSSD. **Results:** Results showed that RMSSD measured during SPB was significantly higher than when measured before SPB, right after SPB, and 60min after SPB. No changes were observed in the control condition. **Discussion:** Findings regarding concomitant effects of SPB on CVA are in line with previous literature. The return to baseline observed immediately after SPB and 60min after SPB suggests that the effects on CVA are only transitory. **Practical implications:** Given higher CVA has been linked to decreased cravings in addictions, future research should investigate to which extent SPB may be an effective technique to help coping with craving attacks on an acute basis.

Keywords: vagally-mediated heart rate variability, parasympathetic nervous system, vagus nerve, respiration

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1 Introduction

Dysfunctions in the central and peripheral nervous system, for example caused by stress, are suggested to play a role in the development of addictions and in addiction relapse vulnerability (Milivojevic & Sinha, 2018; Schwabe, Dickinson, & Wolf, 2011; Sinha, 2008; Wemm & Sinha, 2019). Addiction often refers to the compulsive self-administration of drugs, from alcohol and caffeine to cocaine and amphetamine, and also to self-imposed habits, from taking energy-rich food to gambling (Wise & Robble, 2020). For athletes, in addition to the addiction to drugs aimed to improve performance (Kabiri, Shadmanfaat, Howell, Donner, & Cochran, 2020), we find exercise addiction, like in long distance runners or sport science students (Maceri, Cherup, Buckworth, & Hanson, 2019; Szabo & Griffiths, 2007). In complement to traditional addiction treatments, the effectiveness of alternative non-medical treatments has been investigated in the past years, such as with slow-paced breathing (SPB), which is suggested to act on the parasympathetic nervous system (Gerritsen & Band, 2018; Lehrer & Gevirtz, 2014; Noble & Hochman, 2019; Russo, Santarelli, & O'Rourke, 2017; Zaccaro et al., 2018). The link between long-term SPB interventions and the parasympathetic nervous system has previously received some attention, however, the acute effects of SPB are still to be understood, which is the aim of the current study.

SPB is a breathing technique usually employed for relaxation purposes (Russo et al., 2017). It involves controlled inhalation and exhalation durations ("paced"), at a rate of around 6 cycles per minute (cpm), which is slower than spontaneous breathing, usually comprising between 12 and 20cpm (Sherwood, 2011; Tortora & Derrickson, 2013). The exact physiological mechanisms of SPB are still debated, involving the role of the baroreflex and pulmonary afferents, which delineates that SPB influences afferent parasympathetic nervous activity (Gerritsen & Band, 2018; Lehrer & Gevirtz, 2014; Noble & Hochman, 2019; Russo et al., 2017; Zaccaro et al., 2018). However, the links of SPB with efferent parasympathetic nervous activity are still questioned. A non-invasive measure of efferent parasympathetic nervous activity regulating the heart functioning is feasible via heart rate variability (HRV) and is referred to as cardiac vagal activity (CVA; Berntson et al., 1997; Laborde, Mosley, & Thayer, 2017; Malik et al., 1996).

HRV refers to the change in the time-intervals between adjacent heartbeats (Berntson et al., 1997; Malik et al., 1996). HRV has been linked to self-regulatory and inhibitory processes, in particular via the neurovisceral integration model (Smith, Thayer, Khalsa, & Lane, 2017; Thayer, Ahs, Fredrikson, Sollers, & Wager, 2012; Thayer, Hansen, Saus-Rose, & Johnsen, 2009). This model assumes that similar structures are involved in the regulation of executive and cardiac functioning. The functional organization of these structures is depicted by the central autonomic network (Benarroch, 1993), which output is CVA. CVA is considered to reflect the effectiveness of executive functioning, including inhibitory processes (Smith et al., 2017; Thayer et al., 2009). Among the HRV parameters reflecting CVA, we find in particular the root mean square of successive differences (RMSSD) and high-frequency (HF). Given that RMSSD is less influenced by changes in respiratory parameters than HF (Kuss, Schumann, Kluttig, Greiser, & Haerting, 2008; Penttilä et al., 2001), we use it as the main dependent variable of this study to index CVA.

The links between CVA and self-regulatory processes make CVA a good candidate as an outcome indicator in addiction studies (Price & Crowell, 2016). The association between addiction and disruption in self-control, with impulsivity being a key feature of addiction behaviors (American Psychiatric Association, 2013; Baler & Volkow, 2006; Koob & Volkow, 2010), directly aligns with a need to index self-regulation. Indeed, lower CVA has been associated with addictions (D'Souza et al., 2019), such as with alcohol (Cheng, Huang, & Huang, 2019; Yuksel, Yuksel, Sengezer, & Dane, 2016), smoking (Yuksel et al., 2016), gambling (Kennedy et al., 2019), Internet (P.-C. Lin, Kuo, Lee, Sheen, & Chen, 2014; Moretta & Buodo, 2018; Moretta, Sarlo, & Buodo, 2019), computer games (Coyne et al., 2015; Hong et al., 2018; Lee et al., 2018), heroin (I. Mei Lin, Ko, Fan, & Yen, 2016), and food craving (Spitoni et al., 2017). Consequently, interventions increasing CVA, such as SPB, would make sense in the context of addictions in order to foster greater self-regulatory capacity (Tang & Posner, 2014; Tang, Posner, Rothbart, & Volkow, 2015).

Long-term SPB interventions have proved effective to increase CVA (e.g., Laborde, Hosang, Mosley, and Dosseville (2019) and to treat addiction behaviors (Alayan, Eddie, Eller, Bates, & Carmody, 2019; Eddie, Conway, Alayan, Buckman, & Bates, 2018; Penzlin et al., 2017; Penzlin, Siepmann, Illigens, Weidner, & Siepmann, 2015). Specifically, SPB interventions coupled with the use of biofeedback (i.e., where participants are able to directly see the effects of SPB on their heart rate patterns via a dedicated device) were shown to be effective in reducing alcohol dependence (Penzlin et al., 2017; Penzlin et al., 2015) and overall cravings (Alayan et al., 2019; Eddie et al., 2018). The long-term physiological effects of SPB on CVA make it a promising alternative non-medical treatment for addictions (Alayan, Eller, Bates, & Carmody, 2018; Bates, Lesnewich, Uhouse, Gohel, & Buckman, 2019; Eddie, Vaschillo, Vaschillo, & Lehrer, 2015; Leyro, Buckman, & Bates, 2019). Although long-term SPB interventions have been shown to increase CVA, much less is known about the effects of short-term interventions.

The current findings for effects of short-term SPB show benefits on inhibitory mechanisms (Hoffmann, Jendreizik, Ettinger, & Laborde, 2019; Laborde, Allen, Göhring, & Dosseville, 2017; Laborde, Lentes, et al., 2019; Prinsloo et al., 2011) and coping with stress (Laborde, Allen, et al., 2017; Prinsloo, Derman, Lambert, & Laurie Rauch, 2013; Prinsloo, Laurie Rauch, Karpul, & Derman, 2013). This makes it a desirable intervention in addiction research, as illustrated by the effects of a single SPB session on food craving (Meule & Kübler, 2017). Regarding CVA changes during SPB, several studies investigated the effects of single session SPB interventions on HRV (Du Plooy & Venter, 1995; I. M. Lin, Tai, & Fan, 2014; Song & Lehrer, 2003; Van Diest et al., 2014) and argued that CVA was increased during SPB, however only Van Diest et al. (2014) used a valid CVA marker (i.e., respiratory sinus arrhythmia). Regarding CVA changes directly after stopping SPB, no changes in CVA were observed in comparison to CVA baseline before SPB, with CVA indexed with RMSSD (Laborde, Lentes, et al., 2019) or with HF-HRV (Hoffmann et al., 2019), which may indicate that the effects of SPB on CVA may only be during SPB and not have lasting effects. The delayed effects of a single SPB session have yet to be investigated, which consequently forms the aim of the current study.

In summary, previous research investigating the effects of a single SPB session on CVA rarely focused on valid CVA indicators, often lacked a control condition, and did not systematically investigate the effects during, immediately after, and 60min after. Addressing these research gaps would enable to provide valuable insight for addiction research, illustrating the psychophysiological effects at the cardiovascular level of a single-session slow-paced breathing intervention. The current study is aimed to address these issues using a within-subject design, as recommended in HRV research (Laborde, Mosley, et al., 2017; Quintana & Heathers, 2014). Based on the suggested mechanisms underlying SPB at the physiological level linked to the parasympathetic nervous system (Gerritsen & Band, 2018; Lehrer & Gevirtz, 2014; Noble & Hochman, 2019; Russo et al., 2017; Zaccaro et al., 2018), we hypothesize that in comparison to a control condition involving spontaneous breathing, RMSSD will be higher in the SPB condition than in the control condition during the SPB session, immediately after the SPB session, and one hour after the SPB session. Finally, the current study focuses on an athletic sample, due to the potential risk for athletes to develop addiction behaviors (de Grace, Knight, Rodgers, & Clark, 2017; Kirkwood, 2017; Koçak, 2018; Nowak, 2018; Richard, Paskus, & Derevensky, 2019).

2 Method

2.1 Participants

Based on the sample size used in previous research with single SPB session using a within-subject design (Van Diest et al., 2014), twenty-eight athletes were recruited for this study. However, due to technical issues (related to ECG recording), we could only use the data of 24 participants (17 female, M_{age} = 22.5 years old, age range = 21-26, *BMI* = 23.2 ± 2.2; Waist-to-hips ratio = .81 ± .11, sport practice per week = 6.7hrs ± 3.2). Exclusion criteria were self-reported cardiovascular conditions, and other conditions that may influence breathing or HRV patterns, such as asthma (Kazuma, Otsuka, Matsuoka, & Murata, 1997). None of the participants were smokers. The experimental protocol was approved by the Ethics Committee of the local University (Project identification code 17/09/2014).

2.2 Material and Measures

2.2.1 Vagally-mediated heart rate variability

An ECG device was used to measure HRV (Faros 180°, Bittium, Kuopio, Finland), at a sampling rate of 500 Hz. Two disposable ECG pre-gelled electrodes (Ambu L-00-S/25, Ambu GmbH, Bad Nauheim, Germany). The negative electrode was placed in the right infraclavicular fossa (just below the right clavicle) while the positive electrode was placed on the left side of the chest, below the pectoral muscle in the left anterior axillary line. From ECG recordings we extracted RMSSD with Kubios (University of Eastern Finland, Kuopio, Finland). In order to provide an overview of the different HRV parameters, as recommended by Laborde, Mosley, et al. (2017), we also extracted the R-R interval, the heart frequency, the standard deviation of the NN interval (SDNN) for the time-domain, and for the frequency-domain (with Fast Fourier Transform) the low-frequency (LF), the high-frequency (HF), and the LF/HF ratio.

2.2.2 Slow-paced breathing

Similar to previous research (Laborde, Allen, et al., 2017; Laborde, Lentes, et al., 2019), the SPB exercise was conducted with a video showing a ball moving up and down at the rate of 6 cpm, based on the EZ-Air software (Thought Technology Ltd., Montreal, Canada). Participants were instructed to inhale continuously through the nose while the ball was going up, and exhale continuously with pursed lips when the ball was going down. The video used displayed a 3 x 5min SPB exercise, with a 1min break between each unit, corresponding to a total of 17min. Exhalation (5.5s) was slightly longer than inhalation (4.5s), because a prolonged exhalation was found to contribute to higher activation of vagally-mediated HRV (Strauss-Blasche et al., 2000; Van Diest et al., 2014).

2.2.3 TV Neutral documentary

The TV documentary used as a control condition and during the 60min for both groups after the intervention was taken from the TV program “Abenteuer Forschung”. This is a German TV show explaining diverse research topics in layman’s terms in order for it to apply to a wide audience. The documentary was found to be subjectively emotionally neutral in a previous pilot study.

2.3 Procedure

Participants were recruited via flyers on the campus of the local university and via posts on social networks groups linked to the local university. Participants were instructed to follow their usual sleep routine the night prior to the experiment, not to consume alcohol or engage in strenuous physical activity in the previous 24hrs, nor to drink or eat 2hrs before taking part in the experiment (Laborde, Mosley, et al., 2017). All participants gave written informed consent before participation, and were informed that they could withdraw from the study at any time without explanation and without any consequences. There were two testing sessions involved, lasting around 100 minutes each (see Figure 1 for full description). The design of the experiment follows the 3Rs of cardiac vagal activity functioning: resting, reactivity, and recovery (Laborde, Mosley, & Mertgen, 2018; Laborde, Mosley, et al., 2017). The order of the testing sessions were counterbalanced within one week of each other, on the same day, at the same time, to guarantee that the environmental conditions were as similar as possible. Upon arrival to the laboratory, participants were asked to fill out an informed consent form and a demographic questionnaire regarding variables potentially influencing HRV (Laborde, Mosley, et al., 2017). All HRV measures proceeded with eyes open, in a seated position, knees at 90°, and hands on the thighs. All HRV measurements were taken for 5min (for the intervention phase, the last 5min were taken into account to be able to compare with the resting measurements) (Malik et al., 1996). When performing the slow-paced breathing exercise, the experimenter ensured the participant was doing it correctly. At the end of the second session, participants were thanked and debriefed.

Insert Figure 1 near here

2.4 Data analysis

HRV variables were exported from the Kubios output. Data were checked for normality. As the RMSSD data was non-normally distributed, a log-transformation was applied, as it is usually recommended for HRV research (Laborde, Mosley, et al., 2017). We then ran the analyses with log RMSSD, however in Figure 2 we report the raw RMSSD data for an easier interpretation.

We conducted a repeated-measures ANOVA, with time (resting, intervention, immediately after intervention, 60min after intervention) and condition (slow-paced breathing vs. control) as independent variables, and log RMSSD as dependent variable. Based on our hypothesis, we focused on the condition x time interaction. The analysis was first run without covariates and then with the covariates included (session order, age, sex, BMI, waist-to-hips ratio), in order to see whether individual differences affected the results.

In case of a significant condition x time interaction, post-hoc tests were ran with Bonferroni correction, with an alpha level adjusted to p = .003 (.05/16).

Insert Table 1 near here

Insert Figure 2 near here

3 Results

Descriptive statistics are presented in Figure 2 for RMSSD and in Table 1 for all study variables. A repeated-measures ANOVA was conducted and showed no effect of condition Wilks' λ = .999, $F(1, 23) = 0.016$, $p = .902$, partial $\eta^2 = 0$, a significant main effect of time Wilks' λ = .377, $F(3, 21) = 11.554$, $p < .001$, partial $\eta^2 = .62$, and significant interaction effect for condition x time, Wilks' λ = .462, $F(3, 21) = 8.167$, $p = .001$, partial $\eta^2 = .54$. Given our hypothesis, we focus on the condition x time interaction. Sixteen post-hoc tests were ran. The following mean comparisons were found to be significant: in the SPB condition, RMSSD during intervention was found to be higher than during resting measurement, $t(23) = 6.268$, $p < .001$, $d = 1.28$; as well as higher than immediately after the intervention, $t(23) = 4.527$, $p < .001$, $d = 0.92$; and higher than 60min after the intervention, $t(23) = 3.266$, $p = .003$, $d = 0.67$. In the SPB condition, there was a tendency for the measurement 60min after the intervention to be higher than before the intervention $t(23) = 2.983$, $p = .007$, $d = 0.61$. Regarding comparisons between conditions, there was a tendency for the resting measurement to be higher in the control condition in comparison to the one of the SPB condition, $t(23) = 2.378$, $p = .026$, $d = 0.49$; and there was a tendency for RMSSD to be higher during the intervention in the SPB condition in comparison to the control condition, $t(23) = 2.488$, $p = .021$, $d = 0.51$.

4 Discussion

This study aimed to investigate the effects of a single SPB session on CVA during, immediately after, and 60min after the intervention, in comparison to a control condition. Our hypothesis was only partially confirmed: there was a significant condition x time interaction, however the follow-up post-hoc tests revealed only a tendency for RMSSD to be higher during SPB than during the control condition, for the RMSSD in the control condition to be higher than in the SPB condition at baseline, and no differences at the time points immediately after and a further 60min after the intervention. Further, in the SPB condition, RMSSD was higher during the intervention in comparison to the previous resting measurement (d = 1.28), as well as immediately after the intervention (d = 0.92), and 60min after the intervention (d = 0.67).

When focusing on the results of the SPB condition, findings suggest that CVA was increased during SPB, but then returned to baseline. This would be in line with the suggestion that SPB influences vagal afferent activity (Gerritsen & Band, 2018; Lehrer & Gevirtz, 2014; Noble & Hochman, 2019; Russo et al., 2017; Zaccaro et al., 2018), and this would also be reflected in vagal efferent activity at the level of the heart (CVA), also similar to what was suggested by previous research (Van Diest et al., 2014). Further argument for this conclusion is that no changes in RMSSD can be observed in the control condition. The fact that RMSSD returns to baseline after SPB in the SPB condition, in line with previous research (Hoffmann et al., 2019; Laborde, Lentes, et al., 2019), would suggest the transitory characteristic of such changes triggered by SPB. This is also confirmed by the findings observed 60min after the SPB session, where RMSSD values remain similar to those observed right after the SPB session. Further research should then investigate the mechanisms underlying the long-term effects of SPB on CVA (e.g., Laborde, Hosang, et al. (2019), and question specifically the dose-response relationship, and the number of sessions necessary to increase resting CVA. Suggested mechanisms for long-term adaptations to SPB interventions encompass for example improvements in baroreflex sensitivity (Lehrer & Gevirtz, 2014) and a chronic adaptation of the pulmonary stretch receptors, reacting to the habitual slow-breathing stimulation (Cooke et al., 1998; Grossman, Grossman, Schein, Zimlichman, & Gavish, 2001; Spicuzza, Gabutti, Porta, Montano, & Bernardi, 2000).

The current study is not without limitations. First, future studies investigating immediate and delayed effects of SPB on HRV should consider larger samples, given the large effects found regarding the influence of SPB on CVA during the intervention and which drove sample size selection (Van Diest et al., 2014) appear to cease when the stimulus (i.e., SPB) stops. Second, alternative control conditions should be considered, given the condition used (watching a neutral TV documentary) does not require a conscious attentional focus on breathing. An alternative could be to have a control paced breathing condition matching the spontaneous breathing frequency, at 12cpm, like in Tsai, Kuo, Lee, and Yang (2015).

5 Conclusion

This study showed that a single SPB session increases CVA, however the effects cease when the stimulus stops. Regarding addictions, this means that SPB could be used to help reducing acute cravings (Meule & Kübler, 2017), and thus belongs to the new technologies that can be implemented easily in the era of e-Addictology, as an alternative to traditional treatments (Ferreri, Bourla, Mouchabac, & Karila, 2018). Given athletes may be at risk to develop addiction behaviors (de Grace et al., 2017; Kirkwood, 2017; Koçak, 2018; Nowak, 2018; Richard et al., 2019), our finding suggest that slow-paced breathing may be integrated to their training to help prevent cravings. However, further research is required to understand how the effect of several single SPB sessions add up to provoke long-term effects on CVA, given this is the mechanism suggested to help coping with addiction behavior (Alayan et al., 2018; Bates et al., 2019; Eddie et al., 2015; Leyro et al., 2019).

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