FEATURE ARTICLE

A Single-Participants Investigation of the Effects of Various Biofeedback-Assisted Breathing Patterns on Heart Rate Variability: A Practitioner’s Approach

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The objective of this study was to define specific breathing patterns and examine the effects these patterns have on indicators of heart rate variability. Perceived accounts of ease and comfort in relation to the patterned breathing applications also were assessed. A breathing pattern is the within-cycle respiratory timing or the ratio between the inspiration and expiration of breath, including the pause time at the top of the inspiration and at the bottom of the expiration. The within-participants analysis (N = 14), including the subjective components, revealed significant differences and illuminated the strength of the effects the varied breathing patterns had on each participant.

Introduction

Self-regulated breathing strategies have been developed and researched to elicit high-amplitude oscillations within the cardiovascular system, which have been shown to have strong therapeutic effects (Lehrer, 2007). This technique is aimed at synchronizing heart rate oscillations with respiration cycles and is, in part, a function of increased heart rate during inhalation and decreased heart rate upon exhalation. The variation in cardiopulmonary functions is known as respiratory sinus arrhythmia (RSA), a noninvasive measure of cardiac vagal tone, and can be augmented via biofeedback (BFB). Research has shown that negative emotional and physical states such as panic disorder and depression are associated with abnormal breathing patterns and subsequent suboptimal RSA (Blechert, Michael, Grossman, Lajtman, & Wilhelm, 2007; Gevirtz, 2000; Ley, 1993).

Although breathing techniques have been used for centuries to improve mental and physical well-being as well as for spiritual growth, only recently has BFB or physiological monitoring been paired with these breathing strategies. Specifically, the effectiveness of the BFB-assisted breathing therapies can be evidenced through changes in cardiac variability, otherwise known as heart rate variability (HRV), which is a measure of the naturally occurring beat-to-beat changes in heart rate. HRV output is an indirect but powerful indicator of the overall health and state of the autonomic nervous system (Bernston et al., 1997; Saul et al., 1991), positive and negative emotional states (Cacioppo, Larsen, Smith, & Berntson, 2004; Childre & McCraty, 2001), and self-regulatory control (Appelhans & Lueckcn, 2006; Segerstrom & Nes, 2007).

Lehrer, Vaschillo, and Vaschillo (2000) produced a landmark study in the area of cardiovascular regulation. They guided the patient’s breathing rates by BFB and measured the effects on heart rate oscillations. This allowed them to determine each individual’s resonance frequency (i.e., the breathing rate at which the oscillations of heart rate and blood pressure are 180° out of phase with each other). Their primary findings suggested that standardized paced breathing in approximately 9.25- to 13-second cycles (i.e., roughly six breaths per minute or about .1 Hz) will enhance optimal heart rate oscillations and produce “desired” therapeutic effects. Although these studies are clear and specific regarding breathing rates (i.e., the number of breathing cycles per minute), optimal breathing patterns are only partially addressed.

A breathing pattern is the within-cycle respiratory time or the ratio between the inspiration and expiration of breath, including the pause time at the top of the inspiration and at the bottom of the expiration. Although very little attention has been given to the study of breathing patterns in BFB research, a body of research exists on the effects of breathing rates on HRV BFB (Lehrer et al., 2000; Ritz & Dahme, 2006; Song & Lehrer, 2003; Vaschillo, Vaschillo, & Lehrer, 2006). Lehrer et al. (2000) briefly commented on breathing patterns in their manual for determining resonance frequency, stating that one should (a) not breathe too deeply, (b) breathe in a relaxed way, and (c) allow for a longer expiration than inspiration. Song and Lehrer’s examination of various breathing rates and resonance frequency used an electronic pacer and...
guided the participants to breathe at equal intervals for the inspiration and expiration. Vaschillo et al. (2006) mentioned that they utilized a computerized pacing stimulus that moved up for inspiration and down for expiration while determining individuals’ resonance frequency, but no further specifics were provided. Although there is a lack of clarity in previous BFB research that addresses breathing patterns, practitioners often use varied breathing patterns with alternating inspiration and expiration ratios when applying HRV BFB.

The primary objective of the current study was to examine the individual effects of various breathing patterns on HRV. As stated, many practitioners in the field of BFB are teaching clients variations of patterned breathing with minimal empirical support to substantiate their rationale (Hughes, 2008). Respiratory research focused on breathing strategies has identified various breathing patterns but has not fully justified or substantiated this in conjunction with breathing rates.

Grossman (1983) posited that slow and controlled breathing with brief pauses at the top and bottom of the inspiration and expiration could improve RSA. Strauss-Blasche et al. (2000) investigated the relative timing of inspiration and expiration and its effects on RSA. The authors examined four inspiration/expiration time ratios (I/E ratio) that included two variations of short then long inspiration and two variations of long inhalation and short expiration. Although they did not specify the exact time in milliseconds for each I/E-ratio condition, they did reveal that heart rate oscillations can be modulated by the I/E ratio. Pastor, Menéndez, Sanz, and Abad (2008) reviewed and discussed a compilation of their work examining the effects of respiratory patterns on skin conductance levels, but they did not include indicators of HRV or RSA. In addition, the authors were not clear on the specifics (time in milliseconds) of the various I/E ratios used, but they did conclude that an expiration time twice as long as an inspiration produced the greatest reductions in skin conductance levels.

In order to substantiate the interplay between breathing patterns and autonomic functioning while keeping breathing rate constant (i.e., about six breaths per minute), the following objectives were addressed in the present study:

1. Conceptually define a breathing pattern so it can be (a) appropriately measured and (b) systematically differentiated from a breathing rate.
2. Define five specific breathing patterns utilized by BFB practitioners, including the I/E ratio and the times in milliseconds.
3. Determine a breathing pattern that yields (a) maximal increases in amplitude of heart rate oscillations via HRV within-participants analyses and (b) the highest rated perceived values of “ease” and “comfort.”

**Methods**

**Participants**

Fourteen individuals (8 men, 6 women, \(M_{age} = 33.0\) years, \(SD = 6.08\); age range, 21 to 40 years) participated in this study. All participants were considered generally healthy and the major exclusionary criteria included asthma, emphysema, chronic obstructive pulmonary disease, smoking, or some history of heart disease.

**Measures and Instruments**

**System and software.** BioTrace+ Software® Advanced Physiological Monitoring and Feedback developed by Mind Media B.V. (version 2008a; US, Roermond-Herten, The Netherlands) was used to manage the data collection acquired from a NeXus-10™ wireless Bluetooth BFB system (Mind Media B.V.).

**Respiration.** An abdominal strain gauge was used to measure respiratory activity. The onscreen pacer had four settings that included “Inhale” and “Sustain” (pause at the top of inspiration), “Exhale” and “Pause” (pause at the bottom of the expiration) times.

**HRV.** An electrocardiogram was used to collect the following HRV measures:

1. The standard deviation of the normal beat-to-beat heart rate intervals in milliseconds (SDNN)
2. The percentage of successive normal interbeat intervals, which differ by 50 milliseconds or more (pNN50)
3. The spectral analysis: (a) high frequency (HF; .15 to .4 Hz), (b) low frequency (LF; .04 to .15 Hz), and (c) very low frequency (VLF; .003 to .04 Hz)

**Ease and comfort scale.** Participants were asked to rate “How easy was this breathing condition for you?” and “How comfortable was this breathing condition for you?” according to a 10-point scale.

**Procedure**

The participants underwent an adaptation period and were in a relaxed seated position. We utilized a dual-monitor setup that allowed the researcher to view an extended display of all the modalities on one screen and a specific limited view for the participants’ screen.
Conditions. The respiration rates in the first four conditions were approximately six breaths per minute (i.e., six oscillation per minute). Conditions 1 to 4 included a variation of I/E ratios, whereas Condition 5 required the participants to breathe in phase with the heart (see Figure 1). Specifically, the participants were instructed, in line with Lehrer’s (2000) protocol, to follow the cardiotochometer trace line with their respiration line and were allowed time to practice and adapt to each condition equally. The BioTrace+ Software® included a computerized pacer that accounted for four different settings (i.e., inhale, sustain, exhale, and pause times; see Table 1).

Design. Similar to a Latin square design (see Figure 2), the design included four different sessions presented in a varied order to control for differential effect; within each session the participants were guided through a series of five breathing conditions. Immediately following each condition, the participants were asked to rate their perceptions of ease and comfort. Treatment fidelity was addressed by means of utilizing the dual-monitor setup to ensure that (a) the participant was breathing at six breaths per minute, and (b) the participant was breathing in line with the breathing pacer.

Results
As seen in Table 2, the descriptive statistics demonstrate the magnitude of the differences of each condition once the results were aggregated. Each breathing condition yielded more than 80% activity in the low-frequency while minimizing activity in the high-frequency (<11%) and very low-frequency (<9%) ranges, with marginal differences revealed between each condition. In addition, participants across all five conditions produced relatively high SDNN values (>72.0) and pNN50 values (>20.5).

Within-Participants Analysis
Considering the sample size (N = 14), as well as theoretical and practical considerations, the individual participants were used as the primary unit of analysis, which necessitated a single-participant approach. The assumptions to use a parametric procedure for the within-participants method were not all met; therefore, a Kruskal-Wallis procedure was conducted to analyze the differences among the five conditions on median change in perceptions of ease and comfort for each participant. Analysis revealed a strong positive association between each variable (ease and comfort [r = .91]), therefore results for each variable were collapsed to produce a single score of ease and comfort. The tests indicated significance (p < .05) for 11 of the 14 participants (see Table 3). Follow-up Mann-Whitney U tests were conducted to specify the pairwise differences at the .05 significance level among the five conditions. As depicted in Table 3, Conditions 3 and 4 accounted for most of the variation of differences among all the groups.

Descriptive statistics reveal that at least one condition for each participant yielded the highest value of activity in the low-frequency (LF) range and SDNN values. Participants 1, 7, and 10 maintained their highest values of LF percentage and SDNN in the same condition, whereas the other participants yielded their highest values of LF percentage and SDNN in separate conditions. For example, Participant 2’s highest and lowest LF activity values were 93% in Condition 1 and 72% in Condition 3, respectively, although this individual’s highest and lowest SDNN values

| Table 1. Electronic pacer settings for inspiration, sustain, expiration, and pause times in milliseconds for Conditions 1 to 4 |
|---|---|---|---|---|
| **Direction of respiration** | **1** | **2** | **3** | **4** |
| Inspiration | 3,750 | 4,990 | 3,300 | 2,500 |
| Sustain | 1,250 | 10 | 0 | 1,250 |
| Expiration | 3,750 | 4,990 | 6,600 | 5,000 |
| Pause | 1,250 | 10 | 0 | 1,250 |

*Note. All conditions equal approximately six breaths per minute with the exception of Condition 5, which is not shown here.*
were 54.05 in Condition 3 and 42.48 in Condition 5, respectively. Most participants indicated their strongest subjectively perceived values of ease and comfort in association with the condition that yielded the highest LF percentage or SDNN value (see Table 3).

**Discussion**

A wealth of research has been conducted to delineate the positive effects of specific BFB techniques on optimizing maximum HR oscillations at varying resonance frequencies (see Lehrer, 2007, for an in-depth review). This research has concentrated primarily on determining resonance frequencies through the manipulation of breathing rates ranging anywhere from four to seven breaths per minute. Practitioners can apply these empirical findings when working with patients or clients as a means to attend to issues such as stress or pain management. However, within the general parameter that values resonance frequency at ~1 Hz or six breaths per minute, there are unlimited breathing patterns (or ratios) that can be applied.

**Significance of Breathing Patterns**

Five specific breathing patterns were defined by examining I/E ratios used from past research, in conjunction with considerations taken from training seminars provided by the Biofeedback Certification Institute of America (Hughes, 2008; Pastor et al., 2008; Strauss-Blasche et al., 2000). As noted, a breathing rate refers to the number of breathing cycles per minute (e.g., six oscillations per minute equates to about six breaths per minute), whereas a breathing pattern is the within-cycle respiratory time or the ratio between the inspiration and expiration of breath, including the pause time at the top of the inspiration and at the bottom of the expiration. The breathing patterns defined (see Figure 1 and Table 1 for specifics) were as follows: (a) 1:1 breathing ratio with a brief pause at the top and bottom of the breath, (b) 1:1 ratio with no pauses (i.e., .1 second was required between the inspiration and expiration to create the rolling breathing pattern), (c) 1:2 breathing ratio with no pauses, and (d) 1:2 breathing ratio with a pause at the top and bottom of each breath. Based on Lehrer’s (2007) contention that six breaths per minute is likely to provide therapeutic effects for all, the four breathing conditions were set at six breaths per minute with the exception of Condition 5 where participants were guided by the cardiotachometer.

As expected, all breathing conditions produced high levels of low-frequency activity with minimal activity in the high- and very low-frequency ranges. As seen in the results of the objective data, the magnitude of the differences among the conditions was minimal. As a result, we believe using a between-participants approach with a larger sample may reveal statistically significant differences; however, the effects magnitude would likely be small (Cohen, 1994). Further examinations are required to verify this postulation.

Our finding was that, while keeping the breathing rate at ~1 Hz, all of the breathing ratios produced optimal HR oscillations (with only nominal variations). This supports previous research that placed the emphasis on respiratory

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**Table 2. Means and SDs of heart rate variability indices aggregated across all five conditions**

<table>
<thead>
<tr>
<th>Indices</th>
<th>Condition 1</th>
<th>Condition 2</th>
<th>Condition 3</th>
<th>Condition 4</th>
<th>Condition 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDNN</td>
<td>76.05 (28.05)</td>
<td>75.01 (27.87)</td>
<td>72.94 (23.91)</td>
<td>75.20 (28.98)</td>
<td>69.39 (27.77)</td>
</tr>
<tr>
<td>pNN50</td>
<td>20.94 (16.12)</td>
<td>22.14 (16.52)</td>
<td>20.83 (15.01)</td>
<td>20.66 (15.20)</td>
<td>20.54 (16.16)</td>
</tr>
<tr>
<td>HF %</td>
<td>10.17 (8.24)</td>
<td>8.36 (5.77)</td>
<td>10.68 (7.80)</td>
<td>10.88 (5.00)</td>
<td>7.50 (5.40)</td>
</tr>
<tr>
<td>LF %</td>
<td>84.78 (8.07)</td>
<td>86.40 (6.67)</td>
<td>82.06 (8.66)</td>
<td>82.13 (6.44)</td>
<td>84.36 (8.05)</td>
</tr>
<tr>
<td>VLF %</td>
<td>5.02 (2.35)</td>
<td>5.25 (2.64)</td>
<td>7.27 (5.25)</td>
<td>6.57 (3.77)</td>
<td>8.15 (5.42)</td>
</tr>
</tbody>
</table>

*Note. SDNN = SD of the normal beat-to-beat heart rate intervals; pNN50 = percentage of successive normal interbeat intervals that differ by 50 milliseconds; HF % = % of high frequency (.15 to .4 Hz); LF % = % of low frequency (.04 to .15 Hz); VLF % = % of very low frequency (.003 to .04 Hz).*
rates as opposed to patterns (i.e., I/E ratio) (Song & Lehrer, 2003; Vaschillo et al., 2006). However, it will be necessary to further explore whether one condition (i.e., pattern) produces the most improved autonomic functioning.

The cross-participants analysis revealed that specific conditions more frequently yielded positive and stronger values for improved autonomic activity than other conditions. Perceived values of ease and comfort were also in line with the cross-participants analysis (i.e., the condition that participants felt was the easiest and most comfortable also tended to be the condition that yielded the highest low-frequency activity or SDNN value).

As a practitioner, on a case-by-case basis, it is important to consider the client or patient’s comfort level with a specific breathing pattern (i.e., the within-cycle respiratory times) in association with the objective HRV analysis and, upon application, find the balance between the two (Hughes, 2008). This contention follows Malmo and Shagass’ (1949) individual response stereotypy, which states that individuals maintain idiosyncratic patterns of responding. Additionally, these considerations also are relevant for optimizing patient adherence to treatment protocols, particularly when they are expected to participate in at-home training (O’Donohue & Levensky, 2006).

**Limitations and Future Directions**

Future research in this area should not only aim at determining the individual subjective experiences but should also account for tidal volume effects (see Ritz & Dahme, 2006) and variations in blood volume, which are a function of gender and height and are known to affect resonance frequency (Vaschillo et al., 2006). Larger sample sizes using a between-participants design also may provide definitive conclusions in support of the findings, whereas utilizing gender in a fixed-effects, two-factor, repeated measures analysis of variance to explain the additional residual variance between males and females.

Varied ratio breathing also may be appropriate when applying HRV BFB and examining the baroreflex effects along with blood pressure in patients with dysfunctional breath disorders and neuromuscular diseases. Patients may be sensitive and respond positively to having the option to vary breathing ratios when receiving breathing interventions, which may improve treatment adherence (Dubovsky, 2005). The array of applications and diversity of popula-

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**Table 3. Cross-subject analysis of LF percentage, SDNN, and highest perceived value of ease and comfort across all five conditions**

<table>
<thead>
<tr>
<th>Condition</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>88.96 (60.79)</td>
<td>89.38 (63.01)</td>
<td>86.01 (57.61)*</td>
<td>86.73 (56.61)</td>
<td>84.87 (59.69)</td>
<td>.008</td>
</tr>
<tr>
<td>2</td>
<td>83.72 (58.42)</td>
<td>87.65 (58.26)</td>
<td>86.82 (63.98)</td>
<td>87.61 (55.26)</td>
<td><strong>84.46 (45.42)</strong></td>
<td>.046</td>
</tr>
<tr>
<td>3</td>
<td>93.96 (50.78)</td>
<td>89.78 (46.38)</td>
<td>72.56 (54.05)</td>
<td>76.24 (54.92)</td>
<td>86.27 (42.48)</td>
<td>.031</td>
</tr>
<tr>
<td>4</td>
<td>68.26 (182.71)</td>
<td>74.75 (139.65)</td>
<td>64.83 (145.99)</td>
<td><strong>78.09 (151.79)</strong></td>
<td>68.00 (178.82)</td>
<td>.062</td>
</tr>
<tr>
<td>5</td>
<td>81.57 (125.11)</td>
<td>87.98 (132.08)</td>
<td>81.47 (133.79)</td>
<td>76.74 (130.52)*</td>
<td><strong>93.75 (132.05)</strong></td>
<td>.005</td>
</tr>
<tr>
<td>6</td>
<td>86.13 (43.03)</td>
<td><strong>89.19 (41.06)</strong></td>
<td>82.47 (46.47)</td>
<td>82.77 (41.50)*</td>
<td>79.09 (33.33)</td>
<td>.12</td>
</tr>
<tr>
<td>7</td>
<td>86.32 (43.91)</td>
<td>86.93 (42.14)</td>
<td><strong>88.89 (43.92)</strong></td>
<td>83.81 (39.49)</td>
<td>77.18 (46.74)</td>
<td>.084</td>
</tr>
<tr>
<td>8</td>
<td>91.70 (82.88)</td>
<td><strong>92.83 (84.48)</strong></td>
<td>90.05 (78.89)*</td>
<td>88.75 (83.64)</td>
<td><strong>90.15 (95.91)</strong></td>
<td>.049</td>
</tr>
<tr>
<td>9</td>
<td>84.13 (74.62)</td>
<td>83.16 (66.30)</td>
<td>81.57 (67.20)</td>
<td><strong>88.24 (74.59)</strong></td>
<td>81.38 (64.98)</td>
<td>.023</td>
</tr>
<tr>
<td>10</td>
<td>88.85 (108.85)</td>
<td>91.27 (109.41)</td>
<td>86.74 (82.82)</td>
<td>88.04 (114.39)</td>
<td><strong>92.05 (99.84)</strong></td>
<td>.067</td>
</tr>
<tr>
<td>11</td>
<td>89.61 (134.39)*</td>
<td><strong>90.92 (132.03)</strong></td>
<td>82.47 (132.47)</td>
<td>85.11 (132.21)</td>
<td>90.49 (128.38)</td>
<td>.009</td>
</tr>
<tr>
<td>12</td>
<td><strong>89.30 (87.56)</strong></td>
<td>84.33 (84.72)</td>
<td>89.86 (84.29)</td>
<td>87.54 (87.34)*</td>
<td><strong>92.56 (82.17)</strong></td>
<td>.038</td>
</tr>
<tr>
<td>13</td>
<td>85.94 (66.73)</td>
<td><strong>91.73 (78.29)</strong></td>
<td>89.98 (75.43)*</td>
<td>83.26 (70.38)</td>
<td>89.45 (68.66)</td>
<td>.021</td>
</tr>
</tbody>
</table>

**Note:** LF percentage = % of low frequency (.04 to .15 Hz); SDNN = SD of the normal beat-to-beat heart rate intervals; P = participant; c = the strongest perceived value of ease and comfort; p value = $\chi^2$ level of significance from Kruskal-Wallis test, n = 25 P/subjects sig (p < .05); * = condition yielding significant pairwise difference at the .05 level. The strongest indicators of LF % (SDNN) are bolded.
tions warrants additional examinations and should consider multidimensional approaches while factoring in the subjective and objective within-participants variances.

References


