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Resonant Frequency Training in elite sport: A case study example

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Resonant Frequency Training in Elite Sport: A case study example

Abstract

Resonant Frequency Training (RFT; Lehrer, Vaschillo, & Vaschillo, 2000) is a heart rate variability (HRV) biofeedback technique where participants learn bespoke breathing patterns to inhibit autonomic nervous system changes resulting from stress. To demonstrate RFT in sport, we present an intervention case study with an elite female shooter that enabled her to perform optimally, even after missed shots or unexpected interruptions (e.g., target malfunction). This case study represents a data-driven intervention using biofeedback equipment, however we provide suggestions for low-cost and free methods to widen the use of HRV biofeedback in sport.

Resonant Frequency Training in Elite Sport: A case study example

Natural breaks during self-paced sports, such as moments between shots in shooting, make athletes susceptible to positive and negative emotions arising from corresponding facilitative and debilitative appraisals (e.g., Neil, Fletcher, Hanton, & Mellalieu, 2007; Uphill & Jones, 2007). Heart rate variability (HRV) biofeedback interventions (e.g., Lagos et al., 2008) teach athletes to perform breathing techniques which acutely increase HRV in order to manage emotional states on-demand and facilitate performance (Lehrer & Gevirtz, 2014). HRV is the change in intervals between heart beats and provides an indicator of regulatory influences on the heart (Shaffer, McCraty, & Zerr, 2014). Broadly, increased HRV indicates increased physiological and psychological adapatability to internal and external demands (Bertsch, Hagemann, Naumann, Schachunger, & Schulz, 2012).

Research demonstrates that HRV biofeedback interventions have benefits for a range of clinical and performance related conditions (see Gevirtz, 2013 for a review). Lehrer & Gevirtz (2014) propose a number of mechanisms for these benefits including; restoring autonomic homeostatic balance to reduce sympathetic overflows; stimulating the regulatory baroreflex to provide context-appropriate blood pressure; stimulating the cholinergic anti-inflammatory system; enhancing the vagus nerve mediated heart-brain link to provide emotional centres of the brain with a relaxed visceral state; increased gaseous exchange in the alveoli via phased relations of breathing and heart rate; mechanical stretching of airwaves by slow rhythmic breathing; and meditation or mindfulness related effects of focused attention on one's breathing. However, reducing autonomic stress by stimulating the regulatory baroreflex, and enhancing vagal afferent signals (heart-brain communications regarding the visceral state of the body) are the most widely evidenced therapeutic mechanisms (e.g., Thayer, Åhs, Fredrikson, Sollers III, & Wager, 2012). In sport, these two related mechanisms may combine with distraction-related effects of focused breathing to reduce cognitive and somatic competitive anxiety.

HRV biofeedback interventions have reduced anxiety-related deficits in dance technique (Gruzelier, Thompson, Redding, Brandt, Steffert, 2014) and basketball skills (Paul & Garg, 2012). Similar benefits for self-paced sport skills, such as enhanced positive emotions, decreases in cognitive and somatic anxiety, and objective improvements in performance have also been observed (Lagos et al. 2008; Paul, Garg, & Sandhu, 2012). Improvements in major depression have been achieved after four sessions of HRV biofeedback (e.g., Karavidas et al., 2007), and five-session interventions with 5-minute daily home practice sessions improved the on-demand emotional regulation abilities of elite sport support and management staff (Gross et al., 2016). This evidence indicates that HRV biofeedback may be a time-efficient method to achieve affective and performance-related benefits. Resonant Frequency Training (RFT) is a specific HRV biofeedback method that consists of rhythmic, abdominal breathing at approximately six breaths per minute (0.1Hz; Lehrer, Vaschillo, & Vaschillo, 2000). The method identifies and teaches participants to perform their Resonant Frequency (RF; bespoke breathing rate at which maximal HRV occurs; Lehrer et al.). Users become more aware of psychophysiological interactions by observing live changes in their data on a display, and can use their RF to premptively or reactively manage the effects of anxiety and stress (Gross et al.). This article presents an applied case study of a RFT intervention with an elite athlete to learn an on-demand emotional regulation technique.

Case Study

Louise (pseudonym) is a 45 year old Olympic Trap shooter with 16 years competitive experience. Louise was experiencing negative thoughts and emotions between shots (especially after missed targets), and difficulties dealing with unexpected interruptions to the flow of a competitive round (e.g., target malfunctions), both which were unhelpful for her preparation and performance of the next shot. During an Olympic Trap round there is approximatley 1-minute between shots in which athletes can prepare for the next, and one lost target can mean the difference between silver or gold medals. Louise had found reciting songs useful to substitute anxious thoughts, however this technique was not consistently effective in major competitions where anxiety also manifested as somatic symptoms (i.e., perceptible increases in breathing & heart rates). The cognitive and somatic anxiety relieving effects of HRV biofeedback (Lehrer & Gevirtz, 2014) meant that RFT was a suitable intervention to provide Louise with an on-demand emotional regulation tool for use between shots. Additionally, logistical constraints and the potential for benefits from five-sessions (e.g., Gross et al., 2016; Karavidas et al., 2007) meant that RFT was an efficient and convenient intervention for Louise.

Measures

Lifestyle & Adherence Measures. Factors that may influence HRV indices (e.g., caffeine; Notarius & Floras, 2012) were recorded at the beginning of each RFT session (cf. Gross et al., 2016). At the beginning of sessions three, five, and Simulated Competition, Louise self-reported the number of advised home practice sessions that she had not performed. These numbers were used to calculate the percentage of advised home practice sessions performed between practitioner-led sessions. Louise was not contacted between practitioner-led sessions, nor asked to keep a diary of her practice sessions.

Physiological Measures. All RFT physiological measures were captured by the Nexus-10 encoder (Mind Media, Roermond-Herten, the Netherlands) with dedicated photoplethsmograph (PPG; placed on non-dominant middle finger; sampled at 128Hz) and respiration sensors (pneumonary impedance; Velcro attached 1-inch above the navel; sampled at 128Hz) via bluetooth to the Biotrace+ software. HRV indices included total spectral power (TP; indicative of total HRV), low frequency band percentage of TP (LF%; representative of baroreflexive activity and vagal afferents; Goldstein et al., 2011), low frequency peak percentage of TP (LFPK%; indicative of HRV % influenced by RF breathing), and the route-mean square of successive differences (RMSSD; representative of parasympathetic HRV). Respiratory indices included mean respiratory rate (mResp; breaths per minute) and mean distance from the target resonant frequency (mDist; breaths per minute). During a simulated competition, respiratory data was captured (via pneumonary impedance) using a Hexoskin undergarment & encoder (Hexoskin, Montréal, Canada). The Hexoskin mobile application was used to view live computed statistics (i.e., 1Hz respiratory rates) and a 10-second window of live raw respiratory data. Tri-axis accelerometer (sampled at 64Hz with 0.004g resolution) and electrocardiogram (ECG; 1-channel sampled at 256Hz) data were also collected via the Hexoskin. Hexoskin data were analysed using the EDFbrowser software (Version 1.55; Van Beelen, 2014). For home RF practice, Louise's mobile device (iOS) was equipped with the Breathe2Relax (National Centre for Telehealth & Technology; United States of America) breath pacing application.

Client Feedback. Two client feedback interviews were used to reflect on the intervention experience, use of RF, and benefits to performance. At the final RFT session, Louise was asked "Please tell me about your experiences of the intervention" and "When have you used your resonant frequency?". Following the simulated competition, Louise and her coach were asked "What are the benefits of using RF breathing during a shooting round?". Responses were recorded verbatim in hand-written notes during both interviews. Twelve months after the simulated competition, Louise described the performance impact via email.

Intervention

Ethical approval was granted via the corresponding author's institution and Louise provided informed consent before the intervention began. Figure 1 illustrates Louise's progression through the RFT intervention and temporal gaps between sessions. The RFT sessions consisted of RF paced breathing (PB) and accuracy test (AT) activities, each now described in succession.

Session 1. To record resting physiology data, Louise was connected to the PPG and respiration sensors and asked to relax for 5-minutes while sitting up-right and alone (see Kleck et al., 1976). Louise then completed an RF estimation procedure which guided her breathing via a bar graph at seven consecutively reducing frequencies (i.e., 7 breaths/minute to 4 breaths/minute) for 2-minutes each with an inhale to exhale ratio of 2:3 (cf. Lehrer et al., 2000). Louise's RF was estimated using TP, LF%, and LFPK% for each frequency derived from the Fast Fourier Transformation (FFT) function in Biotrace+.

Session 2. To confirm her RF, Louise's breathing was paced at three consecutively reducing frequencies for 3-minutes each (the estimated RF from Session 1 was placed as the middle frequency). LFPK% derived from the FFT was used to immediately confirm Louise's RF, which she then performed for 5-minutes using the breath pacer (PB1). Louise's Breathe2Relax application was programmed with her RF timings, she was advised to practice for 5-minutes each day, and told that her RF accuracy would be tested in the future sessions.

Session 3. Louise was assessed on her ability to perform her RF for 3-minutes without a breath pacer (AT1). As per Gross et al., (2016), verbal feedback on RF accuracy was provided at the half-way point (e.g., 'too slow, shorten your exhale'), and a discussion of TP, LFPK%, mResp and mDist data followed the end of the accuracy test. Following AT1, Louise completed a 5-minute RF paced breathing exercise (PB2; as per PB1) and then performed an identical 3-minute RF accuracy test (AT2), again with data discussions.

Session 4. This session was identical to Session 3 except the accuracy tests either side of paced RF breathing (PB3) were 4-minutes in length (AT3 & AT4). In a discussion around RF use during performance, Louise suggested that the approximate 1-minute pause between shots would be an appropriate time to incorporate her RF into her performance.

Session 5. The accuracy tests in this session (AT5 & AT6) were altered to simulate how Louise would incorporate her RF into performance. Conducted either side of the final paced RF breathing activity (PB4), both accuracy tests comprised five separate, 1-minute between-shot periods. Louise was instructed to stand in her firing position, imagine that she had performed a shot and reproduce the same movements (e.g., throwing away the empty cartridges), then perform her RF for 1-minute. No feedback was given during these accuracy tests, however data were discussed after each activity (as per Session 4). As this was the final RFT session, Louise was debriefed and instructed to use her RF on-demand for pre-competition and every-day emotional regulation, to use her RF between shots, and to periodically practice her RF using Breathe2Relax.

Simulated Competition. Louise's RF accuracy between shots was assessed during a simulated Olympic Trap round with five other shooters, following International Sport Shooting Federation protocols. Louise wore the Hexoskin and computed statistics were visually monitored on the mobile application, Louise suggested that wearing the Hexoskin did not impact her shooting. A debrief including Louise's coach followed the round, quantitatively focused on RF accuracy between shots (using mResp), and qualitatively focused on accuracy difficulties. Louise and her coach then commented on the benefits of using her RF between shots and were provided with a written RF accuracy report using mDist values.

Data Analysis

Using guidance for HRV data cleaning and analysis (Nunan, Sandercock, & Brodie, 2010; Task Force, 1996), six recordings required some inter-beat intervals (IBI) to be removed due to artifacts in the PPG signal (See Gross et al. 2016 for full details of these procedures). All PPG heart beat waveforms were visually compared to three previous and three preceeding beats to assess the morphology for Biotrace+ to accurately determine IBI. Recordings with IBIs removed were interpolated at 4 Hz. Mean IBIs and mResp for all recordings are available upon request to the corresponding author. Four resting recordings required between 1.6% and 14.2% of IBI removal, two were accuracy tests that required 0.7% (AT3) and 1.4% (AT4) IBI removal. For AT5 and AT6, the combined mDist across all five 1-minute accuracy tests was used. Raw Hexoskin x-axis accelerometer and abdominal respiration data were time-synchronised to identify shots during the simulated competiton, and thus highlight periods of RF breathing between shots. mResp and mDist were then calculated as per the RFT session data, Hexoskin ECG data was not of sufficient quality to derive HRV statistics from.

Results

Lifestyle and Intervention Adherence

Louise reported similar sleep length and quality, and similar water, food and caffeine intake before all sessions. Louise's adherence to home practice increased across the intervention, from 54% (RFT 2 to RFT 3), to 82% (RFT 4 to RTF 5) and 98% between RFT 5 and the simulated competion.

RFT & Simulated Competition

Compared to first resting measures, Louise's percentage of LF activity increased during the final resting measures (from 38.95% to 71.22%), however a lower respiratory rate in the latter recording (mResp = 14.05 vs mResp = 7.85) will have overemphasised this effect. Across the 5-minute paced breathing activities, Louise increased LFPK% (PB1 = 50.23% to PB4 = 56.71%), LF% (PB1 = 87.66% to PB4 = 94.94%), and RMSSD (PB1 = 70.88ms to PB4 = 90.58ms). She achieved similar effects in 4-minute RF accuracy tests (i.e., AT4; LFPK% = 50.65%, LF% = 81.45%, RMSSD = 82.24ms), and similar LF% effects in 1-minute accuracy tests (AT5; 70.15% ±10.07, & AT6; 62.31% ±15.71) both of which increased in comparison to average resting LF% values (39.68% ±8.64). These increases in HRV were accompanied by increased RF accuracy (decreased mDist) across the six accuracy tests, see Figure 2. These results demonstrate that during standing RF breathing for 1-minute Louise was able to increase HRV above resting levels and to a similar extent as seated paced breathing. Hexoskin respiratory data indicated that Louise was able to accurately reproduce her RF between shots during a simulated competiton, however, there was some variance in her accuracy as indicated by mDist in Figure 3.

Client Feedback

Louise indicated that RF tests enhanced her confidence to implement RF and efficacy beliefs in generating the psychophysiological benefits:

> I feel confident that I can use my breathing and still create those heart rate changes we see after I've followed the pacer on the computer.

Louise also described an instance during a competition when she used her RF:

> I used it almost as soon as I had missed the second target and I instantly felt calmer and more controlled…I felt back to normal and cleared up the rest with my first barrel [using one shot to hit each target].

Louise described the benefits she saw in RF breathing during performance:

> …I can keep calm during a round and handle unexpected interruptions, it's like a safety net.

Louise's coach suggested that he saw a kinematic benefit to Louise's technique when using her RF between shots:

> She's smoother to the shoulder [raising the gun into the shoulder before a shot] and just looks more controlled.

After one year, Louise summarised improvements in her performance which RFT contributed to:

> My average score has lifted approximately one target a round … which doesn't sound much but actually is a massive difference because 3 targets per comp is the difference from being an "also ran" to making the final.

Discussion

Louise's case highlights how RFT interventions can raise an athlete's awareness of their psychophysiological response to stress, swiftly teach a technique to combat cognitive and somatic anxiety, and sucessfully apply the tecnique in elite sport competitions. Louise found that influencing her HRV via paced breathing activities (e.g., RF estimation procedure in Session 1), and reviewing the mechanisms in action raised her awareness of the psychophysiological control she could extert via breathing. She suggested that the RF accuracy tests helped her learn her RF, along with varied (times & situations) home practice and self-testing RF accuracy by periodically looking away from the breath pacing mobile application. High adherence rates reflect Louise's engagement with the intervention, which combined with the simulated competition RF accuracy discussions to reinforce the application to performance. Louise suggested that her focus on RF breathing replaced negative thoughts with a neutral image (i.e., a breath pacing bar-graph), and that the psychophysiological control enabled her to consistently manage cognitive and somatic anxiety during competitions to support optimal performance.

Similar to other HRV biofeedback interventions in sport, during paced RF breathing Louise was able to increase HRV indicative of baroreflex stimulation and increased vagal afferents (cf. Lagos et al., 2008; Paul et al., 2012). By the end of the intervention, she recreated these HRV effects via RF breathing in seated accuracy tests and standing imagined simulations, then reproduced accurate RF breathing patterns between shots during a simulated competition. Partially supporting other case studies such as Lagos et al., Louise may have increased her resting HRV, however a slow respiratory rate in the final resting measures and the removal of some resting data may have overemphasised this effect. Supporting the coaches' kinematic observations, previous research has shown reductions in choice-reaction and movement times (Paul et al.), and improved dance technique (Gruzelier et al., 2014) following HRV biofeedback. Additionally, preparatory heart rate deceleration has been implicated in expertise and success during self-paced closed skills (Cooke et al., 2010), and shooters often exhale during their shot process which decreases heart rate, an effect strengthened by HRV biofeedback (Lehrer et al., 2000).

Outside of RFT sessions, objective evidence for intervention effectiveness is limited to simulated competition respiratory data and anecdotal evidence for both emotional regulation and improved performance. Insufficient simulated competition HRV data quality may have been due to inappropriate Hexoskin fit, and sufficient HRV data may have provided further evidence for psychohysiological benefits. As this was a true case study of applied practice and not a research study, it is important to note the lack of pre-intervention baseline measures of emotional regulation, and the inherent limitations of client feedback. Much of the client feedback has been ommitted due to limited space, however Louise described multiple instances where she used RF breathing to manage competitive and general life stressors. It is difficult to determine the precise contribution that Louise's RFT made to performance improvements, and other interventions have similarly reported concomitant long-term improvements (e.g., Lagos et al.). However, the intervention aim was to teach Louise an on-demand emotional regulation technique for use during competiton. The combination of physiological and anecdotal evidence suggests that this aim was achieved.

More research is needed to explore potential psychomotor benefits of HRV biofeedback for athletes, however growing evidence for psychological benefits alone suggests that these interventions warrant wider adoption in sport psychology practice. Louise's RFT was data-driven using specialist equipment, however the psychophysiological benefits from RFT can be achieved without such investment. As a cost-free solution to teach the techniques without HRV data collection, practitioners can use mobile applications to pace an individual's breathing at a human average RF (four seconds inhale, six seconds exhale; Lehrer et al., 2000). Alternatively, there is growing support for the efficacy and accuracy of low-cost (approximately $120), data-based interventions using smart phone devices (Heathers, 2013). These solutions are often supplied with finger or ear clip PPG sensors to measure HRV during paced breathing activities, and may enable users to program bespoke breathing patterns for differing purposes. Some newer generations of wearable, smart fitness trackers include paced breathing activities to help users manage daily stress, and could provide another way to begin and practice HRV biofeedback techniques. Regardless of the solution, we recommend practice in differing situations and accuracy testing to reinforce confidence and efficacy in achieveing the benefits in performance situations.

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Figure 1. Case study timeline.

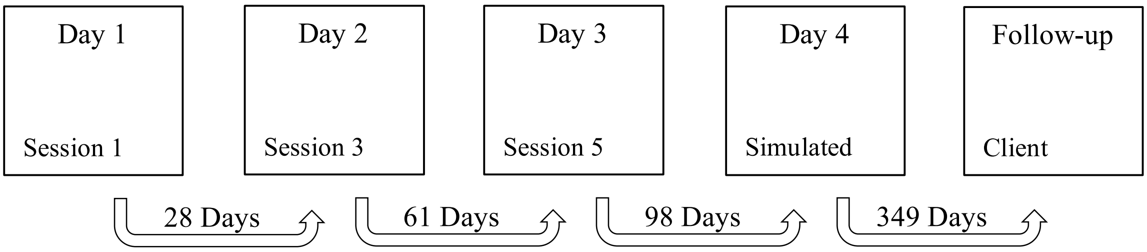

Figure 2. Resonant Frequency (RF) accuracy across six accuracy tests (AT). mDist = mean distance from RF in breaths per minute (bpm).

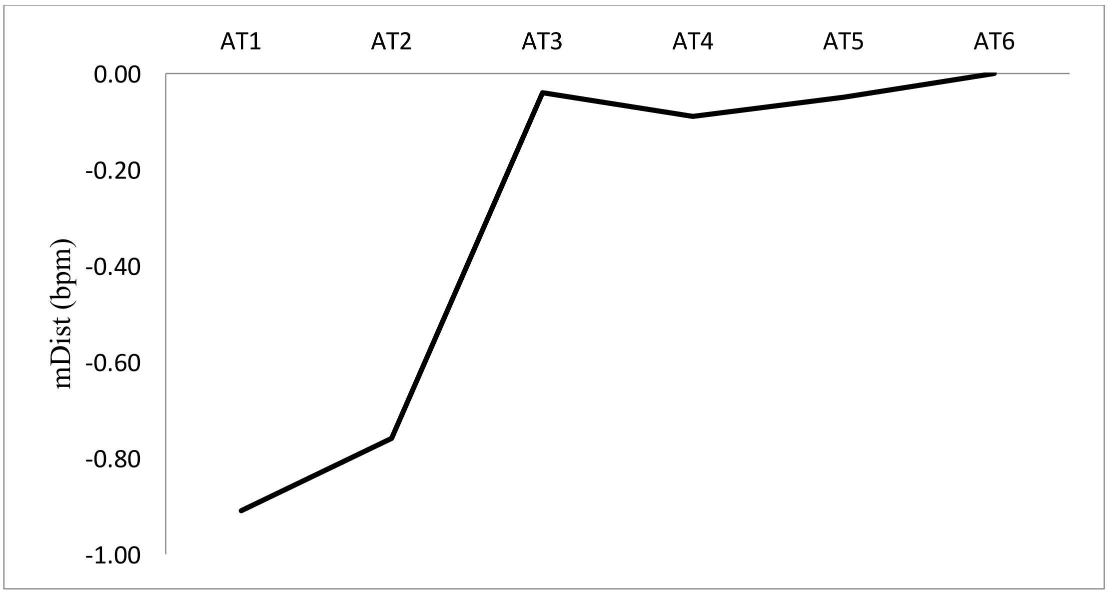

Figure 3. Olympic Trap layout with timing and respiratory data. Targets appear from an underground Clay Trap, traveling away from the shooting positions, shooters fire outwards into the Shooting Range. Six shooters fire from positions 1 to 5, position 6 is a holding position. The average time Louise spent Resonant Frequency (RF) breathing between positions is presented in seconds with standard deviations. RF accuracy is presented as mDist values (mean distance from target RF in breaths per minute), where 0 represents perfect accuracy. Negative values indicate a breathing pace slower than the target RF, whereas positive values indicate a breathing pace faster than the target RF.