Appl Psychophysiol Biofeedback
DOI 10.1007/s10484-017-9364-2

Effect of Heart Rate Variability Biofeedback on Sport Performance, a Systematic Review

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Abstract Aim is to determine if the training with heart rate variability biofeedback allows to improve performance in athletes of different disciplines. Methods such as database search on Web of Science, SpringerLink, EBSCO Academic Search Complete, SPORTDiscus, Pubmed/Medline, and PROQUEST Academic Research Library, as well as manual reference registration. The eligibility criteria were: (a) published scientific articles; (b) experimental studies, quasi-experimental, or case reports; (c) use of HRV BFB as main treatment; (d) sport performance as dependent variable; (e) studies published until October 2016; (f) studies published in English, Spanish, French or Portuguese. The guidelines of the PRISMA statement were followed. Out of the 451 records found, seven items were included. All studies had a small sample size (range from 1 to 30 participants). In 85.71% of the studies (n = 6) the athletes enhanced psychophysiological variables that allowed them to improve their sport performance thanks to training with heart rate variability biofeedback. Despite the limited amount of experimental studies in the field to date, the findings suggest that heart rate variability biofeedback is an effective, safe, and easy-to-learn and apply method for both athletes and coaches in order to improve sport performance.

Keywords Heart rate variability · Biofeedback · Sport performance · Athletes · Autonomic nervous system

Electronic supplementary material The online version of this article (doi:10.1007/s10484-017-9364-2) contains supplementary material, which is available to authorized users.

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Introduction

Heart rate variability (HRV) corresponds to a measure of the variation in duration between each heartbeat over time (Thayer et al. 2012) which, through a conventional electrocardiogram, can be observed as the variability of the N–N intervals, and is considered a quantitative marker for assessing adequate cardiac regulation by the autonomic nervous system as a response to both physical and psychological stimuli (Dong 2016). HRV can be reduced before situations that generate stress and anxiety in the subject (Miu et al. 2009), such as complex decision making or dealing with an audience (Dong 2016), which is inevitable during competition events usually involving observers where athletes decisions turn a matter of winning or losing.

There are several algebraic methods and graphs that allow to study and describe the HRV, among which the most used, correspond to the methods of time domain and frequency domain. A detailed description of each of these methods, as well as their uses and limitations, can be consulted in the guide developed by the *Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology* (1996), which has been widely cited in the field of HRV.

Biofeedback is the process of measuring various normal physiological parameters and visualizing these measurements in real time, to increase a subject's awareness of the effect his actions, thoughts and emotions can cause on his organism, in order to develop greater control of these physiological parameters (Prinsloo et al. 2014). The biofeedback of heart rate variability (HRV BFB) is a technique developed in the late 1980s and early 1990s, systematized and standardized by Lehrer et al. (2000), and consists of a psychophysiological training technique in which the subject observes both his respiratory and heart rates on

Published online: 01 June 2017

a monitor, in order to try to synchronize the two curves until a sinusoidal pattern is obtained, in such a way that a maximum coincidence can be found between the inspiration and the increase of the heart rate (HR), and between expiration and HR decline. That is, the subject is sought to maximize respiratory sinus arrhythmia (Lehrer and Gevirtz 2014) through a method that has important advantages such as ease of learning, economy, speed and non-invasiveness (Prinsloo et al. 2014).

With the technique developed by Lehrer et al. (2000) the subject is expected to breathe slowly. The maximum values of HRV, and the greatest amplitude in respiratory sinus arrhythmia, are obtained in the majority of people with a respiratory rate of approximately six breaths per minute (ie, 0.1 Hz). This respiratory rate, at which respiratory sinus arrhythmia is maximized, is known as a “resonance frequency” (Lehrer et al. 2000). By maximizing respiratory sinus arrhythmia, a greater gaseous exchange at the alveolar level is promoted (Hayano et al. 1996) and, at the same time, a greater fluctuation of blood pressure is stimulated in each respiratory phase (inspiration or expiration). This induces a greater stimulation to the baroreflex mechanism, which is strengthened even at resting states thanks to the practice of HRV BFB twice a day at home with a portable device (Lehrer et al. 2003), and this greater efficiency in the baroreflex allows to increase efficiency in modulating the autonomous system (Lehrer et al. 2000).

A high HRV is associated with a better general health status as it allows the organism to better adjust to external and internal stimuli (Lehrer et al. 2003) and, in parallel, a low HRV is a predictor of cardiovascular and metabolic and higher risk of mortality (Buccelletti et al. 2009; Cornelissen et al. 2010; da Silva et al. 2016). For these reasons, the use of HRV BFB has been evaluated in several pathologies and has shown benefits in physical and psychological variables in multiple pathologies such as asthma, chronic obstructive pulmonary disease, recurrent abdominal pain, irritable bowel syndrome, cyclic vomiting, fibromyalgia, post rehabilitation of acute myocardial infarction, congestive heart failure, coronary artery disease, arterial hypertension, metabolic syndrome, chronic muscle pain, depression, phobias, stress, anxiety, and sleep disorders (see reviews by Gevirtz 2013; and; Prinsloo et al. 2014). The favorable effects in all these pathologies have tried to be explained by diverse mechanisms of action, such as: (a) the restoration of autonomic homeostasis, (b) a greater stimulation of the vagus nerve, which in turn has effects on the central nervous system, and (c) increased stimulation of the cholinergic anti-inflammatory pathway (Gevirtz 2013).

In the case of physical activity and exercise, there are also findings that show that those who are sedentary or have a lower aerobic physical capacity have a lower HRV (Boutcher et al. 2013; Hautala et al. 2003) and that exercising increases HRV in patients with cardiovascular diseases (Routledge et al. 2010) as well as in athletes (Achten and Jeukendrup 2003; Aubert et al. 2003; Sandercock and Brodie 2006). The benefits of HRV BFB has also been studied in coaches and support staff of elite athletes, who also face high level demand and stress in their working environment (Gross et al. 2016).

Considering sport performance as “a complex product of cognitive knowledge about the current situation and past events, combined with a player’s ability to produce the sport skill(s) required” (Thomas et al. 1986, p. 259), and the apparent benefits of HRV BFB in anxiety and other physical variables, this systematic review seeks to assess if there is evidence to support the use of HRV BFB to improve the sport performance of athletes from different disciplines.

Methodology

Search Procedure

The search was conducted between July 1st and October 1st 2016, using the keywords “heart rate variability”, “biofeedback” and “sports performance”, as well as their related terms and synonyms in the electronic databases *Web of Science, SpringerLink, EBSCO Academic Search Complete, SPORTDiscus, Pubmed/Medline*, and *PROQUEST Academic Research Library*. An example of the search strategy (Pubmed) corresponds to (“heart rate” [MeSH terms] OR (“heart” [All fields] AND “rate” [all fields]) OR “heart rate” [all fields]) AND variability [all fields] AND (“biofeedback, psychology” [MeSH terms] OR (“biofeedback” [all fields] AND “psychology” [all fields]) OR “psychology biofeedback” [all fields] OR “biofeedback” [all fields]) AND (“athletic performance” [MeSH terms] OR (“athletic” [all fields] AND “performance” [all fields]) OR “athletic performance” [all fields] OR (“sports” [all fields] AND “performance” [all fields]) OR “sport performance” (all fields]). In addition, a manual reference search was performed on the records found.

Documents that were not initially located in full text were requested directly to the main authors and in cases where no response was obtained, both tracking and acquisition of the full text files were managed through a Librarian of SIBDI (Library System, Documentation and Information) of the University of Costa Rica. No restrictions were set on the insertion date ranges of each database. The guidelines established in the PRISMA statement (Moher et al. 2009) were followed for the preparation and reporting of this systematic review. The management of bibliographic references and file storage was done with Mendeley software version 1.15.3. The data of interest extracted from the articles included in the review were coded and organized with Microsoft Excel® 2010. Bibliographical references of those files that failed in meeting the eligibility criteria, and were not included in the systematic review, were stored in an additional file (Appendix 1), which also contains the exclusion criteria for each case.

Eligibility Criteria

To be included in the systematic review, the studies had to meet the following requirements: (a) published scientific articles; (b) experimental, quasi-experimental, or case reports; (c) use of HRV BFB as the main treatment; (d) sport performance as a dependent variable; (e) studies published until October 2016; (f) studies published in English, Spanish, French or Portuguese.

Selection of Studies and Extraction of Data of Interest

The procedure for searching and selecting the studies was performed independently by both authors, in order to compare and reach a consensus in case of discrepancies. In the same sense, a similar procedure was followed with the coding of the variables. All studies, either included or excluded, were stored in Mendeley Desktop version 1.15.3. For each article included in the analysis, the following data were extracted: country and year of publication, age and sex of participants, sample size, type of study, sport practiced by subjects, measured variables, intervention characteristics and measuring instruments.

Results

Figure 1 shows the flowchart of the search and selection process of studies. Of the total of 451 initial records, 7 studies were included for review. The list of excluded documents (n = 371), together with the exclusion reasons for each, can be found in Appendix 1. Table 1 describes the main characteristics of each study. Of the seven studies included in the review, four were from experimental studies, two were case reports, and one was a quasi-experimental study. The range of the sample size was 1–30 subjects and included the following sports: dance (n = 1), golf (n = 2), basketball (n = 2), volleyball (N = 1). In 85.71% of the studies (n = 6) the authors based their criteria on the HRV BFB protocol of Lehrer et al. (2000).

For the measurement of physiological variables, the most widely used equipment for laboratory measurements was the ProComp Infiniti® 5.0 (Thought Technology, Canada) physiographer in 57.14% of the studies (n = 4). In addition, the Freeze-Framer® photoplethysmograph (Boulder Creek, CA) (Raymond et al. 2005), the physiographer J & J Engineering I-330 (Poulsbo, WA) (Lagos et al. 2008) and the software inWavePC® (HeartMath, USA). In the studies of Lagos et al. (2008, 2011) participants also used a portable StressEraser® device (Helicor, NY) for HRV BFB practice in their homes.

The measurement of the psychological variables was carried out with different instruments and tests, including *profile of mood states (POMS)* (Lagos et al. 2008), *competitive state anxiety inventory (CSAI-2)* (Lagos et al. 2008, 2011), *11-item Stress Scale* and *9-item Seeking Sensation Inventory* (Lagos et al. 2011), test *Concentration Grid* (Paul et al. 2012), *State-Trait Anxiety Inventory* and *Coping Self-Efficacy Scale* (Paul and Garg 2012).

The athletic performance was evaluated with specific instruments according to the technical skills required by the athletes who participated in each study. In the case of dance, Raymond, Sajid, Parkinson and Gruzelier (2005) applied an evaluation scale designed by two professional dancers, based on the dance assessment scale used in US national competitions. Lagos et al. (2008) focused solely on the number of golf strokes required to complete an 18-hole game, while in Lagos et al. (2011) the authors, in addition to the number of hits, evaluated the number of putts, the average of the drive, and the largest drive. In the case of basketball, Paul et al. (2012) evaluated the number of races achieved in perimeter pitches for 3 min, reaction time and travel time, while Paul and Garg (2012) evaluated the number of races achieved in perimeter pitches for 3 min, dribbling (Harrison Basketball Battery) and passing accuracy (Stubb's Ball Handling Test). For the evaluation of technical skills in volleyball, Tanis (2012) applied a rubric designed for the study by volleyball coaches and the researcher, in order to qualify four technical skills (serve, pass the serve, low pass hand and stroke) using a 5-point Likert scale. Finally, Choudhary et al. (2016) evaluated long distance run performance by measuring the time required by athletes to complete a 5 km run.

The main results obtained in each study from the physiological, psychological and sport performance variables can be found in Table 1.

Discussion

The main purpose of this systematic review was to evaluate whether there is scientific evidence to support the use of HRV BFB to improve the performance of athletes from different disciplines. Although there are currently a few experimental studies in this field, from the results found in the studies included in this review it can be stated that HRV BFB could be a useful tool for athletes and their coaches as it is a safe way (non-invasive method), quick and accessible to improve the regulation of the autonomic function

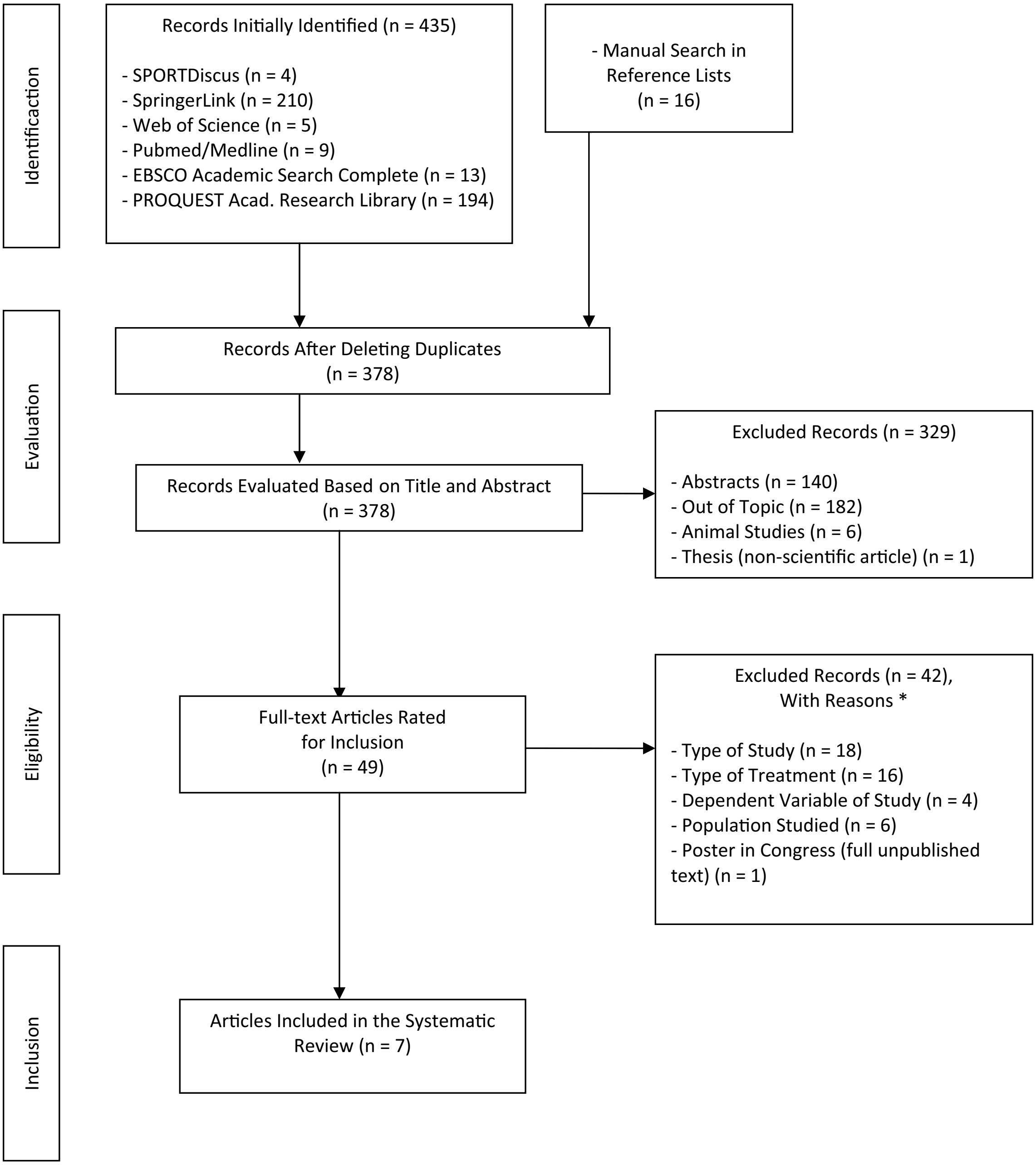

Fig. 1 Flow chart for the selection of studies. *Asterisk* represents the number of reasons exceeds the number of studies because some studies were excluded for more than one reason

of the heart through the practice of slow breathing, which produces an improvement in several psychophysiological variables that could influence sport performance.

It is important to take into account several factors that influence the HRV and the measurements made of this parameter. For example, from birth to 15 years of age, HRV in humans increases progressively and their heart rate remains low (Eyre et al. 2014), but as people age, HRV decreases, the sympathetic tone of autonomic nervous system predominates but decreases the parasympathetic tone (Abhishekh et al. 2013; Shiogai et al. 2010). On the other hand, women tend to have a greater predominance of parasympathetic tone, which can be observed in the higher spectral power of the high frequency in their HRV, compared to men (see meta-analysis by Koenig and Thayer 2016). In addition, ethnic differences were also found recently by Hill et al. (2015), who observed in their meta-analysis that Afro-descendent Americans have significantly higher HRV than those who are Euro-descendants. Likewise, physically active

Table 1 Main features of included studies

Study and country	Sample	Type of study	Sport and variables measured	Characteristics of the intervention	Main results
Raymond et al. (2005) and England	N = 18 9 women 9 men AA = 21.6 years	Experimental Group 1: *Neurofeedback* 3 couples	Dance in pairs Technique, musicality, synchronization, ability to work with a partner, instinct, and overall execution	Group 1: ten sessions of 20 min of neurofeedback in 4 weeks	Compared with the control group, HRV BFB improved "overall performance" ($z = 2.080$, $p < 0.05$) and "technique" ($z = 2.138$, $p = 0.05$). There was no significant improvement in the other skills
		Group 2: HRV BFB 2 couples		Group 2: protocol of Lehrer et al. (2000) modified to only ten sessions of 20 min of HRV BFB for 4 weeks	Compared with control group, neurofeedback improved "synchronization" ($z = 2.688$, $p < 0.05$). There was no significant improvement in the other skills
		Group 3: Control 4 couples		Group 3: dance practice in the normal way	There were no significant differences between neurofeedback and HRV BFB ($Z = 0.176$, $p > 0.05$)
Lagos et al. (2008) and USA	N = 1 Man Age = 14 years	Case report	Golf Psychological variables: anxiety in competition moods Physiological variables: HRV, RR Sports performance: number of strokes per game to complete 18 holes	Standard protocol of Lehrer et al. (2000): one supervised weekly session of 20 min in the laboratory for 10 weeks + unsupervised practice of two daily sessions of 20 min each	Significant reduction in "stress", "anger", "depression", "fatigue" and "self-confidence" (no statistical reporting) Increased total HRV and LF and HF indexes (no statistical reporting) Number of strokes required decreased from 91 (pre-test) to 76 (post-test) (no statistical reporting)
Lagos et al. (2011) and USA	N = 1 Woman Age = 21 years	Case report Use of virtual reality for golf course simulation and 18-hole game during performance evaluation	Golf Psychological variables: competition anxiety, stress Physiological variables: HRV, RR, HR Sport performance: 18-hole score, putts, average drive, higher drive	Standard protocol of Lehrer et al. (2000): one supervised weekly session of 20 min in the laboratory for 10 weeks + unsupervised practice of two daily sessions of 20 min each	Decreased somatic and cognitive anxiety (no statistical reporting). Increase of total HRV and of LF and HF indexes. Decreased LF/HF index (no statistics reported) Reduction in the number of strokes to complete the virtual 18-hole game (46 strokes in the pre-test, 30 in the post-test) as well as an increase in average drive from 170 to 184 yards. Largest drive 219 yards to 221 yards (no statistics reported)

Table 1 (continued)

Study and country	Sample	Type of study	Sport and variables measured	Characteristics of the intervention	Main results
Paul et al. (2012) and India	N = 30 14 women 16 men AA = 21.70 ± 2.71 years	Experimental Group HRV BFB: 2 women and 8 men Group placebo: 8 women and 2 men Group control: 3 women and 7 men	Basketball Psychological variable: concentration Physiological variables: HRV, RR Sport performance: reaction time, travel time, perimeter pitch for 3 min	Group HRV BFB Protocol of Lehrer et al. (2000) modified to a session a day of 20 min each for ten consecutive days Group placebo: observation of basketball motivational videos for 10 min a day for ten consecutive days Group control: follow normal practice	Significant improvement in concentration in the three Groups, with differences between Groups ($F = 39.37$, $p < 0.001$). *Post hoc* (Tukey): differences between HRV BFB and placebo, between HRV BFB and control, but not between placebo and control. Effects were maintained 1 month later Improvement in total HRV in the 3 Groups, with differences between Groups ($F = 6.66$, $p = 0.004$). *Post hoc* (Tukey): same behavior between Groups. Effects were maintained 1 month later Improvement in movement time and throws in the three Groups, with differences between Groups ($F = 4.86$, $p = 0.02$ and $F = 11.05$, $p < 0.001$, respectively). *Post hoc* (Tukey): same behavior between Groups. Effects were maintained 1 month later

Table 1 (continued)

Study and country	Sample	Type of study	Sport and variables measured	Characteristics of the intervention	Main results
Paul and Garg (2012) and India	$N = 30$ 13 women 17 men $AA = 21.13 \pm 2.82$ years	Experimental Group HRV BFB: 2 women and 8 men Placebo Group: 8 women and 2 men Control Group: 3 women and 7 men	Basketball Psychological variable: anxiety Physiological variables: HRV, RR Sport performance: dribbling, pass accuracy, perimeter throws for 3 min	Same design as in Paul et al. (2012) for each of the three groups	Anxiety-status and anxiety-trait improved in the three groups, with differences between groups ($F = 10.767$, $p < 0.001$ and $F = 6.628$, respectively). *Post hoc* (Tukey): differences between HRV BFB and placebo, between HRV BFB and control, but not Between placebo and control. Effects were maintained 1 month later Increase in total HRV in the three groups, with differences between groups ($F = 6.610$, $p < 0.05$). *Post hoc* (Tukey): same behavior between groups. Effects were maintained 1 month later Improvement in dribbling, accuracy of passes and throws in the three groups, with differences between groups ($F = 14.181$, $p < 0.001$); ($F = 9.860$, $p < 0.001$ and $F = 15.206$, $p < 0.001$ respectively) Effects were maintained 1 month later
Tanis (2012) and USA	$N = 13$ women No data of AA	Quasi-experimental Mixed design (qualitative and quantitative)	Volleyball Four technical skills: take out, pass the serve, low pass, and hit Qualitatively: self-perception of improvement or non-improvement with the use of HRV BFB and affective control	Guidelines for HRV BFB from Blumenstein et al. (1997), Culbert et al. (2004), and Quick Coherence Technique (Heart Math Institute 2008) One weekly session for six consecutive weeks of HRV BFB + Personal diary to register affective control and progress in the practice of HRV BFB	Quantitatively, there were no significant differences in the qualification of technical skills in their performance as a team. In his individual performance, only 1 athlete improved his score. Qualitatively, the participants stated in interviews and journals that they did perceive benefits and improvement after the intervention with HRV BFB for affective control mainly

Table 1 (continued)

Study and country	Sample	Type of study	Sport and variables measured	Characteristics of the intervention	Main results
Choudhary et al. (2016) and India	N = 24 12 women 12 men AA = 22.54 ± 1.72 years	Experimental Experimental Group: 12 people Control Group: 12 people	Long-distance running Physiological variables: HRV, skin conductance, venous pulse, VO_2max, RR Sport performance: time to complete 5 km race	Standard protocol of Lehrer et al. (2000): one supervised weekly session of 20 min in the laboratory for 10 weeks + unsupervised practice of two daily sessions of 20 min each	Significant reduction in race time in experimental group (pre-test 18.25 min, post-test 16.99 min, $p < 0.035$) Decreased skin conductance ($p < 0.01$) Increase of VO_2max ($p = 0.041$)

AA average age, *HRV BFB* biofeedback of heart rate variability, *HRV* heart rate variability, *USA* United States of America, *POMS* profile of mood states, *CSAI-2* competitive state anxiety inventory, *HR* heart rate, *RR* respiratory rate, *MOART* multi-operational apparatus for reaction time, *STAI* state-trait anxiety inventory, *CSES* coping self-efficacy scale, *QCST* Queens College Step Test, *LF* low frequency, *HF* high frequency

individuals tend to have higher HRV (see meta-analysis by Sandercock et al. 2005).

Sandercock et al. (2005) also recommend evaluating HRV from both 24-h ambulatory records and resting records, of between 2 and 7 min, since the effect sizes of the influence of recording time on the duration of RR intervals tend to be larger when the HRV recording time is low (Sandercock et al. 2005). This may lead to erroneous conclusions if only short-term records are used. Also, it is advisable to consider the mathematical relationship between HR and HRV (an increase in HR decreases HRV, and vice versa) and perform a mathematical adjustment (HR normalization) instead of directly comparing subjects with different mean HR. This normalization allows to increase the precision in the interpretation of the results of HRV (Billman 2013; Sacha 2013).

The methodological designs of the studies that seek to evaluate the effectiveness of HRV BFB on sports performance must take into account the aforementioned factors, since they can influence the correct interpretation of the HRV and, therefore, one must try to control those factors (for example, Raymond et al. (2005), Paul et al. (2012), Paul & Garg (2012) and Choudhary et al. (2016) mixed men and women in their studies). In the seven studies included in this review only young athletes were evaluated, and in none of the studies were 24-h ambulatory records available to obtain the HRV time and frequency domains.

Another methodological aspect that must be taken into account when evaluating the effectiveness of HRV BFB in athletes is the participation modality (individual or collective sports), since each individual presents a resonance frequency of his own (ie, that frequency in which the respiratory sinus arrhythmia is maximized by synchronizing the respiratory rate with the heart rate). This implies that training with HRV BFB should be personalized and evaluated over time to make adjustments according to the progress and needs of each athlete (Lehrer et al. 2000), which may represent difficulties for research in evaluating the impact of this treatment on sporting performance in collective sports. Of the articles included in this review, only Tanis (2012) studied whether HRV BFB improves performance both individually and as a team in college volleyball players, with negative results. A valuable contribution of this author to the field of HRV BFB in sport performance, and that was not approached by the authors of the other studies of this review, corresponds to the level of training that the athletes possess, since the volleyball players evaluated in that study showed a very high level of technical skill at the time of the intervention, which could have prevented finding quantitative benefits of HRV BFB. Failing in indicating the level of training of athletes in this type of study may make it difficult to obtain more precise conclusions when interpreting HRV results (Sandercock et al. 2005).

Only 42.85% of the studies (n = 3) used the standard protocol of Lehrer et al. (2000), which consists of the practice of HRV BFB for 10 weeks, which are performed either in supervised form (in the laboratory, once a week for 20 min) or unsupervised (at home, with portable device, two sessions per day of 20 min each). Paul et al. (2012) and Paul and Garg (2012) modified this protocol to only ten consecutive days of HRV BFB for 20 min daily, Raymond et al. (2005) modified it to ten sessions of 20 min over 4 weeks, and Tanis (2012) followed the protocol of Blumenstein et al. (1997). As can be seen, there is a high heterogeneity in the protocols followed, especially in terms of session volume and practice time of the HRV BFB technique. However, it is interesting to note that despite these differences all authors, except Tanis (2012), found improvements in most of the physical and psychological variables they studied. In this sense, a greater precision is needed in the reporting of the results, since of the seven studies analyzed only Raymond et al. (2005), Paul et al. (2012), Paul and Garg (2012) and Choudhary et al. (2016) reported the statistics used and their respective values of significance or non-significance.

Psychological Variables and Effectiveness of HRV BFB

Lagos et al. (2008, 2011), Paul and Garg (2012), and Paul et al. (2012) evaluated the effect of HRV BFB on some psychological variables of interest for sport performance such as concentration, stress and anxiety. These factors are important in a sport competition as the result (win or lose) can be determined by both internal factors of the athlete and the external elements surrounding him.

The athlete's state of anxiety when competing results from the interaction between his anxious personality traits and the environment in which he is during the sporting event (Eysenck and Calvo 1992; Eysenck et al. 2007). Meditation has been considered an effective technique for controlling anxiety in different contexts and subjects, including athletes (Krisanaprakornkit et al. 2006). The benefits observed in the psychological variables through HRV BFB training could be explained by the development of a greater capacity in the athlete to reduce the attentional issue on an internal element (his respiratory rate during a competition) and thanks to this to reduce external disturbances (Nideffer 1986, 1989), such as the audience observing competition, sounds, other competitors around them, among other elements.

These characteristics of the HRV BFB make it comparable with mindfulness-type meditation techniques, which led Bruin, van der Zwan and Bögels (2016) to compare this meditation technique with HRV BFB and physical exercise. These authors found that all three treatments were equally effective in improving attention control, executive function, conscious attention, self-pity and concern, with no significant differences between any of the three treatments.

Some oriental disciplines such as yoga, zen and qigong involve slow breathing techniques, which could be compared with the protocol technique of Lehrer et al. (2000), but lack standardized methods that can be easily replicated by athletes and their trainers. Also, those who teach these techniques generally do not explain them in the same way, which limits the extent of their applicability in a standardized way. On the contrary, HRV BFB has the advantage of being a simple replicable and standardized method that can be quickly learned by the subjects (Lehrer et al. 2000) and can be practiced anywhere and at any time thanks to the technological development of portable devices and applications for phones, tablets and computers.

HRV BFB and Technological Advances

Currently there are several devices that allow monitoring of HRV and training subjects in controlled environments, such as university laboratories. For example Biograph Infiniti with Cardiopro® (Thought Technology), Freeze-Framer® (Boulder Creek, California, USA), J&J Engineering® I-330 DSP-12 (Poulsbo, WA), Procomp Infiniti® (Thought Technology). Other devices are portable and allow the subject to train in their own home, such as Wave2® (Quantum Intech), StressEraser® (Western Cape Direct), as well as interactive computer programs such asWave PC® (Quantum Intech), Journey to Wild Divine: Wisdom Quest® (Wild Divine), Relaxing Rhythms® (Wild Divine). The advantage of portable devices is that they can be used even before a stressful situation (Prinsloo et al. 2014) as a sports competition could be.

Likewise, more and more applications are being developed for smartphones and tablets that allow the user to monitor their HRV, some are paid and others are free; for example, for iOS and Android there are MyCalmBeat®, Alive®, Instant Heart Rate®, StressCheck®, Elite HRV®, ithlete®, Hexoskin®, Stress Releaser Meditation®, Vitalmonitor®, Bioforce HRV®, and HeartChart® applications. Many of these applications seek to facilitate athletes' constant monitoring of their HRVs in order to prevent overtraining, a booming area in the HRV BFB field by both coaches and athletes, as there is evidence supporting their use for training schedules and load volumes because low HRV may be indicative of overtraining status (Buchheit 2014, Dong 2016; Mourot et al. 2004).

Conclusions

Although to date there are a few experimental studies with high methodological quality that evaluate the effectiveness of HRV BFB in sporting performance, the results found in this systematic review support the hypothesis that this technique can be a useful, safe, easy to learn and apply tool for both athletes and coaches in order to improve autonomic cardiac regulation, which is impressive to have benefits in different psychophysiological variables that could be determinant in sports performance.

Recommendations

There is a need to develop more studies in this field, with more methodological rigor, to apply the treatment in periods longer than 10 weeks to determine if training with HRV BFB has long-term effects. Further studies are needed to determine how many sessions are required to obtain favorable results, as well as more extensive HRV BFB records that allow a more in-depth exploration of the different HRV frequency domains throughout the day.

The latest technological tools, such as new computer software and applications for phones and tablets, have not been scientifically validated, and studies are needed to obtain more information about their reliability, scope and limitations of use.

Funding No funding was received to perform this systematic review.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Approval This article does not contain any studies with human participants or animals performed by any of the authors.

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