Review Article

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A preliminary systematic review and meta-analysis on the effects of heart rate variability biofeedback on heart rate variability and respiration of athletes

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Abstract: To date, there is no quantitative review examining the influence of heart rate variability biofeedback (HRV BFB) on the athlete population. Such an undertaking may provide valuable information on the autonomic and respiration responses of athletes when performing HRV BFB. Thus, purpose of this preliminary systematic review and meta-analysis on the effects of HRV BFB on HRV and respiration of athletes. Searches of Springerlink, SportDiscus, Web of Science, PROQUEST Academic Research Library, Google Scholar, and ScienceDirect were conducted for studies that met the following criteria: (1) experimental studies involving athletes that underwent randomized control trial; (2) availability of HRV BFB as a treatment compared with a control (CON)/placebo (PLA); (3) any pre and post HRV variable and/or breathing frequency as dependent variable/s; and, (4) peer-reviewed articles written in English. Four out of 660 studies involving 115 athletes (25 females and 90 males) ages 16–30 years old were assessed in this review. Preliminary findings suggest the promising ability of HRV BFB to improve respiratory mechanics in athlete population. More work is needed to determine the autonomic modulatory effect of HRV BFB in athletes.

Keywords: athletes; biofeedback; heart rate variability; resonance frequency breathing.

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Introduction

Cardiac rhythm is controlled by the autonomic nervous system (ANS) through the parasympathetic nervous system (PNS) and sympathetic nervous system (SNS) [1–4]. PNS and SNS operate via the sinoatrial node (SA node) which is mainly responsible for increasing or decreasing heart rate [5]. The interaction of PNS and SNS can be assessed using a non-invasive and reliable method called heart rate variability (HRV) [1, 4]. HRV refers to fluctuations between heartbeats that represent sinus node depolarizations in the QRS complexes of the electrocardiogram (ECG). The QRS intervals, specifically the distance between R to R intervals, are computed to derive time, frequency, and non-linear domains of HRV [4, 6, 7]. Depressed HRV reflect sympathetic overactivation and is linked to various clinical and psychological diseases [8–10]. On the other hand, the presence of high HRV is believed to represent homeostasis and resilience to stress [9, 11, 12].

Over the last decade, interventions aimed at increasing HRV, with the goal of improving health, have received notable attention. Among these is HRV biofeedback (HRV BFB), a non-invasive intervention utilizing paced respiration assisted by visual feedback [9, 13–16]. HRV BFB was first documented in a clinical facility in Russia [17]. A typical HRV BFB set-up consists of heart rate (HR) and respiration sensors linked to a computer screen with breathing pacer and provides real-time values of HR and respiratory rate (RR). HRV BFB use resonance frequency (RF) which presents oscillatory episodes: (a) a 0-degree phase shift between HR and respiration; and, (b) a 180-degree phase relationship between HR and blood pressure (BP) [18–20]. Additionally, researchers also discovered peak gas exchange and oxygen saturation at RF [21, 22].

Autonomic responses from HRV BFB have been linked to various physiological mechanisms [9, 14]. Firstly, HRV BFB is believed to enhance baroreflex sensitivity [14, 23].

The baroreflex system (BRS) plays a critical role in regulating BP that protects the body from acute blood pressure shifts [14, 20]. The BRS operates in a closed loop system wherein baroreceptors react to shifts in BP and increase or decrease HR [20]. Briefly, elevation in BP reduces HR, while BP depression increases HR. Oppositely, increases in HR elevate BP, while decreases in HR elevates BP. The baroreceptors in the BRS are located in the heart and aortic arch that send chemical and mechanical information to the nucleus of the solitary tract [5]. The nucleus of the solitary tract is connected to other regulatory centers in the medulla wherein SNS outflow to the heart and blood vessels are controlled. These reactions present a mechanical delay of about five seconds due to inertia and vascular plasticity. During HRV BFB, the amplitude of HR oscillations is maximized and stimulates baroreflex response [13, 18–20]. With constant HRV BFB practice, improved baroreflex function can be achieved over time [14]. Another possible mechanism in HRV BFB is the vagal afferent pathway stimulation [9, 14]. HRV BFB promotes the activity of subdiaphragmatic vagal afferents and enhance the vagal braking system responsible for immediate control of HR and BP. It has also been postulated that HRV BFB strengthens the parasympathetic vagal efferent pathway through accentuated antagonism, a physiological response that inhibits tonic sympathetic activation from abrupt parasympathetic stimulation under normal physiological conditions in rest and exercise [3, 14, 24]. Similarly, enhancement of cholinergic anti-inflammatory pathway (CAP) may also be present in HRV BFB [25, 26]. During HRV BFB, vagal activation in CAP releases acetylcholine which reduces inflammatory activity in macrophages, thereby diminishing pathogenesis [27, 28].

As the majority of literature reviews in HRV BFB has been conducted on healthy populations or people with chronic conditions, there remains a paucity of systematic literature on the effects of HRV BFB on autonomic indices in athletes. This information may be helpful in understanding the autonomic and respiratory responses of athlete population with HRV BFB training. Thus, the purpose of this study was to conduct preliminary systematic review and meta-analysis on the effects of HRV BFB on HRV and respiration of athletes.

Materials and methods

Search strategy and inclusion criteria

Literature search was administered between July 1st to December 20th 2017 using the search term "heart rate variability biofeedback" AND (athletes OR athletic population OR sport OR performance OR sport performance) in electronic databases (Springerlink, SportDiscus, Web of Science, PROQUEST Academic Research Library, Google Scholar, and ScienceDirect) adhering to the PRISMA guidelines [29, 30]. A manual search in the reference section of relevant articles were performed to include additional studies for assessment. Studies met all the following inclusion criteria: (1) experimental studies that involved random group allocation of athletes; (2) availability of HRV BFB as a treatment group compared with a control (CON)/placebo (PLA); (3) any pre and post HRV parameter and/or breathing frequency as dependent variable/s; and, (4) peer-reviewed articles written in English.

Coding of studies

Literature search and selection of studies was conducted by a single investigator (JP) with studies coded and organized in an Excel spreadsheet. Data extraction was evaluated by a second investigator (YSC). Articles included in the systematic review were encoded by author/s and year of publication, sample size information, intervention, measured HRV parameters, and results. Risk of bias in a study was also assessed by both investigators using the eight-point Consolidated Standards of Reporting Trials (CONSORT) statement [31]. Each item in the CONSORT statement is answerable by 0 (absent or inadequately described) or 1 (explicitly described and present). A study with a score of 0–2 is regarded as having a high risk of bias, 3–5 with medium risk of bias, and 6–8 considered as having low risk of bias [31]. Any disagreement presented in data extraction and CONSORT output was settled by a consensus between the first and second investigator. Personal correspondence to the author/s of an included study for any clarification was also administered.

Meta-analysis

Meta-analysis was carried out if at least two studies provided sufficient data to compute for effect sizes (ES). The natural logarithm of low frequency HRV (lnLF), high frequency HRV (lnHF) and total power (lnTP) were utilised as HRV markers for analysis [4, 32, 33]. LF (0.04–0.15 Hz) is a marker of parasympathetic and sympathetic activity, while HF (0.15–0.40 Hz) depicts parasympathetic activity. Total power (0.04–0.40 Hz) reflects a global marker of autonomic modulation. Additionally, normalized units of LF and HF were also used for HRV analysis [4, 34]. Respiration was examined via breathing frequency. The mean difference and change in standard deviation (SD) from baseline to post-measures were computed in all the studies. Change in SD was derived based on imputed standard deviation method with correlation coefficient set at 0.40 [35–37]. Meta-analysis was conducted in a free software (Review Manager version 5.3). The standard mean difference was used to interpret ES as small=0.20, moderate=0.50, or large=0.80 [38, 39]. Heterogeneity was evaluated using I^2 [40]. The I^2 represents the percentage of between-study variance due to heterogeneity vs. chance based on 0% (no heterogeneity) –100% (high heterogeneity) scale. Visual inspection of a funnel plot was utilised to examine potential publication bias [41]. Lastly, data at resting conditions were utilised in meta-analysis.

Results

Literature search

A total of 656 potential articles and four identified articles from reference lists were included in the database. Removal of duplicates (n=90) led to initial screening of 570 articles on the basis of article title and abstract. After initial screening, 556 articles were eliminated by JP. Then, full articles of 14 studies were assessed for eligibility. An article was then excluded after failing to meet any of the items mentioned in the above inclusion criteria. In addition, the study of Paul and Garg [42] was excluded as it posted the same HRV and respiration values with earlier published study (Paul et al., 2012) [43]. Four studies were eventually included in the systematic review, while three studies qualified for meta-analysis. Figure 1 displays the flow chart and selection process for the systematic review and meta-analysis.

Risk of bias in the study is displayed in Table 1. Two studies scored 5 points [43, 44] while two studies scored 3 points [45, 46].

Experimental protocols

Participants in the four studies involved 115 athletes (25 females and 90 males) which comprised 28 male and 13 female basketball athletes, 50 male football athletes, 12 male and 12 female track and field athletes with ages ranging from 16 to 30 years old.

All four studies included comparison of HRV BFB and CON [44–46], while only one study [43] compared HRV BFB and PLA. CON involved regular sport training in all studies. Paul et al. [43] implemented 10 consecutive days of HRV BFB with each session lasting for 20 min. Additionally, motivational videos were used in PLA. Dziembowska et al. [46] administered HRV BFB for 10 20-min sessions within 3 weeks. Rusciano et al. [44] facilitated 15 sessions of HRV BFB lasting 30 min/session for twice a week. Choudhary et al. [45] conducted 10 formal sessions of HRV BFB alongside with two 20 min daily HRV BFB practice at convenience for 10 weeks.

Different physiological parameters were identified from the studies above. Four studies included LF as a parameter for comparison [43, 44, 46]. Two studies utilized

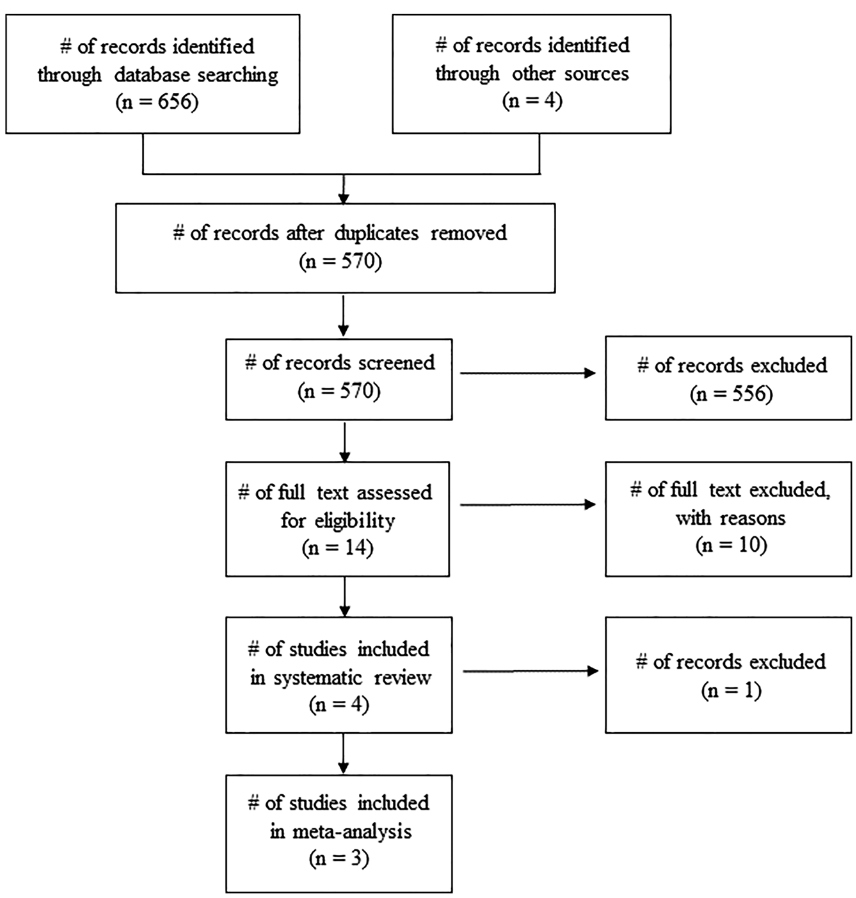

Figure 1: Flow diagram of search Process.

Table 1: CONSORT scores of HRV BFB studies included in systematic review.

	Were the groups comparable at baseline on key characteristics?	Did the study include a true control group (randomised participants – not a comparison group)?	Was the randomisation procedure adequately described and carried out?	Did the study report a power calculation and was the study adequately powered to detect intervention effects?	Were the assessors blinded to treatment allocation at baseline and post-test?	Did at least 80% of participants complete follow up assessments?	Did the study analyses account for potential differences at baseline?	Did the study report effect sizes?	Total
Choudhary et al. 2016	1	0	0	0	0	1	1	0	3
Dziembowska et al. 2016	0	0	1	0	0	1	1	0	3
Paul et al. 2012	1	0	1	0	1	1	1	0	5
Rusciano et al. 2017	1	0	1	0	0	1	1	1	5

high frequency (HF) and total HRV for assessment [43, 46]. One study compared LF/HF output [45]. Respiration rate (RR) was differentiated in two studies [43, 44]. The characteristics of studies are presented in Table 2.

HRV BFB vs. CON

lnLF

There was no significant difference in lnLF between HRV BFB and CON, ES=0.12 [−0.39, 0.62], Z=0.65, $p<0.05$ (Figure 2).

LFnu

The LFnu in HRV BFB was significantly higher compared to CON, ES=0.46 [0.02, 0.91], Z=2.05, $p<0.05$ (Figure 3).

lnHF

The lnHF was not significantly different in HRV BFB and CON, ES=−0.04 [−0.55, 0.46], Z=0.05, $p>0.05$ (Figure 4).

HFnu

Meta-analysis of HFnu between HRV BFB and CON exhibited lower HFnu in HRV BFB than CON, ES=−0.78 [−1.31, −0.25], Z=2.88, $p<0.01$ (Figure 5).

lnTP

There was no significant difference in lnTP in HRV BFB and CON, ES=−0.36 [−1.20, 0.48] Z=0.84, $p>0.05$ (Figure 6).

RR

Meta-analysis of RR between HRV BFB and CON posted significant reductions in RR of HRV BFB than CON, ES=−4.30 [−5.53, −3.08], Z=6.90, $p<0.01$ (Figure 7).

The funnel plots of HRV and respiration measures in the meta-analyses are demonstrated in Figure 8. The HRV values and respiration in HRV BFB and CON are displayed in Table 3.

Discussion

The purpose of this novel study was to conduct a systematic review and meta-analysis on the effect of HRV BFB on physiological indices among athletes. Meta-analyses

Table 2: HRV BFB and physiology of athletes.

Authors	Participants	Intervention	Outcome
Choudhary et al. 2016	18–25 yr old male (n=12) and female (n=12) university, state, and national level long distance runners age: 22.5 ± 1.72 yrs, height: 172 ± 7.95 cm weight: 55.6 ± 7.52 kg	HRV BFB: 10-week HRV BFB; once a week formal HRV BFB; 2 × 20-min/day home practice; regular sport training CON: regular sport training	LF/HF in HRV BFB: post<pre LF/HF in CON: post↔pre
Dziembowska et al. 2016	16–22 yr old male basketball and football players with at least 3 yr experience	HRV BFB (n=20): Ten 20-min HRV BFB in 3 weeks CON (n=21): regular sport training	HRV BFB: post LF, HF, total HRV>pre LF, HF, total HRV CON: post LF, HF, total HRV↔pre LF, HF, total HRV
Paul et al. 2012	18–28 yr old male (n=17) and female (n=13) university, state, and national basketball athletes age: 21.7 ± 2.71 yrs	HRV BFB (males: n=8; females: n=2): 10 consecutive days of 20-min HRV BFB; regular sport training PLA (males: n=2; females: n=8) motivational video clips for 10 days at 10 min/day; regular sport training CON (males: n=7; females: n=3): regular sport training only	LF: HRV BFB>CON; HRV BFB>PLA; HF: HRV BFB>CON; HRV BFB>PLA; Total HRV: HRV BFB>CON; HRV BFB>PLA; RR: HRV BFB<CON; HRV BFB<PLA;
Rusciano et al. 2017	20 male professional football players age: 30.4 ± 4.1 yrs; height: 182 ± 55.9 cm; weight: 79.0 ± 6.3 kg	HRV BFB: Fifteen 30-min biofeedback feedback sessions (2×/week); 4th–9th session: HRV BFB + SCL + EMG + hand temperature 10th - 15th session: HRV BFB + math tasks + hyperventilation + videos of matches won/lost Regular sport training CON: regular sport training	LF: HRV BFB>CON RR: HRV BFB<CON

HRV BFB, heart rate variability biofeedback; PLA, placebo; CON, control; LF, low frequency; HF, high frequency; RR, respiration rate.

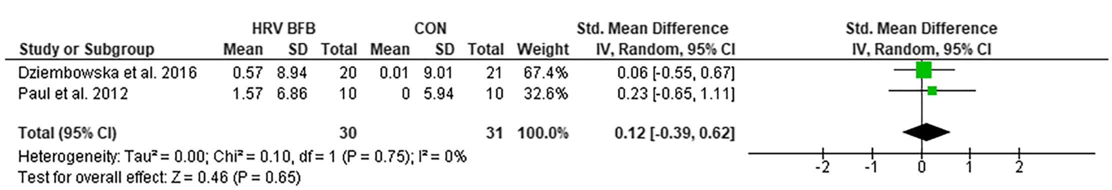

Figure 2: Forest plot of lnLF in HRV BFB vs CON.

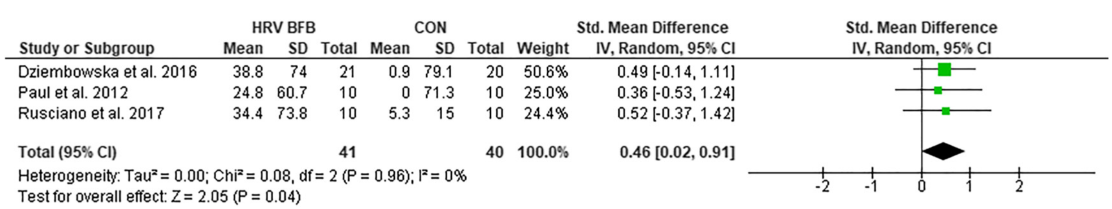

Figure 3: Forest plot of LFnu in HRV BFB vs CON.

Study or Subgroup	HRV BFB Mean	HRV BFB SD	HRV BFB Total	CON Mean	CON SD	CON Total	Weight	Std. Mean Difference IV, Random, 95% CI
Dziembowska et al. 2016	-1.39	8.28	20	-0.5	7.97	21	67.2%	-0.11 [-0.72, 0.51]
Paul et al. 2012	0.56	6.79	10	0	5.27	10	32.8%	0.09 [-0.79, 0.97]
Total (95% CI)			**30**			**31**	**100.0%**	**-0.04 [-0.55, 0.46]**

Heterogeneity: Tau² = 0.00; Chi² = 0.13, df = 1 (P = 0.72); I² = 0%
Test for overall effect: Z = 0.17 (P = 0.87)

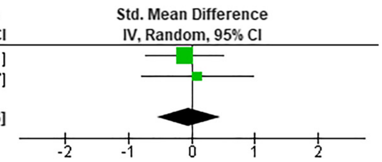

Figure 4: Forest plot of lnHF in HRV BFB vs CON.

Study or Subgroup	HRV BFB Mean	HRV BFB SD	HRV BFB Total	CON Mean	CON SD	CON Total	Weight	Std. Mean Difference IV, Random, 95% CI
Dziembowska et al. 2016	-38.8	44.7	20	-0.82	30.5	21	64.8%	-0.98 [-1.63, -0.33]
Paul et al. 2012	-24.8	62.6	10	-2.48	38.2	10	35.2%	-0.41 [-1.30, 0.48]
Total (95% CI)			**30**			**31**	**100.0%**	**-0.78 [-1.31, -0.25]**

Heterogeneity: Tau² = 0.00; Chi² = 1.01, df = 1 (P = 0.31); I² = 1%
Test for overall effect: Z = 2.88 (P = 0.004)

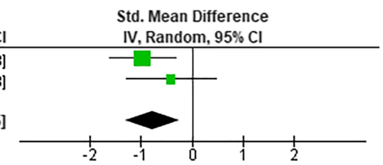

Figure 5: Forest plot of HFnu in HRV BFB vs CON.

Study or Subgroup	HRV BFB Mean	HRV BFB SD	HRV BFB Total	CON Mean	CON SD	CON Total	Weight	Std. Mean Difference IV, Random, 95% CI
Dziembowska et al. 2016	0.05	9.68	20	0.02	9.32	21	58.3%	0.00 [-0.61, 0.62]
Paul et al. 2012	1.01	7.74	10	5.96	0.12	10	41.7%	-0.87 [-1.79, 0.06]
Total (95% CI)			**30**			**31**	**100.0%**	**-0.36 [-1.20, 0.48]**

Heterogeneity: Tau² = 0.22; Chi² = 2.35, df = 1 (P = 0.12); I² = 58%
Test for overall effect: Z = 0.84 (P = 0.40)

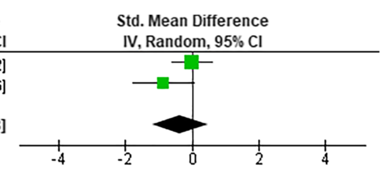

Figure 6: Forest plot of lnTP in HRV BFB vs CON.

revealed the following outcomes comparing HRV BFB and CON: (1) HRV BFB reduced breathing rate compared to CON (ES = −4.34; large); (2) Greater LFnu in HRV BFB than CON (ES=0.46; moderate); (3) relatively, HRV BFB posted lower HFnu than CON (ES=−0.78; moderate).

In this review, HRV BFB demonstrated reduction in breathing frequency compared to CON. This is supported by increased LFnu seen in HRV BFB. HRV BFB practice facilitates respiratory homeostasis by decreasing chemoreceptor activation [22, 47, 48]. This in turn increases arterial oxygen saturation, and reduces breathing frequency [21, 22, 48]. The lower breathing frequency attained with HRV BFB may be crucial to reduction of psychophysiological stressors of athletes, thereby improving performance (Paul and Garg, 2012) [42]. Thus, HRV BFB can serve as a promising intervention to improving the respiration mechanics of athletes at resting condition.

Another finding in this review is the non-enhancement in baroreflex function with HRV BFB. At resting conditions, LF represents baroreceptor activity from PNS, SNS, and blood pressure regulation from PNS [2, 4, 5, 6, 7, 49]. HRV BFB activates resonance in the cardiovascular system and creates oscillatory vagal outflow coinciding with the baroreflex function [2, 13, 16, 21, 50]. This resonance produces large increases in HR amplitudes and 'exercises' the baroreflex [16, 20, 21]. Findings revealed non-differences in lnLF, lnHF and lnTP between HRV BFB and CON. Therefore, the results of these HRV indices under HRV BFB are linked to no enhancement in baroreflex function. Possible factors contributing to non-significant results in autonomic markers supporting baroreflex function are ambiguous. More studies are needed to elucidate information on the mechanism of baroreflex under HRV BFB in athlete population.

Study or Subgroup	HRV BFB Mean	HRV BFB SD	HRV BFB Total	CON Mean	CON SD	CON Total	Weight	Std. Mean Difference IV, Random, 95% CI
Paul et al. 2012	-9.05	1.91	10	0.03	1.92	10	46.2%	-4.54 [-6.34, -2.74]
Rusciano et al. 2017	-11.5	2.58	10	2.2	3.72	10	53.8%	-4.10 [-5.77, -2.43]
Total (95% CI)			**20**			**20**	**100.0%**	**-4.30 [-5.53, -3.08]**

Heterogeneity: Tau² = 0.00; Chi² = 0.12, df = 1 (P = 0.72); I² = 0%
Test for overall effect: Z = 6.90 (P < 0.00001)

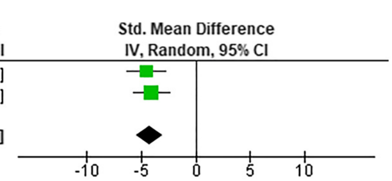

Figure 7: Forest plot of RR in HRV BFB vs CON.

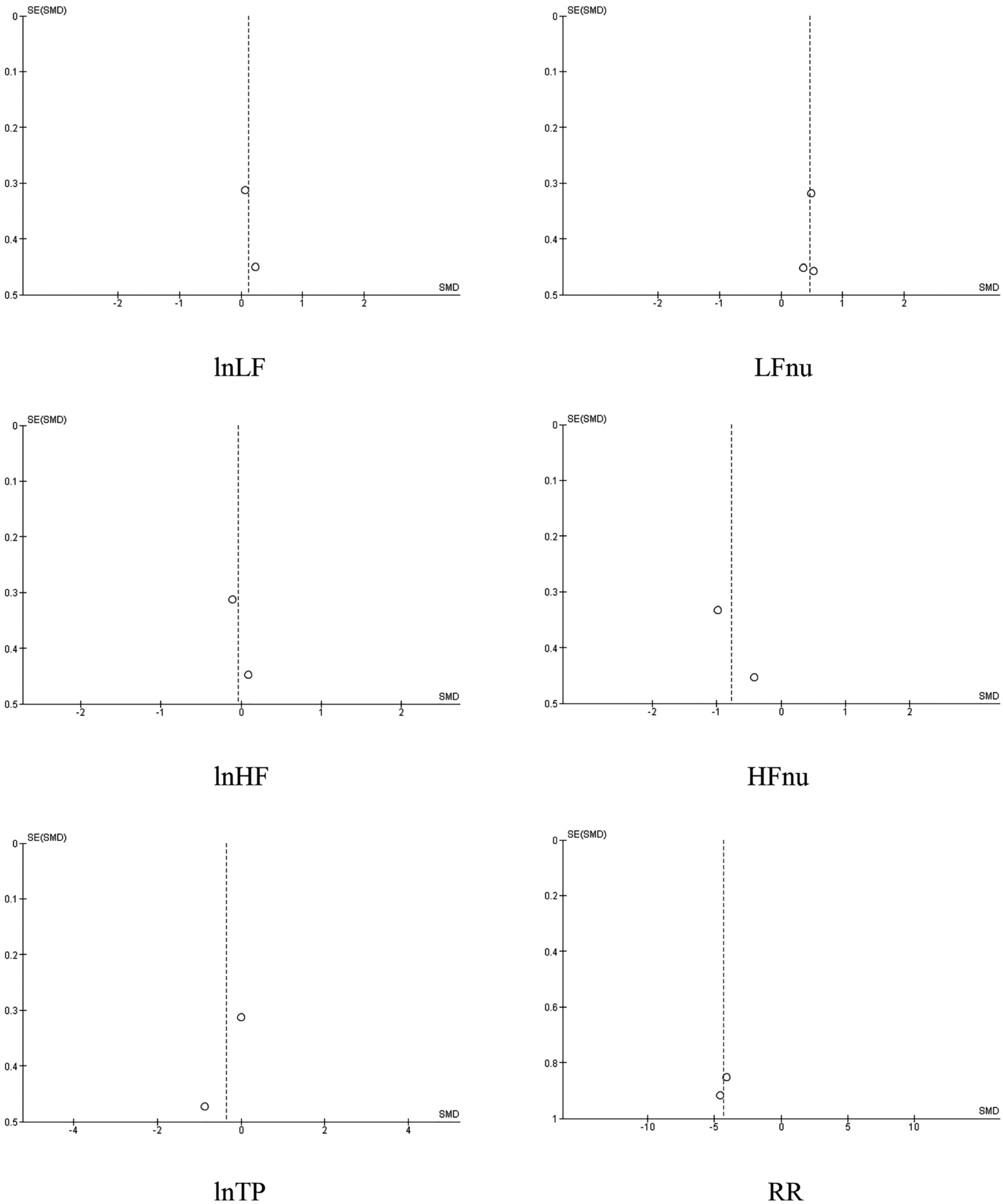

Figure 8: Funnel plots of HRV indices and RR in HRV BFB vs CON.

This review also posted non-alteration in modulating the cardiac vagal tone after HRV BFB among athletes. The cardiac vagal tone characterises the contribution of PNS in cardiac regulation [51]. The lnHF was utilised as an index of vagal modulation in this review [4, 32]. Results revealed non-significant lnHF in HRV BFB and CON. The scarcity in literature constrained the researchers to conduct additional analysis that can identify possible variables that led to non-improvement in lnHF. Further investigation utilising HRV BFB in athlete population should be carried out to demonstrate vagal influence of HRV BFB in athletes.

Adaptations in respiratory sinus arrhythmia (RSA) with HRV BFB in athlete population is unclear [4, 5, 10, 33, 52]. RSA is a cyclical change in HR synchronized with respiration, resulting to vagal discharge in the medulla. Specifically, RSA accelerates and slows down HR during

Table 3: Heart rate variability and respiration in CON and HRV BFB.

HRV	HRV BFB			CON		
	n	Pre	Post	n	Pre	Post
lnLF, ms^2						
Dziembowska et al. 2016	20	8.47 ± 8.08	9.04 ± 8.25	21	8.26 ± 8.27	8.27 ± 8.18
Paul et al. 2012	10	5.54 ± 5.39	7.11 ± 6.92	10	5.50 ± 5.43	5.50 ± 5.42
LFnu						
Dziembowska et al. 2016	20	47.8 ± 51.3	86.6 ± 77.6	21	62.6 ± 72.4	63.5 ± 72.0
Paul et al. 2012	10	39.7 ± 32.1	64.6 ± 65.9	10	65.2 ± 65.1	65.2 ± 65.0
Rusciano et al. 2017	10	52.2 ± 11.3	60.1 ± 11.9	10	49.0 ± 15.7	54.3 ± 10.4
lnHF, ms^2						
Dziembowska et al. 2016	20	8.56 ± 8.03	7.17 ± 7.00	21	7.74 ± 7.31	7.71 ± 7.24
Paul et al. 2012	10	5.96 ± 6.14	6.51 ± 6.26	10	4.88 ± 4.80	4.88 ± 4.80
HFnu						
Dziembowska et al. 2016	20	52.2 ± 48.7	13.4 ± 22.4	21	36.4 ± 27.6	36.5 ± 28.0
Paul et al. 2012	10	60.3 ± 67.9	35.4 ± 34.1	10	37.4 ± 34.9	34.4 ± 35.0
lnTP, ms^2						
Dziembowska et al. 2016	20	9.38 ± 8.99	9.43 ± 8.68	21	8.90 ± 8.50	8.92 ± 8.52
Paul et al. 2012	10	6.70 ± 6.71	7.71 ± 7.39	10	6.12 ± 5.96	6.12 ± 5.96
RR (breaths/min)						
Paul et al. 2012	10	15.3 ± 2.00	6.25 ± 0.25	10	14.6 ± 1.77	14.6 ± 1.73
Rusciano et al. 2017	10	17.1 ± 2.80	5.60 ± 0.90	10	16.7 ± 3.00	18.9 ± 3.70

lnLF, log-transformed low frequency HRV; LFnu, normalized low frequency; lnHF, log-transformed high frequency HRV; HFnu, normalized high frequency; lnTP, log-transformed; total power HRV; RR, respiration rate.

inhalation and expiration respectively. Inhalation inhibits the vagal outflow from the cardiovascular center and speeds up HR. Conversely, exhalation facilitates vagal outflow by acetylcholine release. HRV BFB is believed to increase RSA [13, 21, 51, 53, 54]. Although the change in LFnu and decreased breathing frequency may suggest RSA shift from HF to LF, additional HRV and HR indices (maximal HR and minimum HR) in future HRV BFB studies can allow the robust interpretation of RSA in HRV BFB.

From a methodological perspective, statistical inferences from this preliminary review are less worthwhile due to small sample sizes. In relation to this, the small number of studies lack power to reasonably interpret heterogeneity and publication bias [55]. Additionally, subgroup analyses for potential covariates (e.g. age, level of ability, HRV BFB duration, gender) crucial for understanding autonomic function with HRV BFB were not determined. Also, utilising a common performance marker (e.g. cardiovascular endurance) and relate it to HRV adaptations with HRV BFB was not achieved. In regard to HRV markers in meta-analyses, normalized LF and HF do not reflect unique physiological occurrences within the ANS [34]. As such, LFnu and HFnu were only used to depict breathing dominance within HRV frequency band. Other time-domain HRV parameters that may be helpful for determining autonomic phenomena with HRV BFB in athletes were not available [56, 57]. Despite these limitations, this study has a noteworthy strength in that it is the first meta-analysis on the topic of HRV BFB in athletes.

In conclusion, the application of HRV BFB suggests enhancement of respiratory mechanics in athlete population. More studies are needed to identify the effect of HRV BFB on autonomic modulation among athletes at the resting condition.

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