Can EVH Results Predict Post-Exercise Changes in FEV$_1$ Following Interval and Continuous Exercise?

Carley O'Neill[1] · Joshua Good[1] · Shilpa Dogra[1]

Abstract

The eucapnic voluntary hyperpnea (EVH) challenge is used to determine the presence of exercise-induced bronchoconstriction (EIBC) by monitoring changes in forced expiratory volume in 1 s (FEV$_1$). However, the predictability of the post-EVH decline in FEV$_1$ on post-exercise FEV$_1$ remains unclear. Participants completed an EVH challenge to confirm EIBC and completed a continuous exercise (CONT; $n=21$), high-intensity interval exercise (HI; $n=13$), and sprint interval exercise (SPRT; $n=8$) sessions on separate days. FEV$_1$ was assessed pre- and post exercise. A 1% decline in FEV$_1$, post EVH was associated with 0.44%, 0.85%, and 0.56% declines in FEV$_1$ post CONT, post HI, and post SPRT, respectively. The decline in FEV$_1$ following the EVH challenge was associated with the decline in FEV$_1$ following all exercise conditions, with the strongest association being observed following HI. These findings may have implications for exercise prescription and asthma education for recreationally active adults with EIBC.

Abbreviations

CONT	High-intensity continuous exercise
EIBC	Exercise-induced bronchoconstriction
EVH	Eucapnic voluntary hyperpnea
FEV$_1$	Forced expiratory volume in one second
HI	High-intensity interval exercise
PPO	Peak power output
RPE	Ratings of perceived exertion
RPD	Ratings of perceived dyspnea
SPRT	Sprint interval exercise

Introduction

Exercise-induced bronchoconstriction (EIBC) is characterized by acute bronchoconstriction and an increase in asthma-like symptoms after exercise. It is thought to occur due to evaporative water and heat loss from the airways as a result of sustained high ventilations that occur during exercise of at least moderate intensity [1]. EIBC can be diagnosed by assessing changes in forced expiratory volume in 1 s (FEV$_1$) following a Eucapnic Voluntary Hyperpnea (EVH) challenge [2, 3]. While changes in FEV$_1$ can be used to determine severity, a positive response does not guarantee a person will experience EIBC post exercise, or whether symptoms experienced will correlate to EIBC experienced.

Little is also known of the association between the EVH response and perceived dyspnea or effort during exercise. There is evidence to suggest an association between the decline in FEV$_1$ during a methacholine challenge with the perception of dyspnea [4], and with dyspnea during a subsequent maximal exercise test [5]. Furthermore, results from our laboratory show that among those with EIBC, greater perceptions of effort and dyspnea during exercise are associated with a greater decline in post-exercise FEV$_1$ [6]. It follows that the decline in FEV$_1$ following an EVH challenge may predict perceived effort and dyspnea during exercise; however, this association has not been previously studied.

The primary purpose of this study was to determine whether the decline in FEV$_1$ after an EVH challenge is able to predict the decline in FEV$_1$ after an acute bout of continuous exercise (CONT), high-intensity interval exercise (HI), and sprint interval exercise (SPRT). A secondary purpose was to determine whether the decline in FEV$_1$ observed after an EVH challenge was predictive of perceptions of dyspnea (RPD) and effort (RPE) during an acute bout of CONT.

✉ Carley O'Neill
  carley.oneill@ontariotechu.net

[1] University of Ontario Institute of Technology, 2000 Simcoe St N, Oshawa, ON L1H 7K4, Canada

Methods

Study Design and Participants

Data from two randomized cross-over studies were used for the present analysis (full details on protocols available elsewhere) [6, 7]. Inclusion in these studies was limited to adults between the ages of 18–44 years, with a self-reported physician diagnosis of asthma, a current prescription for a short-acting bronchodilator, to those who self-reported they were meeting the minimum physical activity guidelines of 150 min of moderate to vigorous intensity per week, and to those who had a positive response to the EVH challenge (described below).

Protocol

At baseline, height and weight were assessed. Three repeatable FEV_1 values were obtained, in accordance with the American Thoracic Society guidelines [8]. Participants completed a 6-minute EVH assessment at a target ventilation rate of $25–30 \times$ baseline FEV_1. FEV_1 was re-assessed in duplicate at 0, 5, 10, 15, and 20 min post EVH; the lowest FEV_1 was used to assess the decline in FEV_1 using the following formula:

% Change in FEV_1

$$= -100 \left[FEV_1 \text{ pre-session} - FEV_1 \text{ post-session} \right] / FEV_1 \text{pre-session}.$$

The highest FEV_1 value at each time point was used for the calculations. A response was considered EIB positive if the decline in FEV_1 was greater than 10%, relative to baseline.

On a separate day (minimum of 48 h after the EVH challenge) participants completed a *direct maximal exercise* test on a cycle ergometer (LODE Excaliber, Lode B.V., Netherlands or Monark Ergomedic 894E, Monark Exercise AB, Poland) to determine peak power output (PPO); breath-by-breath gas analysis was used to determine maximal oxygen consumption (VO_{2max}) (Parvo Medics 2400, USA). Participants took their short acting bronchodilator prior to the maximal exercise test to prevent asthma related symptoms during the test.

Participants completed *CONT* ($n = 21$), and either *HI* ($n = 13$) or *SPRT* ($n = 8$), on separate days. CONT consisted of cycling at 65% of their PPO for 20 min at 70-90 rpm. HI consisted of cycling at 10% PPO for one minute followed by 90% PPO for one minute, repeated ten times. SPRT protocol of 4×30 s 'Wingate' sprints at 0.075 kg/kg of body weight, separated by 4.5 min of active recovery. RPE and RPD were assessed each minute.

Average RPE and RPD for each exercise protocol were used for analysis. FEV_1 was assessed at baseline and 0, 5, 10, 15, and 20 min post exercise.

Statistical Analysis

Means and standard deviations were used to describe the sample. Independent sample t-tests were used to determine differences between the participants who completed the HI and the SPRT sessions. Pearson correlations were used to determine correlations between the decline in FEV_1 post EVH with post-exercise decline and RPE and RPD. Crude linear regression models, and models adjusted for sex, were used to determine the association between the decline in FEV_1 post EVH and the outcomes during and following exercise protocols. Outcomes included RPE and RPD during CONT, and the post-exercise decline in FEV_1 following each exercise session. All statistics were completed in IBM SPSS statistics 23.0 (Armonk, NY) and statistical significance was declared at $p < 0.05$.

Results

No differences were observed between participants who completed the HI and SPRT sessions with regards to height, weight, BMI, ACQ, VO_{2max}, or FEV_1 decline following the EVH. Participants were 21.6 ± 2.8 years; 10 of 21 were female, and they were moderately fit ($VO_{2max} = 36.8 \pm 7.5$ ml kg^{-1} min^{-1}). The mean decline in FEV_1 post EVH was -23.5 ± 13.5%. On average, participants reached $23.8 \pm 2.6 \times FEV_1$ during the EVH challenge. According to Anderson et al., $21 \times FEV_1$ during the EVH challenge is sufficient to elicit an EIBC response among those with asthma [1]. Only 2/21 participants failed to reach $21 \times FEV_1$, and these participants both had an FEV_1 decline greater than 45%. Based on a 10% decline in FEV_1 representing a positive EIB response, 43% (9/21), 15% (2/13), and 25% (2/8) of participants were EIB positive following CONT, HI, and SPRT, respectively. Average heart rate was significantly higher during CONT (164.7 ± 15.7 bpm), compared to HI (152.5 ± 11.9 bpm) or SPRT (147.7 ± 15.3 bpm); however, HI and SPRT did not differ. Peak heart rate did not significantly differ between any protocol (178.2 ± 16.6, 173.2 ± 11.4, and 174.1 ± 13.0 bpm for CONT, HI, and SPRT, respectively).

Additional sample characteristics can be found in Table 1.

Correlation coefficients are presented in Table 2. Post-EVH decline in FEV_1 was positively correlated with the decline in FEV_1 following each type of exercise (CONT, HI, and SPRT); however, it was not significantly correlated with RPE or RPD.

Results from linear regressions are presented in Table 3. Post-EVH decline in FEV_1 was associated with post-exercise

Table 1 Sample characteristics for adults with exercise-induced bronchoconstriction ($n = 21$, unless otherwise stated)

	Participants
Age (years)	21.6 ± 2.8
Sex (# of females)	21 (10)
BMI (kg/m^2)	26.5 ± 4.6
VO$_{2max}$ (ml kg^{-1} min^{-1})	36.8 ± 7.5
Post-EVH decline in FEV$_1$ (%)	-23.5 ± 13.5
Post-CONT decline in FEV$_1$ (%)	-12.6 ± 11.3
Post-HI decline in FEV$_1$ (%; $n = 13$)	-7.2 ± 8.3
Post-SPRT decline in FEV$_1$ (%; $n = 8$)	-8.6 ± 12.6
Average RPE—CONT only	13.2 ± 1.7
Average RPD—CONT only	4.6 ± 1.4

Data are presented as mean $\pm$ standard deviation

BMI body mass index, *VO$_{2max}$* maximal oxygen consumption, *FEV$_1$* forced expiratory volume in one second, *CONT* continuous exercise, *HI* high-intensity interval exercise, *SPRT* sprint interval exercise, *RPE* rating of perceived exertion, *RPD* rating of perceived dyspnea

Table 2 Pearson Correlations between changes in FEV$_1$ following EVH or exercise and various subjective responses to exercise

	CONT decline	HI decline	SPRT decline	Average RPD—CONT	Average RPE—CONT
EVH decline	0.52*	0.91*	0.77*	-0.06	-0.05

For correlations involving HI decline ($n = 13$) and SPRT decline ($n = 8$), Pearson Correlation coefficients are based on fewer participants

EVH Eucapnic voluntary hyperpnea, *CONT* continuous exercise, *HI* high-intensity interval exercise, *SPRT* sprint interval exercise, *RPE* rating of perceived exertion, *RPD* rating of perceived dyspnea

$^*p < 0.05$

Table 3 Crude and adjusted associations of subjective responses to CE and the FEV$_1$ decline following exercise

Variable	Crude		Adjusted	
	ß	CI	ß	CI
Average RPD—CONT	-0.01	$(-0.06, 0.04)$	-0.01	$(-0.06, 0.05)$
Average RPE—CONT	-0.01	$(-0.07, 0.05)$	0.00	$(-0.06, 0.06)$
CONT decline	0.44*	$(0.10, 0.78)$	0.53*	$(0.19, 0.87)$
HI decline	0.85*	$(0.60, 1.10)$	0.85*	$(0.58, 1.11)$
SPRT decline	0.56*	$(0.09, 1.03)$	0.74*	$(0.32, 1.16)$

Crude associations include the decline in FEV$_1$ following the EVH. Adjusted associations include sex and decline in FEV$_1$ following the EVH. ß values represent the change associated with a 1% change in the decline in FEV$_1$ following the EVH

CONT continuous exercise, *HI* high-intensity interval exercise, *SPRT* sprint interval exercise, *RPE* rating of perceived exertion, *RPD* rating of perceived dyspnea

$^*p < 0.05$

Discussion

We sought to determine whether the decline in FEV$_1$ observed after an EVH challenge was associated with the decline in FEV$_1$ following various types of exercise, and perceived effort, or dyspnea during exercise. We found that the decline in FEV$_1$ following the EVH was associated with the decline in FEV$_1$ following all exercise protocols, with the strongest association being between EVH and HI. A secondary finding was that the decline in FEV$_1$ post EVH was not associated with RPE or RPD during an acute bout of CONT. Therefore, the EVH response appears to predict objective responses to exercise (FEV$_1$ decline), but not subjective responses *during* exercise (RPE or RPD) among adults with EIBC.

This study is the first, to our knowledge, to look at the association between the FEV$_1$ decline post EVH and the FEV$_1$ decline following an acute bout of exercise among adults with confirmed EIBC. Previous research has compared the decline in FEV$_1$ between EVH and *exercise challenge tests*, which are often administered to elicit and confirm bronchoconstriction. This differs from the present study as we used acute bouts of exercise, similar to the type of exercise many adults with EIBC participate in recreationally. Our data show that a more severe decline in FEV$_1$ post EVH is associated with a more severe decline in FEV$_1$ following any of the exercise sessions (e.g., each 1% decline in FEV$_1$ following the EVH was associated with a 0.44% decline following CONT). Previous research from Evans et al. (2005) comparing the peak FEV$_1$ decline following an EVH challenge and a 6-min exercise challenge, while matching ventilation, reported similar peak declines in FEV$_1$ between the

decline in FEV$_1$ for each exercise protocol. A 1% post-EVH decline in FEV$_1$ was associated with a 0.44%, 0.85%, and 0.56% post-exercise decline in FEV$_1$ for CONT, HI, and SPRT, respectively. Post-EVH decline in FEV$_1$ was not significantly associated with RPE or RPD during CONT. Associations did not change when adjusting for sex. Associations also did not change when EVH decline was normalized to EVH ventilation and used in regressions (data not shown).

two challenges [9]. However, an exercise challenge differs from the protocols used in the current study in the length and intensity of exercise, and the air inspired (dry vs. room air). Although we did not measure ventilation during exercise, it is likely that the ventilation during the EVH was higher than that during any of the exercise protocols, leading to a greater decline in FEV_1 post EVH.

We also found that post-EVH decline was associated with the largest decline in FEV_1 post HI (ß = 0.85; CI 0.60, 1.10), relative to the other two types of exercise. Although this could be related to the high ventilation required during the high-intensity intervals, this is unlikely as the average decline in FEV_1 post HI ($-7.2 \pm 8.3\%$) was smallest compared to CONT ($-23.5 \pm 13.5\%$) and SPRT ($-12.6 \pm 11.3\%$). Thus, small sample sizes and variability may have contributed to differences in the strength of the associations. Future research measuring ventilation in larger samples is needed to further explore this relationship.

Our finding that post-EVH decline in FEV_1 was not associated with either RPE or RPD during CONT may be explained by previous research suggesting that perceptual feedback, and in particular dyspnea, poorly correlates to lung function among adults with asthma [10]. It is possible that some adults with EIBC become de-sensitized while others become hyper-sensitized to dyspnea sensations. Future research should examine the quality or descriptors of dyspnea (i.e., feelings of chest tightness or constriction) experienced during exercise to better understand the impact of dyspnea among adults with EIBC. Alternatively, the post-EVH decline in FEV_1 may show a stronger association with post-exercise symptoms (i.e., coughing, wheezing, chest tightness, and mucous production). Previous research has suggested that EIBC typically occurs post exercise [11]. Therefore, our finding that subjective feedback *during* exercise does not appear to be predicted by the decline in FEV_1 post-EVH challenge may not be surprising; however, whether the EVH is able to predict post-exercise EIBC symptoms is unknown.

One limitation of the current study was that all participants did not complete all three intensities of exercise and therefore, we were unable to explore the response of RPE and RPD to HI and SPRT. An additional limitation was the lack of ventilation monitoring during exercise, which would help to determine whether the differences in FEV_1 decline were related to differences in ventilation. Finally, while there were no significant differences between the HI and SPRT groups, EVH appeared different (-19.2 ± 8.9 and -30.4 ± 17.3 for HI and SPRT, respectively). Thus, we cannot exclude the possibility that the SPRT participants on average had more severe EIBC.

In conclusion, we found that the response to an EVH challenge was associated with the decline in FEV_1 following a variety of exercise sessions; however, this response was not associated with perceived effort or dyspnea during exercise. Future research is needed to determine if the EVH can be used to predict the decline in FEV_1 following different types of exercise and under different environmental conditions.

Compliance with Ethical Standards

Conflict of interest: All authors that they have no conflict of interest.

References

1. Anderson SD et al (2001) Provocation by eucapnic voluntary hyperpnoea to identify exercise induced bronchoconstriction. Br J Sports Med 35(5):344–347
2. Brummel NE et al (2009) The clinical utility of eucapnic voluntary hyperventilation testing for the diagnosis of exercise-induced bronchospasm. J Asthma 46(7):683–686
3. Burman J et al (2018) Eucapnic voluntary hyperventilation test in children. Clin Physiol Funct Imaging 38(4):718–720
4. Koh YI, Choi IS, Lim H (2001) Airway responsiveness as a direct factor contributing to the dyspnoea perception in asthma. Respir Med 95(6):464–470
5. Killian KJ et al (1993) Factors contributing to dyspnoea during bronchoconstriction and exercise in asthmatic subjects. Eur Respir J 6(7):1004–1010
6. O'Neill C et al (2017) The acute response to interval and continuous exercise in adults with confirmed airway hyper-responsiveness. J Sci Med Sport 20(11):976–980
7. Good J et al (2019) Acute responses to sprint-interval and continuous exercise in adults with and without exercise-induced bronchoconstriction. J Sports Sci 37(2):212–220
8. Miller MR et al (2005) Standardisation of spirometry. Eur Respir J 26(2):319–338
9. Evans TM et al (2005) Cold air inhalation does not affect the severity of EIB after exercise or eucapnic voluntary hyperventilation. Med Sci Sports Exerc 37(4):544–549
10. Hardie GE et al (2002) Understanding how asthmatics perceive symptom distress during a methacholine challenge. J Asthma 39(7):611–618
11. Anderson SD, Kippelen P (2008) Airway injury as a mechanism for exercise-induced bronchoconstriction in elite athletes. J Allergy Clin Immunol 122(2):225–235. (**quiz 236–7**).