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Effects of 3 Weeks Yogic Breathing Practice on Ventilation and Running Economy

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ABSTRACT

International Journal of Exercise Science 13(2): 62-74, 2020. Yogic breathing techniques (Pranayama) positively impact respiratory function (RF) in non-endurance trained individuals. The purpose of this study investigated effects of routine Pranayama practice on RF, running economy (RE) and perceptual responses**.** A between subject's case-control study design was incorporated. Eleven runners practiced three styles of Pranayama (30 min/day 6 days/week) for 3 consecutive weeks (YG) and completed a VO_2 max tests on a treadmill (trial 1), basic RF tests, and constant workload RE trials at 60, 70, and 80% VO_2 max (trial 2 and 3). A control group (n = 10) (CT) completed the same pre – post testing without intervention. Pre vs. post values for resting forced vital capacity (FVC), peak expiratory flow rate (PEFR) and forced expiratory flow volume in one second (FEV1). Yoga improved FVC and FEV1, but did not significantly impact RE However, RPE-L for HIGH had an interaction ($p < 0.05$) showing a decrease for YG and an increase for CT. The current study suggests 3 weeks of yogic Pranayama fails to significantly impact RE, however some evidence indicates YG may positively alter perceptual responses at individually prescribed workloads. More work is needed to definitively establish benefits of YG for runners.

KEY WORDS: Aerobic, respiratory, submaximal, ventilation

INTRODUCTION

Some athletes utilize the Western version of yoga asana (YA) that focuses on movement to improve range of motion, kinesthetic awareness, and strength as part of a holistic approach to prevent injury and improve sport performance. While physicality is vital to performance in all sports, improvement of RF can also serve as a factor influencing endurance capacity (19, 24, 29, 32). Regular practice of yogic breathing techniques can improve breathing awareness/patterns during rest or exercise (13). Yogic breathing techniques, referred to as yoga Pranayama (YP), may improve respiratory functions such as lowering resting respiratory rate (RR) while increasing forced vital capacity (FVC), forced expiratory volume (FEV1), maximum voluntary ventilation (MVV), peak expiratory flow rate (PEFR), as well as tidal volume (TV), and 40 mm endurance (breath holding) (13, 15). Another previous study found that 4 weeks of Pranayama significantly reduced RR during rest and significantly increased PEFR which could be attributed to heightened concentration of yogic breathing, thereby improving thoracic-pulmonary transference (37). Though optimal respiration is important for any individual, these improvements would especially be meaningful to an athlete. In terms of exercise ventilation, it has been suggested that running alone does not improve respiration due to shallow breathing, though breathing deeply and with control through the nostrils (as practiced in some Pranayama) will create resistance training for the respiratory muscles (4, 10) Another study found higher values for FVC, FEV1, and PEFR in yogis compared to athletes (29).

In individuals with no prior experience with yoga, YA with integrated YP (40 min x 5 days/week for 10 weeks) resulted in significant improvements in FVC, chest expansion and PEFR, suggesting YP may influence expiratory and inspiratory muscle function (37). A former study prescribed one year (3 days/week, 45 min/session), YA and YP and observed significant improvements in cardiovascular endurance and anaerobic power using a between-subjects study design with yoga practitioners (no prior yoga experience) and non-yogic controls (4). Another study observed significant increases in FVC, MVV, and PEFR after 6 weeks of YP (20 min 2x/day, 1x/day on Saturdays) which included inactive participants that acted as their own control and had no prior yogic training (13). Preliminary research regarding the potential influence of sustained yoga practice on physiological function are encouraging. However, literature is sparse and there are no definitive studies.

RE is defined as the oxygen costs (VO_2) of running at a given velocity (9), with a lower value of oxygen cost reflecting better economy. Multiple factors influence RE including; body mass, gender, training status (24), plasma lactate accumulation (11, 16), HR, and respiratory muscle fatigue (15). Furthermore, higher ventilatory stress has been shown to negatively impact RE and training status in both male and female athletes (24). YA coupled with YP has been related to improvements in respiratory musculature (10), however, the impact of routine Pranayama practice alone on RE is not well-understood. This study investigated 3 weeks Pranayama practice on RE, related physiological variables and perceptual responses in habitual runners having no prior experience with any form of yoga.

METHODS

Participants

Runners of various ability (n = 21), including males (n = 9) and females (n = 12), ages 18-40 yrs. volunteered for this study. All participants reported running 5-100 miles/week with a history of 23:03 min ± 5:02 min average 5k finishing time. A power analysis using alpha of 0.05, beta of 0.8 and an effect size of 3 ml/kg/min; with sigma (SD) of 5 suggested 20 participants were needed. Participants had no prior experience with yoga, represented minimal risk for exercise participation based on current ACSM (2018) (1) health and fitness facility preparticipation questionnaire pre-screening recommendations and the PAR-Q+ (42). Chronic use of any medication other than oral contraceptives excluded participation. All participants were non-smokers and provided written consent prior to data collection. All procedures were approved by the University of North Alabama Institutional Review Board for protection of Human

Subjects prior to data collection. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (27).

Protocol

Participants' skinfold measurements were taken at 3 sites (male: chest, abdomen, thigh; female: tricep, iliac, thigh) using skin fold calipers (Lange Calipers, Cambridge, MA, USA) to estimate body fat percentage. Height (cm) was measured using a stadiometer (Invicta Plastics Limited, Leicester, England) and body mass (kg) was assessed using a digital scale (BWB-800, Tanita Inc. Tokyo, Japan). All descriptive characteristics for participants are reported in table 1. Participants were assessed for resting blood pressure using a manual sphygmomanometer and stethoscope (Safety-Lok™, Becton, Dickinson and Company, Franklin Lakes, NJ, USA). Resting FVC, FEV1, and PEFR were tested with a spirometer (Vacumed, Ventura, CA, USA) in which the best of 3 attempts was recorded. Each participant estimated typical running volume (miles/week) for descriptive purposes along with an estimated personal best 5-k finishing time within the past 2 years, also found in Table 1.

Table 1. Descriptive Data for Participants (n = 21) Mean ± SD

Variable	YG (n = 11)	CT (n = 10)	Overall (n= 21)
Age (yrs)	20.82 ± 2.27	23.30 ± 6.11	22.00 ± 4.58
Height (cm)	168.71 ± 9.18	173.02 ± 7.96	170.80 ± 8.69
Weight (kg)	65.02 ± 10.41	70.95 ± 9.15	67.80 ± 10.05
Body Fat (%)	14.86 ± 7.00	18.35 ± 8.92	16.50 ± 7.97
VO_2 Max (ml/kg/min)	52.09 ± 11.06	44.35 ± 5.29	48.40 ± 9.46
Basal Heart Rate (bpm)	56 ± 9	59 ± 11	58 ± 10
Systolic Blood Pressure (mmHg)	120 ± 14	119 ± 5	119 ± 10
Diastolic Blood Pressure (mmHg)	71 ± 6	80 ± 8	78 ± 7
Miles per week	33.36 ± 35.33	14.10 ±10.48	24.20 ± 27.76
Estimated 5k pace (min)	22 ± 5	25 ± 4	22 ± 6

Following anthropometric data collection, participants were fitted with a HR monitor (T31 Transmitter, Polar Electro, Kempele, Finland) and completed a graded exercise test to volitional exhaustion on a motor-driven treadmill (TrackMaster TMX425C, Fullvision Inc., Newton, KS, USA). Participants reported estimated 5-k race pace to assess a starting speed for the VO_2 max test, in which the treadmill protocol began at a speed reflecting a comfortable 5-k race pace (1.5 mph slower than finishing pace). The treadmill remained at a 1% incline and speed was increased 0.5 mph (13.4 meters/min) every 2-min until the runner reached volitional exhaustion. Metabolic data (VO_2, RR, TV, and MV) were assessed via indirect calorimetry (Parvo Medics TrueOne 2400, Sandy, UT, USA) which was calibrated prior to each test in accordance with manufacturer guidelines using calibration gases and a 3-liter syringe. VO_2max was recorded as the highest 60-sec average near test completion.

Running economy (RE) trials 2 & 3: Participants returned to the lab at least 48 hours after max trial, well rested (> 24 hours with no strenuous physical activity) and instructions to be well hydrated. FCV/FEV1/PEFR were measured immediately prior to the constant workload running trial. Sessions 2 (pre-intervention) and 3 (post-intervention) consisted of a 15-minute treadmill trial in which participants followed a protocol of submaximal running at individualized velocities approximating a lower (60% VO_2 max) (LOW), moderate (70% VO_2 max) (MOD), and high (80% VO_2 max) (HIGH) intensities. After a 3-5-min warm-up, participant's speed was adjusted to the submaximal speed prescribed. HR, VO_2, RR, MV, and TV as well as RPE for legs (RPE-L), breathing (RPE-B) and overall (RPE-O) were obtained every minute for 5-minutes total at each relative intensity. LOW, MED, and HIGH were completed sequentially with no recovery. RE was measured from the end of minute 4 to the end of minute 5 min via indirect calorimetry steady metabolic rate. Pre and post trials were completed at a similar time of day for each participant. Following the pre-RE trial, each participant was randomly assigned to a treatment (completing yoga) (YG) or control (no yoga) (CT) group, using random assignment.

Yoga treatment: YG participants met with a certified yoga instructor to learn three Pranayama breathing techniques: Dirgha, Kapalabhati, and Bhastrika. Dirgha is related to as breath awareness (BAW), whereas both Kapalabhati and Bhastrika are considered high-frequency yoga breathing (HFYB).

Coaching technique for each breath:

1. *Dirgha*: diaphragmic breathing; 3-part breath for filling 3 parts of the lung: belly (lower lung), rib cage (mid lung), and chest (upper lung). For in-depth description see (2, 45)
2. *Kapalabhati*: Forceful exhalation (quickly contracting abs) and passive inhalation. For in-depth description see (21, 35, 36).
3. *Bhastrika:* Rapid yet complete inhalation and exhalation, both forceful and equal in length. For in-depth description see (40).

Once participants showed an understanding (subjectively evaluated by the instructor) of performing each breath properly through coaching, they were given written and verbal guidelines for an at home practice to be completed at their residence, in the morning 6 days/week (1 session/day), 30 min per session. Breath types were practiced for 10 min each in the above order. The participants were instructed to practice in the morning, so they would have no physical or mental activity beforehand and have no food in their stomach (40). YG participants were instructed to start the Pranayama practice at home the day following the pre-RE trial and continue for 3 weeks (18 total sessions) or until the post-RE trial was completed. Participants were provided with practice logs to be completed with each daily YG session. Any participant who did < 5 full practices per week (15 total sessions) was excluded from the study. All participants (YG and CT) were instructed to continue running habits as normal (no increases or decreases in training volume, intensity) for the duration of the study.

Statistical Analysis

Means and standard deviations were calculated for descriptive data for participants (Table 1). Self-reported running volumes are also presented in Table 1 as means, standard deviations and ranges by group (CT vs. YG). Pre vs. post measurements for resting ventilation and treadmill (RE) trials were compared using a 2 (group) x 2 (time point) repeated measures ANOVA for LOW and a separate ANOVA for MOD and HIGH. When appropriate, follow up paired t tests were used to assess pre vs. post means within groups. Results were considered significant at $p \le 0.05$. SPSS ver. 24.0 (IBM, Chicago, IL) was used for data analysis.

RESULTS

For FVC no significance was found for the main effect trial ($p = 0.14$) or the main effect group ($p = 0.83$). FEV1 the main effects were ($p = 0.09$) for trial and ($p = 0.64$) for group. For PEFR the main effects were ($p = 0.19$) for trial and ($p = 0.79$) for group. Follow up t test were conducted with results in P values for paired samples follow up t test (pre vs. post) within each group are included in Table 2. RE was not significant for the main effect trial for LOW ($p = 0.45$), MOD ($p = 0.26$), or HIGH ($p = 0.37$), but approached significance for the main effect group for LOW ($p = 0.09$), MOD ($p = 0.06$), and HIGH ($p = 0.06$) (Table 3). Other dependent variables HR, TV, RR, and MV were not significantly different for either main effect trial or group. RPE-L was not significant for LOW or MOD intensities, however for HIGH intensity the interaction approached significance ($p = 0.09$) showing a significant increase in RPE-L for CT (Figure 1). RPE-B within LOW and HIGH were not significantly different. However, there was a significant main effect for trial in MOD intensity ($p = 0.02$) showing a similar decline for RPE-B for both YG and CT. RPE-O showed no significant difference within groups between pre/post trials.

Table 2. Spirometry pre vs. post between yoga (YG) and control (CT).

Group	FVC Pre	FVC Post	FEV1 Pre	FEV1 Post	PEFR Pre	PEFR Post
Yoga (YG)	5.7 ± 1.8	4.7 ± 1.3**	4.9 ± 1.6	4.0 ± 1.0*	9.3 ± 3.0	8.0 ± 2.1*
Control (CT)	5.2 ± 1.6	5.1 ± 0.9	4.3 ± 1.3	4.2 ± 0.9	9.0 ± 2.4	8.8 ± 2.3

Values are as mean ± 1 SD and approached significance at $p^* = 0.10$ and $p^{**} = 0.12$ as compared to levels in similar conditions (at rest, before exercise) before Pranayama training. FVC forced vital capacity (L), FEV1 forced expiratory flow rate in one second (L), PEFR peak expiratory flow rate (L/sec).

Table 3. Physiological Measures During Exercise pre vs. post between yoga (YG) and control (CT). Mean (SD).

Velocity	Group	RE Pre	RE Post	RR Pre	RR Post	TV Pre	TV Post	MV Pre	MV Post	HR Pre	HR Post
LOW	YG	35.97 (6.44)	36.34 (6.37)	33.00 (7.33)	34.18 (6.26)	1.71 (0.42)	1.71 (0.32)	57.32 (21.94)	59.01 (18.67)	160 (12)	162 (9)
	CT	32.23 (5.18)	31.22* (4.89)	35.80 (4.59)	33.80* (4.42)	1.62 (0.40)	1.75 (0.34)	57.69 (16.51)	58.97 (13.12)	157 (14)	154 (16)
MOD	YG	40.42 (6.49)	39.84 (6.86)	38.82 (6.54)	39.64 (6.27)	1.85 (0.36)	1.76 (0.39)	71.57 (19.77)	69.53 (19.75)	173 (12)	176 (10)
	CT	35.46 (4.37)	34.9 (4.67)	40.70 (7.70)	39.70 (6.07)	1.83 (0.33)	1.85 (0.32)	73.48 (17.00)	73.16 (17.11)	171 (12)	168† (14)
HIGH	YG	42.65 (6.07)	44.39** (7.76)	42.18 (5.76)	43.73 (6.05)	1.86 (0.40)	1.86 (0.33)	77.6 (17.56)	81.01** (18.84)	180 (10)	181 (12)

CT	38.92 (4.15)	38.33 (4.55)	44.50 (8.55)	43.50* (8.62)	1.87 (0.34)	1.92 (0.34)	82.79 (21.70)	74.41 (32.24)	178 (12)	175† (14)

Values are as mean ± 1 SD $p^* \leq 0.05$ and approached significance at $p^{**} = 0.07$ and $p^{\dagger} = 0.08$. Values represent measurements during exercise at 3 separate intensities. V1 velocity 1 (60% of VO_2max), V2 velocity 2 (70% of VO_2max), V3 velocity 3 (80% of VO_2max), RE running economy (VO_2 ml/kg/min), RR respiratory rate (breaths per min), TV tidal volume (L), MV minute ventilation (mL/min), HR heart rate (beats per min).

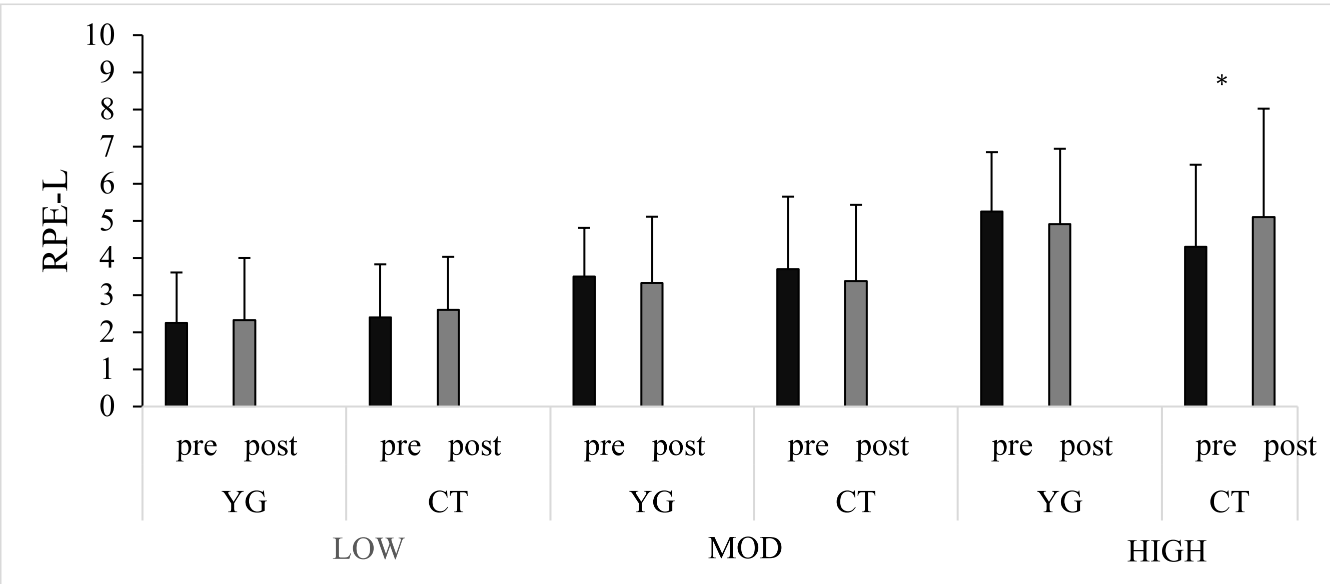

Figure 1. Ratings of perceived exertion for legs (RPE-L), during exercise at 3 separate intensities. LOW velocity 1 (60% of VO2max), MOD velocity 2 (70% of VO2max), HIGH velocity 3 (80% of VO2max), YG yoga, CT control. Significant at $p^* < 0.05$**.**

DISCUSSION

This investigation examined effects of routine yogic breathing practice on ventilation at rest (FVC, FEV1, PEFR) as well as acute perceptual responses, RE, MV, RR, TV and HR during exercise. The time period and volume of yoga (30 min/session 6 days/week, 3 weeks total) was selected to determine if such a dosage of YG would impact resting dependent variables similar to other investigations (2, 43, 45) with the addition of several variables at exercise. Previously, it has been shown that a 15-day regimen of 45 min daily Pranayama results in a significant increase for chest expansion, breath holding, and PEFR (19). Positive responses resulting from short term (3 week) YG would be beneficial for competitors desiring to gain an edge prior to competition in a short time frame.

The lack of a significant improvement in PEFR could be related to a former study that observed resting pulmonary values for pre, mid, and post Pranayama treatment, in which 6 weeks of yoga did not improve PEFR significantly but 12 weeks yoga did have statistically better values (45). In terms of total volume of Pranayama practice, a former study included 6-weeks with a total of 420-630 minutes, whereas the current study was 3 weeks with a total of 450 minutes. In the current study, 450 minutes was insufficient to prompt significant overall changes. However, with 420-630 minutes there were effects noted for FVC, FEV1, and PEFR (45). Because the total volume of practice was similar in these studies, with discordant results, it may be that the body responds to yoga more positively if the dosage is presented across a longer time frame than 3 weeks.

Several other studies have shown a significant improvement in one or more of the following RF post yoga treatment: PEFR, FVC, MVV, FEV1, and TV (13, 24, 37, 41). Many studies attribute improved RF to increased strength and endurance of respiratory muscles. Positive results have been shown in acute studies (same day) as well as studies examining 6-12 weeks Pranayama practice, though the amount of time spent in YP practice across studies differs widely (10, 13, 24, 37, 41). Increased PEFR has been specifically associated with incorporation of small airway openings in the lungs (not commonly utilized with shallow breathing) as well as engagement of total lung spaces as the chest inflates and deflates more fully during Pranayama (13, 33, 36). In contrast to utilizing full lung capacity, normal/shallow breathing, predominantly referred to as a chest-breath, is much less effective in regard to performance and total lung compliance (15). Ankad et al. (3) proposed that by increasing personal awareness to a slow/deep breath, thoracic-pulmonary inhalation and thereby lung compliance is better developed through a more operative use of the diaphragm. With this approach overall ventilatory exchange (inhalation/exhalation) is more effective (2). The current study differs from others in terms of length of the Pranayama practice. Though others have found positive effects (2, 10), current results indicate 3 weeks Pranayama is insufficient duration in novel yoga practitioners to significantly impact RF and RE.

Because shallow breathing performed during running alone does not solicit enough training to improve respiratory strength (10), it is plausible that individuals could enhance their aerobic capacity and exercise ventilation by adding routine Pranayama to their normal running program given a Pranayama training period of longer than 3 weeks. Suggesting, Pranayama has the potential to improve respiratory function as seen in respiratory training with endurance trained individuals (7). Physiological measures of the lung may improve, and conscious breathing may become an easier task (reduced fatigue) over practice, as the stretch receptors in the lungs get used to higher concentrations of carbon dioxide in the lungs (2). Many types of Pranayama encourage a greater degree of stretch receptors be used in alveoli, which requires strong voluntary control enabling the alveoli walls to be stretched to their maximal extent above tidal volume (3, 19, 31). This training of the alveoli also presented a delayed onset of fatigue (19), which could also may explain why running "felt easier" to most participants in the present study post yoga treatment. The voluntarily slow rhythm of Dirgha attenuates basal (resting) rhythm of breathing (41). The bulbopontine complex is then modified to allow the lungs to work to their full extent for both the elongated inhalation and exhalation, which works to maximally take O_2 in the body as well as remove CO_2 from the body, subsequently decreasing in RR (14, 41). Slower styles of Pranayama, such as Dirgha, practiced for 6-12 weeks had a significantly positive impact on RF and has been connected to the broncho-constrictor effect, which calms the mind and helps alleviate restriction in the lungs (45).

Parasympathetic activity increases during slow Pranayama (such as Dirgha) due to its concentration and focus on the breath, thus decreasing resting RR (21). A previous study found parasympathetic tone to be markedly increased in yogis, and further notes that long duration yoga practice decreases blood pressure and reduces sympathetic tone along with peripheral resistance (14). In contrast to some types of Pranayama, Khapalabati and Bhastrika (HFYB) are two techniques shown to excite the sympathetic nervous system (15, 30), while strongly engaging the diaphragm, abdominal, and intercostal muscles. Although Dirgha breathing trains the respiratory apparatus to fill more efficiently (20), the HFYB techniques, such as Khapalabati and Bhastrika, may further enhance ventilation by way of forceful inhalations and/or exhalations that refresh air in the lungs (2) and help to remove secretions in the lung bronchioles (20). This clearing of the lungs clears the passage to the alveoli in such a way that allows more air to be moved through the respiratory channel, which reflected in greater overall ventilation in the former study, in which the authors attribute powerful exhalations practiced with Khapalabati breathing technique (20).

Furthermore, another study suggests that YP such as Kapalbhati and Bhastrika provides resistance training for respiratory muscles due to the rapid inhalations to total lung capacity and forceful exhalations to residual volume, which causes a decrease in cross sectional area turbulence during breathing (41). Significant changes in ventilation for PEFR or dependent running measures were not found in the present study, possibly due to the use of other types of breathing techniques performed variously in the other studies such as: breath holding time, alternate nostril, sectional breathing (vibhagiya), thoratic/intercostal breathing (madhyama vibhagiya), and upper lobar/clavicular breathing (aadya jesta vibhagiya), bhramari, or udgeeth pranyamas (19, 21, 30, 37). Insufficient duration, total dosage, and type of yogic breathing technique practiced may explain the lack of significant outcomes for PEFR or exercise measures.

For effects of YG during 3 submaximal treadmill trials, current results do not show an improvement for RE, though RE at a HIGH intensity did approach significance ($p = 0.07$) (Table 3). There is some existing evidence in former studies of a significant improvement in cardiorespiratory and autonomic function with just 3 weeks practice (19). One study investigated the effects of slow and fast breathing techniques, including Bhastrika and Dirgha, on cardiorespiratory function with the same general dosage of yoga sessions as prescribed in the current study (3 weeks, 30 min, 5 days/week) (10). In the former study, slow Pranayama decreased HR, rate pressure product (RPP) and double product (DP) significantly while it increased respiratory pressures and respiratory endurance significantly (19). Fast Pranayama (HFYB) significantly increased HR, RPP, and DP (34). Results also showed a 36.5% increase in respiratory endurance (time in seconds that a participant could forcefully exhale against 20mm mercury) from Bhastirka Pranayama $p < 0.001$ as well as a 28.9% increase in maximum expiratory pressure (MEP) and a 42.6% increase of maximum inspiratory pressure (MIP) $p < 0.05$ (19). These outcomes suggest that the two different breathing styles produces different physiological outcomes. The present study had a strict criteria of no less than 15 days total Pranayama over the course of 3 weeks, similar to the former studies time frame, but lacked the practice of breath holding time (respiratory endurance) which is a popular technique used in other related research (10, 13, 19, 20, 29, 34, 41).

Endurance sports are impacted by physiological responses such as RE, where a runner may be able to withstand submaximal running speeds at a lower oxygen cost (43). RE is therefore directly influenced by alterations in the availability of O_2 in the circulatory/skeletal system (32) in which subtle changes in heart rate and ventilation during exercise may accompany probable improvements in RE (12). However, these improvements may be more difficult to achieve in competitive runners whom have years of sufficiently developing RE (12). The current studies participants included a wide range of runners including several collegiate cross-country runners; therefore, it is possible that individuals in the current study failed to respond to yoga because of a reasonably well-elevated fitness level. Benefits of yoga may be limited somewhat to those who have a greater room to improve overall. Many of the previous studies tested participants who were otherwise "inactive" and did not complete any type of exercise outside of the prescribed yoga (13, 14, 21, 37, 41). In lower fit or sedentary individuals there is greater room for potential improvement, while in trained runners as in the current study, potential impact of yoga may be miniscule and therefore overshadowed by changes resulting from habitual training. An untrained/inactive treatment group in former studies may have given more room for positive correlations in ventilatory and cardiorespiratory measures (13, 14, 21, 37, 41). Additionally, the use of oral contraceptives among the female population was not controlled for, which may impact ventilator variables. More work is needed to clarify if potential benefits of yoga are limited to certain populations.

In addition to possible RE biomarkers, velocity at VO_{2max} (vVO_{2max}) may be a better predictor of economical running ability than RE or VO_{2max} alone since velocity at a self-selected running pace provides athletic ability for how fast a runner can perform when operating at VO_{2max} or a fraction of VO_{2max} (26). Lastly, RE may be better assessed by taking caloric cost (kcal ·kg-1 ·km-1) into consideration, as VO_2 measurements do not consider the energy equivalent of a volume of oxygen that differs in varying exercise intensities (31) which should be considered in future research. This study found that when expressed as O_2 unit cost, caloric unit cost was more sensitive to changes in relative speed than RE when measured at 75%, 85%, and 95% of speed lactate at threshold (sLT). Because caloric cost increased significantly with speed ($p < 0.001$) (11), the former study's findings suggests that this measurement may offer another appropriate way to measure aerobic capacity.

Results in this study reflect statistical significance for perceptual measures (RPE). It is plausible that participants admitting to the overall activity of running "feeling" easier after 3 weeks YG in the current study be related to better lung compliance and use of the diaphragm, especially during heavy breathing as running necessitates. RPE for legs at velocity 3 (80% VO_{2max}) increased from 4.3 to 5.1 between trials 2 and 3 for CT, while RPE decreased from 5.18 to 5.09 for the YG (Figure 1). However, because it is impossible to blind participants to yoga treatment, there may be a psychological link and participants may have anticipated that YG should make it feel easier or lead to improvements. Few studies have tested yoga in relation to perceptual measures such as RPE, and further investigation in this area should follow.

The current study investigated 3 types of yoga, limited to breathing techniques alone. Other popular and widely studied yogic breathing techniques, such as alternate nostril technique

(Nadishuddi), has been shown to significantly improve functions of the lung (10, 19, 29, 30, 33, 45) and more research is needed to fully understand the various forms of yoga and potential impact on physiological measures during running. Other investigations held their experimental period over the course of 6 weeks to several months (13, 20, 22, 25, 29, 30, 37, 45). It is reasonable that a training effect from yoga would take a longer time or a heavier total dosage than employed in the current investigation. From the current study, 3 weeks (15 days minimum) yogic breathing practice is not enough time to significantly alter physiological variables during exercise.

The current participants had no previous exposure to any form of yoga. Other studies recruited experienced yoga practitioners in comparison to a non-yogic control group (14, 20, 29, 30, 32, 34, 36). Many studies used those with sedentary lifestyles (who remained inactive during the course of the study) while participants in the current study were either recreational or competitive runners at the collegiate level and continued their current running routine. It is possible that assessing change in active individuals masked improvements that may otherwise have been observed had participants been less fit.

It is possible that the benefits of yoga in this paradigm are limited to those having a particular level of training compared to their potential for improvement. Those who have achieved near their top potential fitness level may not benefit, however those who are somewhat fit (running average < 10 miles/week) may be more impressionable with yogic training. Future research concerning proper stimulus is needed for runners of varying ability to solicit significant ventilatory improvements should follow. Furthermore, participants in the current study could practice Pranayama on their own and record their practice for compliance, making it an ecologically valid procedure. However, scheduled practices with the yoga teacher may have been beneficial to the participants understanding towards correct performance/timing of the breathing techniques.

Pranayama may be useful for runners given enough time and proper selection of Pranayama techniques. Though the present study was perhaps too short in overall duration for YP and did not show direct impact towards RE, improvements upon RF shown in the former studies discussed may contribute to the overall performance on an athlete. Perceptual measure such as RPE for breathing and legs that did solicit a meaningful change upon YP may contribute to delayed onset of fatigue during exercise (44), which could benefit athletes in long duration events such as running. Those interested in benefiting from yoga in terms of perceived exertion and overall RE should allow more than 3 weeks of routine YP.

Current results indicate Pranayama yoga practiced in the dosage prescribed in the current study is ineffective for prompting changes in RE, though some significant findings for RF during exercise are encouraging. More research is needed to fully understand the effects of YP and RF. Yoga can reasonably be implemented into an athletic training program. However longer than 3 weeks duration of practice/experience may be necessary to experience improvements. It is also possible that benefits of yoga are limited by fitness or activity status and future studies should investigate this more in-depth and consider longer length of YG practice.

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