



Comparative Analysis of Acute Effects of Different Aerobic Exercises on Clinical Symptoms and Cytokine Levels in Patients with Allergic Rhinitis: A Randomized Crossover Study

RESEARCH

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ABSTRACT

Introduction: Aerobic exercise has been shown to improve allergic symptoms. The purpose of this study was to investigate the impact of various moderate-intensity aerobic exercises on clinical symptoms and cytokines.

Methods: Fifteen allergic rhinitis patients aged between 18 and 35 years were randomly assigned to complete three experimental sessions of aerobic exercise: running, cycling, and swimming. Physiological, symptoms, nasal blood flow (NBF), peak nasal inspiratory flow (PNIF), and cytokines variables were examined pre- and post-exercise. Statistical analyses included the Two-way ANOVA and Linear Mixed Model (LMM), with significance set at $p < 0.05$.

Results: The results showed that all exercise protocols significantly reduced total rhinitis symptoms and itching scores compared to pre-test levels. Running notably decreased nasal congestion, sneezing, and rhinorrhea scores, while cycling and swimming each decreased specific symptoms. Both running and cycling exercises significantly altered NBF and PNIF. Furthermore, running exercise significantly reduced levels of various cytokines, whereas cycling and swimming exercises had more limited effects on cytokine levels.

Conclusion: Moderate-intensity aerobic exercises, including running, cycling, and swimming, effectively alleviate rhinitis symptoms. Running stands out as particularly effective in reducing all symptoms and lowering pro-inflammatory cytokine levels. Thus, moderate running appears to be a suitable aerobic exercise option for individuals with allergic rhinitis.

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Allergic rhinitis (AR) is a widespread and chronic health issue with a high prevalence and significant financial impact. It is estimated to affect up to 40% of the world's population, with a particularly high frequency in developed countries ([Izquierdo-Domínguez, Valero, & Mullol, 2013](#)). In Thailand, more than 20% of adults and 40% of children are affected by AR, and the prevalence is increasing every year ([Tantilipikorn et al., 2019](#)). AR is caused by allergens, which lead to inflammation of the nasal mucosa and one or more symptoms, such as nasal congestion, itching, sneezing, and rhinorrhea ([Passali et al., 2018](#)).

Several hypotheses exist for allergic rhinitis sensitization, with the most important being genetic factors and diatheses for Immunoglobulin-E (IgE) antibody formation ([Corsico et al., 2017](#); [Bernstein et al., 2024](#); [Rosenfield et al., 2024](#)). IgE antibodies are generated in the nasal mucosa and regional lymphatic tissues in response to antigen penetration into the mucous membrane. In response to an antigen-antibody interaction, mast cells release chemical mediators such as histamine and peptide leukotrienes, which irritate the sensory nerve terminals and blood vessels of the nasal mucosa, causing sneezing, rhinorrhea, and nasal congestion ([Okubo et al., 2020](#)). This is a reaction in the early stages.

Allergens promote Th2 lymphocyte development in allergy sufferers by releasing cytokines (IL-3, IL-4, IL-5, IL-6, IL-13, TNF- α), along with Th1 (IFN- γ , IL-2) and regulatory cytokines (IL-10) ([Baraniuk, 1997](#); [Wagenmann et al., 2005](#); [Deraz, 2010](#); [Scadding, 2014](#)). Silva et al. (2010) reported that aerobic exercise training increased plasma IgE while reducing eosinophils, IL-4, IL-5, IL-13, airway remodeling, mucus synthesis, and nasal resistance in a chronic murine model of allergic airway disease. However, evidence on the effects of acute aerobic exercise on allergic rhinitis remains limited. Hewitt et al. (2009) found that a single session of moderate-intensity treadmill exercise in mice lowered Th2 cytokines IL-5 and IL-13. In addition, our previous study showed that acute moderate exercise (walking or running on a treadmill) significantly increased the IL-2/IL-4 ratio in allergic rhinitis patients ([Tongtako et al., 2012](#)). Cytokine profiles were evaluated using serum and nasal secretions ([Tyurin et al., 2017](#)), with our results showing significantly higher cytokine levels in nasal secretions than in serum ([Tongtako et al., 2012](#)). Based on these findings, we chose to analyze cytokines from nasal secretions in this study.

Aerobic exercise has been shown to improve allergic symptoms, quality of life and exercise capacity ([Tongtako et al., 2012](#); [Tongtako et al., 2018](#); [Prosegger et al., 2019](#); [Ang et al., 2023](#)). Various types of aerobic exercise exist, such as walking, running, cycling, swimming, and aerobic dancing. Aerobic exercise effectively improves cardiorespiratory fitness while also enhancing the nervous system's ability to regulate muscle control.

Running is an impact exercise that requires no equipment and is easy to perform ([Lin et al., 2015](#)). Cycling, on the other hand, is a low-impact exercise that reduces the risk of injury. Submaximal running typically results in greater oxygen consumption and potentially higher energy expenditure than cycling performed at an equivalent intensity ([Sedlock et al., 1989](#); [Kravitz et al., 1997](#)). Additionally, these activities involve different movements of the chest and upper extremity muscles, which may trigger chest wall proprioceptors in different ways ([Kalsås, & Thorsen, 2009](#)). Research has shown that in individuals with lung diseases, perceived breathlessness and tidal volume were higher during exercise on a cycle ergometer than on a treadmill at comparable ventilation ([Cochrane, & Clark, 1990](#)). Furthermore, arm exercise has a distinct respiratory rhythm compared to leg exercise ([Ramonatxo, Prioux, & Prefaut, 1996](#)). Previous studies have indicated that moderate-intensity walking or running on a treadmill can reduce allergic rhinitis symptoms, decrease nasal blood flow, increase peak nasal inspiratory flow, and positively impact cytokine levels ([Tongtako et al., 2012](#); [Tongtako et al., 2018](#)).

Swimming is recognized as an aerobic exercise with a low impact on the body. Unlike other sports, swimming involves unique breathing techniques and muscle usage due to the resistance provided by water, which increases pressure in the chest cavity and results in a strengthened venous return rate ([Lazar et al., 2013](#)). It is a beneficial exercise that improves respiratory function, asthma symptoms, and aerobic fitness ([LaKind, Richardson, & Blount, 2010](#)). Cross-sectional studies that compare highly trained swimmers to non-swimmers have consistently found that swimmers have larger lung volumes ([Bougault et al., 2009](#); [Lazovic-Popovic et al., 2016](#)).

Nevertheless, chlorine exposure can have irritating effects that are linked to neutrophilic inflammation and may worsen symptoms of allergic rhinitis (Bougault, Turmel, & Boulet, 2010).

While running, cycling, and swimming are all classified as aerobic exercises, they differ in terms of environment (land vs. water), energy expenditure, and postural demands. However, limited research has compared their specific effects on symptoms in individuals with allergic rhinitis. Therefore, the purpose of this study was to investigate the impact of various moderate intensity aerobic exercises, such as running, cycling, and swimming, on clinical symptoms and cytokines in allergic rhinitis patients. The goal was to determine whether these exercises could affect physiological, rhinitis symptoms, nasal blood flow (NBF), peak nasal inspiratory flow (PNIF) and cytokines variables, in patients with allergic rhinitis, and to provide insight into the physiological mechanisms of exercise in allergic diseases. This study is unique and could serve as a useful guide for maintaining the health of patients with allergic rhinitis, leading to a better quality of life and reduced treatment costs for both individuals and society as a whole.

METHODS

STUDY DESIGN AND PROCEDURE

Ethics Statement

All participants provided written consent to participate in the study. The study protocol was approved by the Institutional Review Board of the Health Sciences Group, (approval no. 185/62). This study was registered as a clinical trial with clinical trials.gov (no. NCT05707611).

Sample size

The sample size of participants was calculated by the G*Power program (3.1.9.2) with an alpha error of 0.05, and a power of 0.80; the total sample size of 12 patients would be required. This study recruited 15 individuals between the ages of 18 and 45 who are allergic rhinitis patients and visited the Health Service Center. All participants had persistent symptoms of rhinitis, including nasal congestion, sneezing, itching, and rhinorrhea for more than four days each week and had positive results on a skin prick test for house dust mites (weal diameter > 3 mm). Individuals with asthma, chronic rhinosinusitis, hypertension, or cardiovascular diseases were not eligible to participate. To ensure accurate results, participants were asked to avoid taking antihistamines for at least three days and to refrain from using oral and nasal steroids for at least two weeks prior to the study. They were also instructed not to use leukotriene receptor antagonists for at least one week before the study. Participants who had not engaged in regular exercise for at least six months prior to the study were included.

Study design

This study employed stratified randomization, first separating participants by gender. They were then randomly assigned, using a computer-generated randomization sequence, to complete three experimental sessions (crossover design—over seven separate days) of moderate-intensity aerobic exercise: running (n = 5; 3 males, 2 females), cycling (n = 5; 2 males, 3 females), and swimming (n = 5; 3 males, 2 females). Physiological, allergic rhinitis symptoms, peak nasal inspiratory flow, nasal blood flow, nasal secretion for cytokine analysis, pulmonary function, and respiratory muscle strength variables were investigated at pre and immediately post exercise for each exercise protocol. Only the medical laboratory scientists who analyzed cytokines were blinded to the interventions. Blinding of other study outcomes was not feasible due to the nature of the interventions.

Exercise Protocol

The participants' exercise regimen consisted of a 5-minute warm-up and stretching, followed by running on a treadmill, cycling on an ergometer, or freestyle swimming in a water flume at a moderate intensity of 50–55% heart rate reserve (ACSM, 2018) for approximately 30 minutes, followed by a cool-down for 5 minutes. The researcher used a Polar H10 heart rate monitor chest strap to track heart rate and ensure it remained within the specified intensity range. The heart rate was continually monitored.

General physiological characteristics

The blood pressure monitor (Omron SEM-1 model, Japan) was used to measure the resting heart rate and blood pressure. Body composition was measured with a bioelectrical impedance analyzer (InBody 220; Biospace, Seoul, Korea).

Rhinitis symptom scores

The Total Nasal Symptom Score (TNSS) questionnaire was used to assess nasal symptoms. 22 patients with persistent allergic rhinitis rated their nasal congestion, itching, sneezing, and rhinorrhea symptoms pre- and post-each exercise protocol. The four individual scores were added together to obtain the total nasal symptom score, which ranged from 0 to 3 (0 indicating no symptoms and 3 indicating severe symptoms).

Peak nasal inspiratory flow

To measure peak nasal inspiratory flow (PNIF), an PNIF meter was used (In-Check nasal, UK), which was connected to an anesthesia mask. The participants were instructed to tightly close their lips and forcefully inhale through their nose while wearing the mask. The maximum peak flow was measured on a scale of 30–370 L/min using a diaphragm inside a plastic cylinder that moves with the airflow. PNIF was measured before and after each exercise protocol.

Nasal blood flow

Laser Doppler Flowmetry (LDF) (Perimed, PeriFlux 5000, Sweden) was used to measure NBF. All participants were instructed to breathe properly throughout the test and to refrain from speaking, moving, or coughing. On the front of the nose was positioned a side delivery endoscopic probe with a 1.34 mm diameter flexible nylon sleeve.

Nasal secretion collection and handing

Nasal secretions collection was performed bilaterally with filter paper strips (7 × 30 mm Whatman No. 42; Whatman, Clifton, NJ). The anterior portion of the inferior turbinate was targeted by sequentially placing three filter paper strips for 10 minutes. After collection, the filter paper strips were put into tubes and centrifuged at 3,000 rpm for 5 minutes at 4°C, and then frozen at –70°C for subsequent analysis.

Multiplex cytokine measurements

To do the multiplex cytokines from the nasal fluid, the Human Th Cytokine Panel 8-plex (IL-2, IL-4, IL-5, IL-6, IL-10, IL-13, IFN- γ and TNF- α ; Biolegend, USA) were used. 25 μ l of assay buffer was added into each well. Then, 25 μ l of diluted standard or nasal fluid were added in standard or sample wells. After that, 25 μ l of mixed beads and 25 μ l of detection antibodies were added into each well and incubated for 2 hours at room temperature on an orbital plate shaker. After incubation, 25 μ l of streptavidin-PE solution was added and then incubated for 30 minutes at room temperature on an orbital plate shaker. The plates were centrifuged at 1,000 rpm for 5 minutes. After decant liquid and wash more one time with wash buffer. All wells added 150 μ l of wash buffer and shake for 2–3 minutes prior to analyze by flow cytometry (BD LSRII, Becton Dickinson, USA).

Statistical analysis

Statistical analysis was performed using IBM SPSS Version 28 for Windows (SPSS Inc., Chicago, USA). The Shapiro–Wilk test was applied to assess the normality of the data. Two-way ANOVA was used to analyze physiological characteristics, pulmonary function, and respiratory muscle strength variables, while the Linear Mixed Model (LMM) in RStudio statistical software was used to evaluate NBF, PNIF, rhinitis symptoms, and cytokine variables. A p-value of less than 0.05 was considered statistically significant. Results are presented as mean $\pm$ standard deviation (SD).

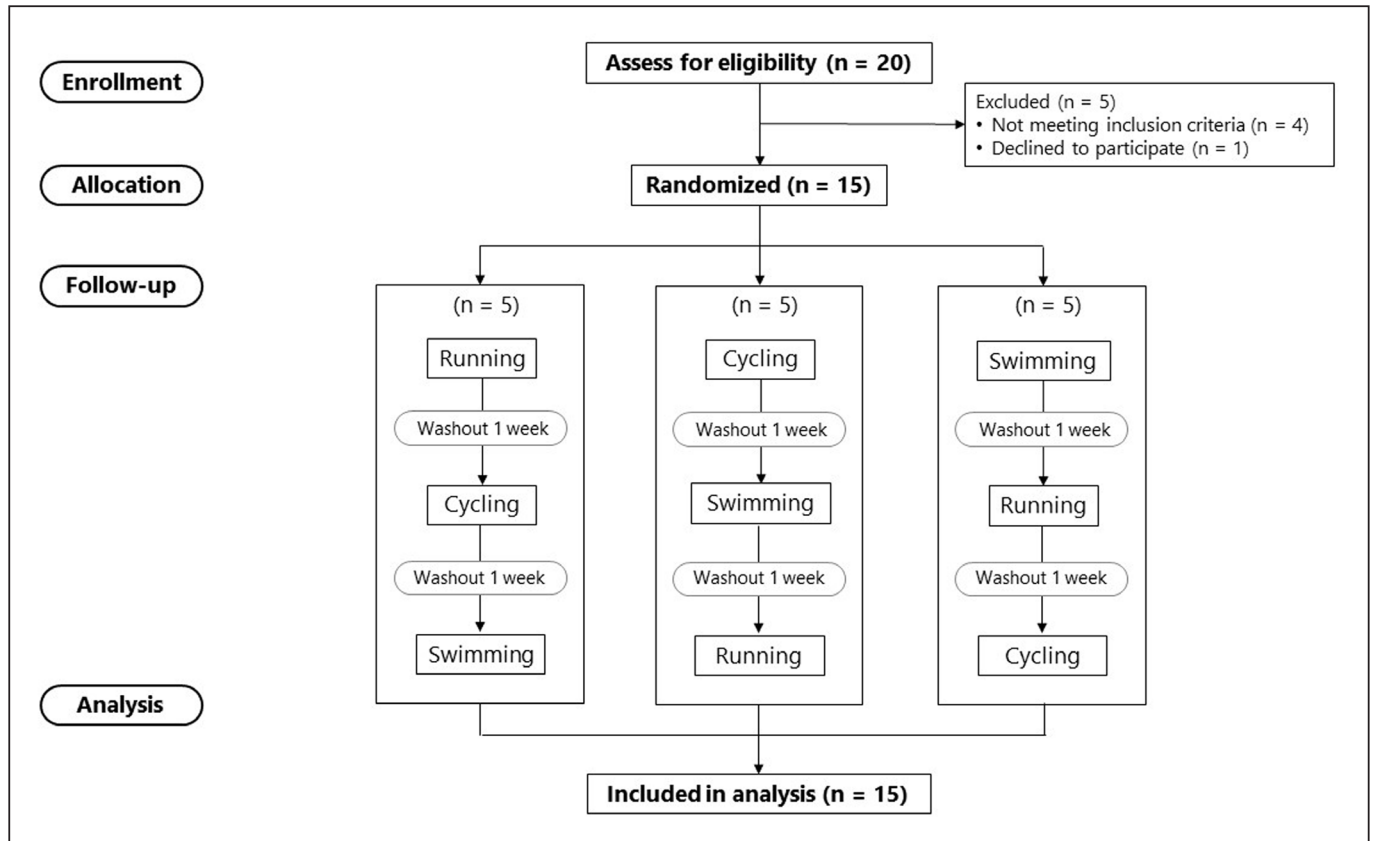
RESULTS

GENERAL PHYSIOLOGICAL CHARACTERISTICS, PULMONARY FUNCTION AND RESPIRATORY MUSCLE STRENGTH VARIABLES

There were 15 participants (8 males, 7 females) in the study, with a mean age of 22.13 ± 2.29 years (Figure 1). The general physiological characteristics, pulmonary function, and respiratory

muscle strength variables of the subjects are summarized in Table 1. After all exercise protocols (running, cycling, and swimming), the heart rate (HR) was significantly higher than pre-test ($p = 0.003$, $p < 0.001$, $p < 0.001$). Moreover, percent body fat was significantly decreased after only running ($p = 0.046$). There were no significant differences ($p > 0.05$) in body weight (BW), body mass index (BMI), systolic blood pressure (SBP), diastolic blood pressure (DBP), forced vital capacity (FVC), forced expiratory volume in one second (FEV1), the ratio of the forced expiratory volume in the first second to the forced vital capacity (FEV1/FVC), maximum voluntary ventilation (MVV), maximum inspiratory pressure (MIP), and maximum expiratory pressure (MEP) between pre- and post-tests or among exercise protocols.

Figure 1 CONSORT flow diagram of participant allocation, follow-up and analysis.



VARIABLES	n = 15						TWO-WAY ANOVA REPEATED		
	RUNNING		CYCLING		SWIMMING		TIME	EXER-CISE	TIME x EXER-CISE
	PRE-TEST	POST-TEST	PRE-TEST	POST-TEST	PRE-TEST	POST-TEST			
BW (kg)	66.21 ± 12.51	66.02 ± 12.32	66.64 ± 11.67	66.55 ± 11.55	67.28 ± 11.37	67.77 ± 11.39	.271	.774	.445
Body Fat (%)	22.12 ± 9.12	21.67 ± 8.82	21.78 ± 8.91	22.17 ± 8.75	21.28 ± 9.43	21.52 ± 9.44	.560	.641	.069
BMI (kg/m ²)	23.15 ± 4.07	23.06 ± 4.09	23.02 ± 4.04	22.94 ± 4.05	22.80 ± 4.12	22.78 ± 4.07	.167	.119	.683
HR (bpm)	72.66 ± 14.01	93.13 ± 15.31*	76.73 ± 15.21	93.86 ± 17.79*	74.20 ± 14.38	98.73 ± 12.45*	<.001*	.433	.262
SBP (mmHg)	116.70 ± 7.60	121.00 ± 7.57	117.06 ± 64.67	119.67 ± 8.33	112.46 ± 9.91	115.73 ± 17.30	.152	.075	.882
DBP (mmHg)	64.93 ± 6.68	68.80 ± 6.51	64.67 ± 8.05	64.26 ± 6.86	69.33 ± 8.26	67.20 ± 5.34	.097	.715	.176
FVC (L)	3.28 ± 0.70	3.28 ± 0.74	3.34 ± 0.91	3.29 ± 0.95	3.36 ± 0.97	3.36 ± 0.91	.574	.731	.673
FEV1 (L)	3.13 ± 0.68	3.01 ± 0.63	3.12 ± 0.79	3.04 ± 0.83	3.16 ± 0.89	3.21 ± 0.83	.064	.442	.527
FEV1/FVC (%pred)	90.47 ± 5.47	92.09 ± 8.00	88.45 ± 22.48	89.22 ± 22.90	90.06 ± 16.20	91.79 ± 15.48	.470	.692	.139
MVV (L/min)	130.65 ± 30.49	134.32 ± 28.03	133.36 ± 33.63	135.22 ± 32.26	142.39 ± 32.31	145.72 ± 32.65	.064	.205	.879
MIP (cmH ₂ O)	93.93 ± 18.91	95.16 ± 24.15	88.30 ± 17.85	94.10 ± 21.60	101.80 ± 19.76	98.13 ± 16.92	.069	.571	.169
MEP (cmH ₂ O)	94.46 ± 19.41	97.23 ± 18.16	95.66 ± 19.14	97.40 ± 19.35	97.93 ± 16.99	97.46 ± 15.51	.806	.258	.416

Table 1 The comparison of general physiological characteristics, pulmonary function, and respiratory muscle strength variables was conducted using two-way repeated measures ANOVA among running, cycling, and swimming exercises, and between pre- and post-tests within each exercise protocol.

Data are presented as mean ± SD. * $p < .05$ vs. pre-test.

(BW = Body weight, BMI = Body Mass Index, HR = Heart rate, SBP = Systolic blood pressure, DBP = Diastolic blood pressure, FVC = Force Vital Capacity, FEV1 = Forced Expiratory Volume in one second, MVV = Maximum Voluntary Ventilation, MIP = Maximum Inspiratory Pressure, MEP = Maximum Expiratory Pressure).

NBF and PNIF

Figure 2 and Table 2 showed that after both running and cycling exercise, NBF significantly decreased ($p = 0.001$, $p = 0.009$, respectively) and PNIF significantly increased ($p = 0.001$, $p = 0.001$, respectively) compared with the pre-test.

VARIABLES	n = 15									
	RUNNING (R) $\bar{x} \pm SD$		CYCLING (C) $\bar{x} \pm SD$		SWIMMING (S) $\bar{x} \pm SD$		LMM ANALYSIS			
	PRE-TEST	POST-TEST	PRE-TEST	POST-TEST	PRE-TEST	POST-TEST	BETWEEN GROUPS	ESTIMATE	SE	p-value
NBF (PU)	126.78 $\pm$ 16.43	75.62 $\pm$ 8.34	134.48 $\pm$ 17.77	94.18 $\pm$ 10.05	114.63 $\pm$ 9.32	102.52 $\pm$ 9.80				
Estimate	51.2		40.3		12.1		R vs C	-18.56	15.2	0.674
SE	15.2		15.2		15.2		R vs S	-26.90	15.2	0.240
p-value	0.001*		0.009*		0.426		C vs S	-8.34	15.2	1.000
PNIF (L/min)	108.67 $\pm$ 8.62	135.00 $\pm$ 8.15	110.00 $\pm$ 8.76	136.33 $\pm$ 7.99	126.66 $\pm$ 6.06	135.67 $\pm$ 6.98				
Estimate	-26.30		-26.30		-9.00		R vs C	-1.33	8.04	1.000
SE	8.04		8.04		8.04		R vs S	-0.66	8.04	1.000
p-value	0.001*		0.001*		0.267		C vs S	0.66	8.04	1.000
Rhinitis symptoms (Scores)										
Nasal congestion	1.20 $\pm$ 0.20	0.40 $\pm$ 0.16	1.00 $\pm$ 0.21	0.46 $\pm$ 0.19	1.00 $\pm$ 0.21	0.33 $\pm$ 0.15				
Estimate	0.80		0.53		0.66		R vs C	-0.06	0.26	1.000
SE	0.26		0.26		0.26		R vs S	0.06	0.26	1.000
p-value	0.003*		0.050		0.015*		C vs S	0.13	0.26	1.000
Itching	0.80 $\pm$ 0.22	0.20 $\pm$ 0.14	0.86 $\pm$ 0.23	0.13 $\pm$ 0.09	0.93 $\pm$ 0.22	0.13 $\pm$ 0.09				
Estimate	0.60		0.73		0.80		R vs C	0.06	0.25	1.000
SE	0.25		0.25		0.25		R vs S	0.06	0.25	1.000
p-value	0.021*		0.005*		0.002*		C vs S	0.00	0.25	1.000
Sneezing	0.66 $\pm$ 0.25	0.00 $\pm$ 0.00	0.60 $\pm$ 0.19	0.00 $\pm$ 0.00	0.46 $\pm$ 0.23	0.66 $\pm$ 0.06				
Estimate	0.66		0.60		0.40		R vs C	0.00	0.23	1.000
SE	0.23		0.23		0.23		R vs S	-0.06	0.23	1.000
p-value	0.005*		0.011*		0.087		C vs S	-0.06	0.23	1.000
Rhinorrhea	1.06 $\pm$ 0.26	0.53 $\pm$ 0.21	0.80 $\pm$ 0.24	0.60 $\pm$ 0.19	0.86 $\pm$ 0.23	0.46 $\pm$ 0.16				
Estimate	0.53		0.20		0.40		R vs C	-0.06	0.28	1.000
SE	0.28		0.28		0.28		R vs S	0.06	0.28	1.000
p-value	0.068		0.489		0.169		C vs S	0.13	0.28	1.000
Total rhinitis symptoms	3.73 $\pm$ 0.67	1.13 $\pm$ 0.29	3.26 $\pm$ 0.71	1.20 $\pm$ 0.32	3.26 $\pm$ 0.75	1.00 $\pm$ 0.25				
Estimate	2.60		2.07		2.27		R vs C	-0.06	0.77	1.000
SE	0.77		0.77		0.77		R vs S	0.13	0.77	1.000
p-value	0.001*		0.009*		0.004*		C vs S	0.20	0.77	1.000

Rhinitis symptom scores

The total rhinitis symptoms ($p = 0.001$, $p = 0.009$, $p = 0.004$) and itching score ($p = 0.021$, $p = 0.005$, $p = 0.002$) were significantly lower than pre-test after all exercise regimens (running, cycling, and swimming, respectively). In comparison to the pre-test, the post-running exercise nasal congestion, itching, and sneezing scores significantly decreased ($p = 0.003$, $p = 0.021$, and $p = 0.005$, respectively). Additionally, the itching ($p = 0.005$) and sneezing ($p = 0.011$) score significantly decreased after cycling exercise, and the nasal congestion ($p = 0.015$) and itching ($p = 0.002$) score significantly decreased after swimming exercise. There were no significant differences ($p > 0.05$) in rhinitis symptom scores among exercise protocols (Figure 2 and Table 2).

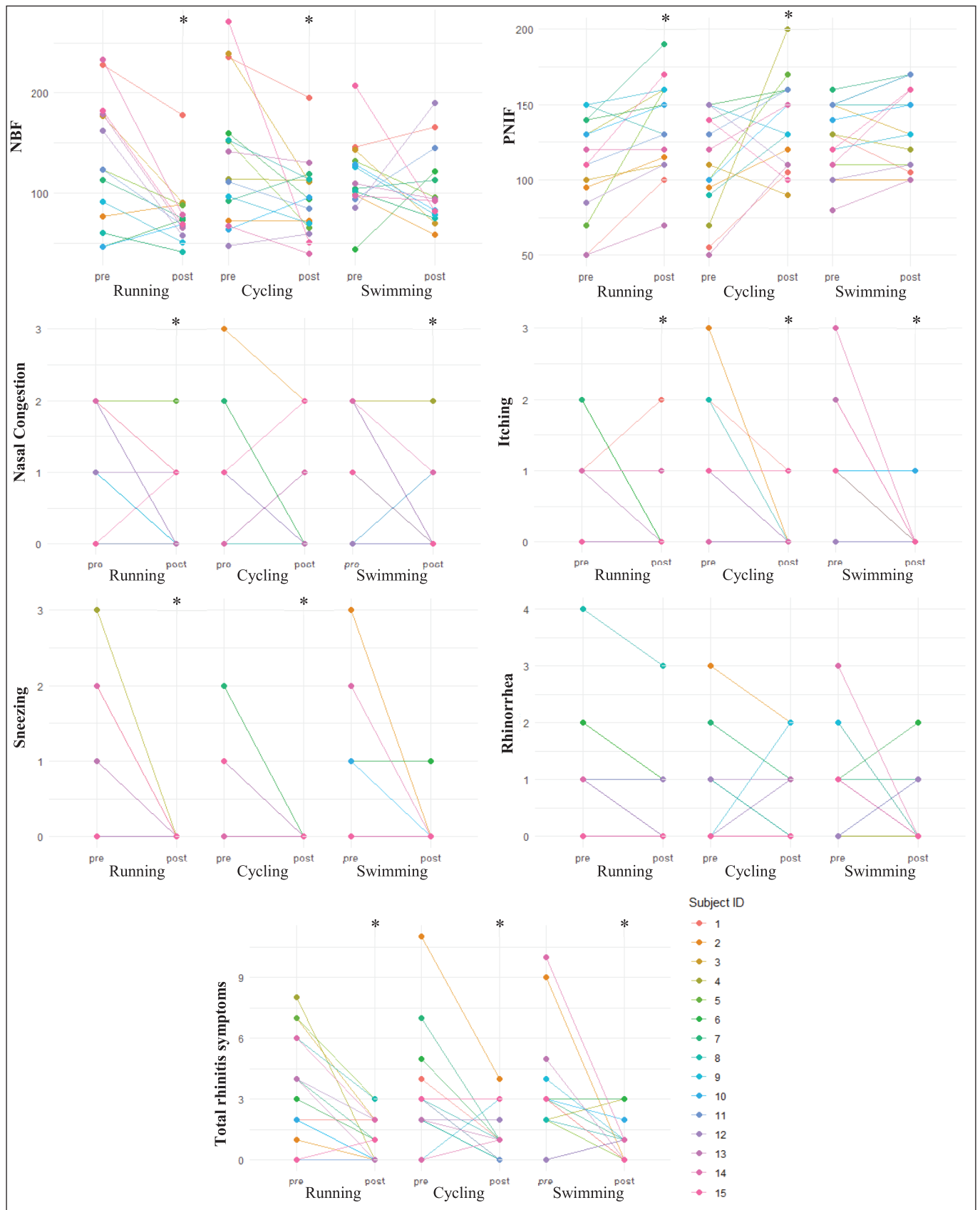
Cytokines levels in nasal secretion

Figure 3 and Table 3 presents the cytokine levels in nasal secretion variables. After running exercise, the IL-4, IL-5, IL-13, and TNF- α levels in nasal secretion had significantly decrease ($p = 0.012$, $p = 0.017$, $p = 0.001$, $p = 0.036$, respectively) when compared with pre-test. After cycling exercise, the IL-4, and TNF- α levels had significantly decrease ($p = 0.045$, $p = 0.031$, respectively) when compared with pre-test. In addition, after swimming exercise, the IL-4, and TNF- α levels had significantly decrease ($p = 0.012$, $p = 0.026$, respectively) when compared with

Table 2 The comparison of NBF, PNIF, and rhinitis symptom score variables including nasal congestion, itching, sneezing, rhinorrhea, and total rhinitis symptoms was conducted using the LMM analysis among running, cycling, and swimming exercises, and between pre- and post-tests within each exercise protocol.

Data are presented as mean $\pm$ SD. * $p < .05$ vs. pre-test.

(NBF = Nasal blood flow, PNIF = Peak nasal inspiratory flow).



pre-test. Moreover, only after running exercise, the IL-4/IL-10 ratios were significantly lower than pre-test ($p = 0.014$). No significant differences were found in cytokine profiles among exercise protocols.

DISCUSSION

The principal finding of the present study is that all aerobic exercise protocols, such as running, cycling, and swimming, reduced rhinitis symptoms in allergic rhinitis patients. However, NBF

Figure 2 The LMM analysis of NBF, PNIF, and rhinitis symptom score variables. * $p < .05$ vs. pre-test.

VARIABLES	n = 15									
	RUNNING (R)		CYCLING (C)		SWIMMING (S)		LMM ANALYSIS			
	PRE-TEST	POST-TEST	PRE-TEST	POST-TEST	PRE-TEST	POST-TEST	BETWEEN GROUPS	ESTIMATE	SE	p-value
IL-2 (pg/ml)	14.82 ± 3.60	7.72 ± 2.57	15.17 ± 5.05	9.33 ± 3.31	47.58 ± 25.99	30.45 ± 20.54				
Estimate	7.09		5.84		17.14		R vs C	-1.60	17.90	1.000
SE	17.90		17.90		17.90		R vs S	-22.72	17.90	0.623
p-value	0.692		0.744		0.341		C vs S	-21.12	17.90	0.724
IL-4 (pg/ml)	72.49 ± 22.31	37.45 ± 15.13	75.37 ± 24.86	47.37 ± 17.55	73.53 ± 20.94	38.17 ± 15.38				
Estimate	35.00		28.00		35.40		R vs C	-9.91	13.70	1.000
SE	13.70		13.70		13.70		R vs S	-0.71	13.70	1.000
p-value	0.012*		0.045*		0.012*		C vs S	9.20	13.70	1.000
IL-5 (pg/ml)	35.83 ± 17.86	7.97 ± 2.24	11.02 ± 3.85	5.89 ± 2.08	20.35 ± 8.79	9.91 ± 2.75				
Estimate	27.87		5.13		10.44		R vs C	2.07	11.40	1.000
SE	11.40		11.40		11.40		R vs S	-1.94	11.40	1.000
p-value	0.017*		0.655		0.364		C vs S	-4.02	11.40	1.000
IL-6 (pg/ml)	46.17 ± 11.10	21.70 ± 3.93	78.36 ± 49.45	79.91 ± 54.12	79.34 ± 52.86	45.75 ± 27.97				
Estimate	24.47		-1.55		33.60		R vs C	-58.20	49.90	0.741
SE	49.90		49.90		49.90		R vs S	-24.04	49.90	1.000
p-value	0.625		0.975		0.502		C vs S	34.16	49.90	1.000
IL-10 (pg/ml)	1.20 ± 0.19	0.88 ± 0.08	2.16 ± 1.05	2.28 ± 1.16	6.22 ± 4.86	6.11 ± 5.09				
Estimate	0.32		-0.11		0.11		R vs C	-1.39	3.75	1.000
SE	3.75		3.75		3.75		R vs S	-5.23	3.75	0.502
p-value	0.931		0.975		0.976		C vs S	-3.83	3.75	0.931
IL-13 (pg/ml)	7.49 ± 2.36	2.87 ± 0.94	5.45 ± 1.73	3.21 ± 1.08	5.01 ± 1.52	2.78 ± 1.03				
Estimate	4.63		2.24		2.23		R vs C	-0.33	1.37	1.000
SE	1.37		1.37		1.37		R vs S	0.08	1.37	1.000
p-value	0.001*		0.107		0.108		C vs S	0.42	1.37	1.000
TNF-α (pg/ml)	15.93 ± 1.21	7.95 ± 3.02	18.72 ± 6.56	10.49 ± 3.74	16.65 ± 4.33	8.17 ± 3.05				
Estimate	7.99		8.23		8.48		R vs C	-2.54	3.75	1.000
SE	3.75		3.75		3.75		R vs S	-0.21	3.75	1.000
p-value	0.036*		0.031*		0.026*		C vs S	2.32	3.75	1.000
IFN-γ (pg/ml)	7.01 ± 2.89	3.94 ± 1.70	7.06 ± 3.71	4.80 ± 2.75	10.71 ± 4.11	6.34 ± 2.60				
Estimate	3.07		2.26		4.38		R vs C	-0.86	3.09	1.000
SE	3.09		3.09		3.09		R vs S	-2.39	3.09	1.000
p-value	0.324		0.466		0.161		C vs S	-1.53	3.09	1.000
IL-4/IL-10	66.05 ± 22.26	40.08 ± 16.11	73.76 ± 27.51	42.86 ± 17.80	78.21 ± 26.50	52.74 ± 14.55				
Estimate	26.00		30.90		45.50		R vs C	-2.78	17.6	1.000
SE	17.60		17.60		17.60		R vs S	7.34	17.6	1.000
p-value	0.014*		0.083		0.119		C vs S	10.11	17.6	1.000

decreased and PNIF increased only after both running and cycling exercises. Moreover, NBF decreased after running compared to swimming exercise. After running exercise, levels of IL-4, IL-5, IL-13, and TNF-α significantly decreased compared to pre-test levels. Additionally, the IL-4/IL-10 ratios were significantly lower than pre-test levels. After cycling exercise, only IL-4, and TNF-α levels decreased. In addition, after swimming exercise, only IL-4, and TNF-α levels decreased.

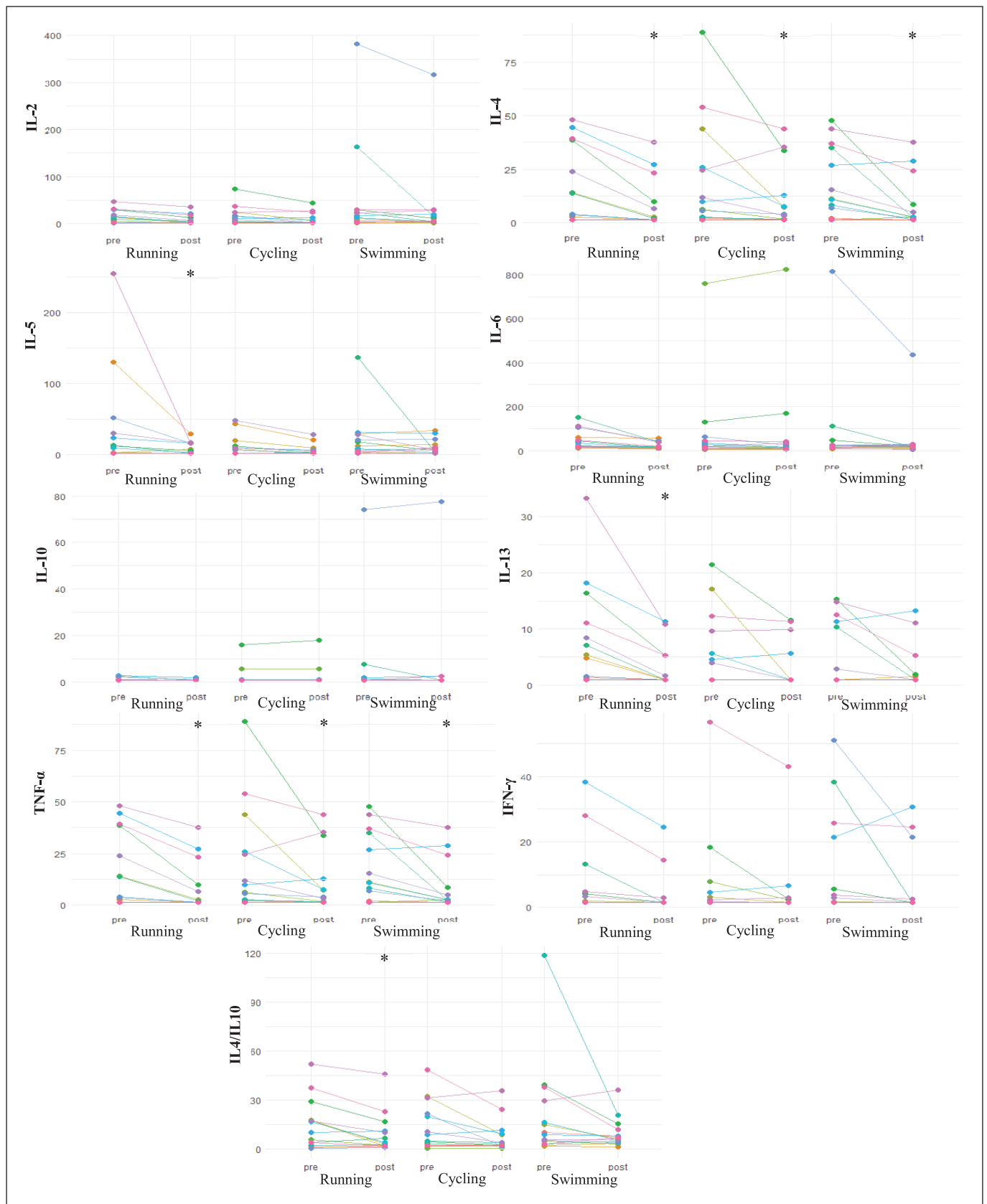
Our study demonstrated that individuals with allergic rhinitis were able to alleviate their symptoms with all three types of aerobic exercise: running, cycling, and swimming. Nevertheless, running exercises exhibited a more pronounced beneficial effect on several aspects when compared to cycling or swimming. On the other hand, swimming exercise appeared to have the least favorable effects on the factors measured in the study.

The findings of the current study indicate that moderate running and cycling exercises, each lasting 30 minutes, led to a significant reduction in symptoms related to allergic rhinitis in patients affected by the condition. These results are consistent with previous research conducted in 2012, which investigated the effects of acute exhaustive and moderate exercises on cytokine levels and clinical symptoms in allergic rhinitis patients. That study demonstrated that moderate-intensity exercise through running significantly improved allergic rhinitis symptoms (Tongtako et al., 2012).

Table 3 The comparison of NBF, PNIF, and rhinitis symptom score variables including nasal congestion, itching, sneezing, rhinorrhea, and total rhinitis symptoms was conducted using the LMM analysis among running, cycling, and swimming exercises, and between pre- and post-tests within each exercise protocol.

Data are presented as mean ± SD. *p < .05 vs. pre-test.

(IL = interleukin, TNF-α = Tumor necrosis factor-alpha, IFN-γ = Interferon-gamma).



Both running and cycling exercises may exert a positive impact on allergic rhinitis symptoms by reducing nasal resistance, thereby mitigating sympathetic vasoconstriction in the nasal mucosa (Olson, & Strohl, 1987; Tongtako et al., 2012; Tongtako et al., 2018; Prossegger et al., 2019; Ang et al., 2023). This reduction in nasal resistance, potentially facilitated by decreased blood flow leading to less nasal congestion, could contribute to the alleviation of symptoms (Ramey, Bailen, & Lockey, 2006). Aerobic exercise such as running and cycling has been suggested to enhance nasal airflow, elevate nasal temperature, and modulate the autonomic nervous system (Olson, & Strohl, 1987; Fonseca et al., 2006; Tongtako et al., 2018; Daniela et al., 2022). Autonomic reflexes improve nasal function and decrease nasal resistance

Figure 3 The LMM analysis of cytokines variables.

during exercise by increasing sympathetic activity, which leads to the constriction of nasal blood vessels through adrenoceptor stimulation (Alves et al., 2010; Eksi et al., 2021). These physiological adaptations may collectively contribute to improved nasal patency, decreased nasal congestion, and ultimately reduced rhinitis symptoms.

However, our findings indicate that running provides a more significant improvement in rhinitis patient compared to cycling or swimming. This may be attributed to its higher cardiorespiratory demands which reflected in greater VO_2 and heart rate responses as reported in previous studies (Scott et al., 2006; Abrantes et al., 2012). Differences in ventilatory patterns and posture, such as the upright position during running versus seated hip flexion during cycling, may also influence diaphragm movement and lung volume (Tanner, Duke, & Stager, 2014). Additionally, the biomechanical dynamics of running such as leg rhythm, thoracic rotation, and arm swing may enhance ventilatory efficiency and effect to nasal blood flow. Together, these physiological and mechanical factors may explain the superior benefits of running on rhinitis symptoms.

Using multiplex cytokines from nasal secretions, we observed that all cytokine levels, such as IL-4, IL-5, IL-13, and TNF- α were significantly lower after running exercise compared to pre-exercise levels. Furthermore, following running exercise, the ratios of IL-4/IL-10 notably decreased compared to their pre-testing levels. Meanwhile, after cycling exercise, there was a decrease in only some cytokines, including IL-4, and TNF- α . After swimming exercise, there was a decrease in IL-4, and TNF- α . The production of IL-4, IL-5, IL-6, IL-13, and TNF- α , which are responsible for B cell synthesis of IgE, eosinophil activation and recruitment, and mucus production, is linked to allergic inflammation (Wheatley, & Togias, 2015; Meng, Wang, & Zhang, 2019). On the other hand, the release of IFN- γ , IL-2, and IL-10 is crucial for the intracellular eradication of phagocytosed microorganisms and inhibits IgE synthesis (Benson, Adner, & Cardell, 2001; Ngoc et al., 2005).

The findings of this study align with prior research (Tongtako et al., 2012) indicating that engaging in acute aerobic exercise, such as running, leads to a decrease in pro-inflammatory cytokines among individuals with allergic rhinitis. In addition, following running exercise, there was a decrease observed in the ratio of IL-4/IL-10 cytokines, representing the ratio of pro-inflammatory to anti-inflammatory cytokines. This decline in ratio suggests a potentially beneficial impact of running exercise in lowering levels of pro-inflammatory cytokines, while the levels of anti-inflammatory cytokines may remain relatively stable. Nonetheless, the findings of this study differ from those of previous studies (Suzuki, & Hayashida, 2021; Małkowska, & Sawczuk, 2023), which observed that the immediate effects of exercise increased levels of IL-6, TNF- α , and IL-10. This disparity could be attributed to the fact that their report analyzed cytokine concentrations in the bloodstream, whereas our research focused on secretions within the nasal cavity. However, more research is required since the mechanisms behind this cytokine response in nasal secretion to acute exercise are unknown.

The results of this study showed that swimming did not lead to an increase in PNIF or a decrease in NBF. In contrast, a reduction in NBF was observed following running compared to swimming. Previous studies (Bonsignore et al., 2003; Gelardi et al., 2012) suggest that factors such as water temperature, pH, and hyperventilation may influence nasal physiology; however, chlorine exposure appears to be the most significant contributor. Chlorine's irritant properties are associated with neutrophilic inflammation and may exacerbate allergic rhinitis symptoms (Deitmer & Scheffler, 1990; Bougault, Turmel, & Boulet, 2010; Swinarew et al., 2020). Competitive swimmers, in particular, have reported increased nasal symptoms attributed to prolonged chlorine exposure during intense training (Bougault et al., 2010). Additionally, Deitmer and Scheffler (1990) found a significantly higher incidence of sinusitis and nasal symptoms such as discharge, obstruction, and itching among swimmers, likely due to water entering the nasal cavity and sinuses. Furthermore, both supine and prone positions are associated with increased nasal blockage, as well as a decrease in nasal cross-sectional area and volume (Roithmann et al., 2005; Wang et al., 2023). Swimming in a horizontal position may influence nasal hydrodynamics by altering the airflow and water flow through the nasal passages. This postural change can impact nasal resistance, airflow patterns, and the distribution of water pressure, all of which may affect nasal function during exercise.

This study has some limitations, including a small sample size of only 15 individuals. Hence, further research is warranted to explore a larger sample size and examine additional variables to elucidate the mechanism of cytokine response in nasal secretions following acute exercise. Moreover, future studies should also investigate the effects of exercise training.

CONCLUSIONS

In conclusion, our data show that single bout of moderate-intensity aerobic activity, such as running, cycling, and swimming, reduces rhinitis symptoms, while both running and cycling have a beneficial impact on NBF and PNIF. The only exercise that can lessen all symptoms, including nasal congestion, itching, sneezing, and rhinorrhea, is running. Additionally, running exercise is associated with a reduction in pro-inflammatory cytokines, as indicated by the decreased IL-4/IL-10 ratio. We consequently come to the conclusion that running at a moderate level is a suitable form of aerobic exercise for those with allergic rhinitis.

DATA ACCESSIBILITY STATEMENT

The data that support the findings of this study are not publicly available due to privacy data of participant but are available from the corresponding author on reasonable request.

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COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

W.T. conceptualized and designed the study, data collection, analyzed the data, interpreting the results, discussion, conclusion, drafted the manuscript and revise/review the manuscript. J.K. designed and performed the experiments, contributed to sample preparation, aided in interpreting the results, and conclusion. T.D. designed the experiments and reviewed the manuscript. D.S. designed the experiments, aided in interpreting the results, discussion, conclusion, and reviewed the manuscript. All authors have read and approved the manuscript and gave consent to publish it.

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