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Original Article

Immediate impact of various breathing modes on short-term local muscular endurance performance and physiological responses

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Abstract
Problem statement: Previous studies have underscored differences between nose and mouth breathing concerning health implications, yet the immediate impact of these breathing modes on strength and physiological responses still needs to be clarified. **Purpose:** This study aimed to explore the immediate effects of different breathing modes on short-term local muscle endurance performance (SLMEP) and physiological responses. **Methods:** In this randomized crossover experimental study, 110 individuals (70 men and 40 women) underwent a 60-s sit-up test (SU60) three times under three different breathing conditions nasal inhale + nasal exhale (NN); oral inhale + oral exhale (MM); nasal inhale + oral exhale (NM) on separate days in random order. Dependent variables included the number of repetitions in SU60 (repsSU60), heart rate (HR), perceived exertion (RPE), and blood oxygen saturation (SpO2). **Results:** Repeated measures ANOVA indicated no significant differences in repsSU60, RPE, and SpO2 between the selected breathing modes in both genders. However, the male group exhibited significantly lower HR for the NN mode compared to NM ($p = 0.026$) and compared to MM in the female group ($p = 0.047$). **Conclusions:** Various breathing modes exhibit no immediate effects on SLMEP and physiological responses such as RPE and SpO2. Even without the need for adaptation, NN appears to be equally effective in SLMEP as the other two more commonly used breathing modes (NM and MM). While selected breathing modes may potentially impact HR, the immediate effects in the context of SLMEP are only minor. Given the lack of significant differences between various breathing modes in SLMEP, individuals can select their breathing modes based on personal preference. Still, using a potentially healthier mode (NN) seems more appropriate.
Keywords: **physiology, respiration, mouth breathing, nose, exercise, resistance training**

Introduction

Breathing, an essential yet often underestimated aspect of sports practice (Lörinczi, et al., 2023a), plays a pivotal role in both athletic performance and overall health (Dallam & Kies, 2020). Various modes of breathing, including nasal, oral, and oronasal, have been the focus of recent research due to their potential to impact athletic performance and health outcomes.

During exercise, individuals employ both nasal and oral breathing (Saibene et al., 1978). While pure nasal breathing is suitable for light to moderate intensities (Bennett et al., 2003), as exercise intensity rises, individuals tend to transition to faster, mouth-dominant breathing (Niinimaa, 1983). This shift typically occurs when ventilation reaches approximately 11-44 liters per minute (Niinimaa et al., 1980; Saibene et al., 1978). Continuous, high-intensity exercise tends to minimize nasal breathing's contribution without yielding additional performance benefits compared to restricted oral breathing (Meir et al., 2014; Morton et al., 1995). Sports performance and physiological responses do not appear to significantly differ between oral and oronasal breathing (Dallam & Kies, 2020; Meir et al., 2014), but unadapted individuals may experience decreased aerobic performance while performing with pure nasal breathing (Garner et al., 2011; LaComb et al., 2017; Morton et al., 1995). However, adapted individuals can maintain long-term aerobic performance at submaximal intensities with no significant decrease compared to oronasal and oral (Dallam et al., 2018; Hostetter & Mcclaran, 2016). Short-term anaerobic performance, even in unadapted individuals, does not seem to be restricted by nasal breathing (Recinto et al., 2017).

Moreover, pure nasal breathing offers the advantage of improved ventilatory efficiency, resulting in 10-20% higher oxygen uptake (Sevoz-Couche & Laborde, 2022) and increased diaphragm activation (Trevisan et al., 2015), potentially leading to improved torso stabilization and injury prevention (Kolar et al., 2010). However, pure nasal breathing can in nonadapted individuals lead to feelings of hypoventilation and higher perceived exertion (Niinimaa, 1983; Saibene et al., 1978). These findings suggest that the choice of breathing mode may impact athletic performance and subjectively perceived exertion.

Further benefits of pure nasal breathing encompass more efficient filtration, preheating, and humidification of inhaled air (Van Cauwenberge et al., 2004), the enrichment of inhaled air with nitric oxide (Arnal et al.,

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1999), known for its vasodilatory, bronchodilatory, antibacterial, and antiviral effects (Martina et al., 2012), as well as maintaining moisture within the nasal cavities (Scheithauer, 2010). Additionally, pure nasal breathing helps retain more water (Svensson et al., 2006) and CO_2 (Dallam et al., 2018; LaComb et al., 2017) in the body and also helps to prevent exercise-induced bronchoconstriction and asthma (Shturman-Ellstein et al., 1978).

On the other hand, chronic mouth breathing can have detrimental consequences for dental health, giving rise to various issues including malocclusion, tooth decay, plaque buildup, crowded and misaligned teeth, halitosis (bad breath), gum disease, an open bite, and dysfunctional jaw joints (Fraga et al., 2018; Lee et al., 2012; Triana et al., 2016). Furthermore, it can negatively impact one's overall facial appearance (Basheer et al., 2014). Mouth breathing is also associated with problems related to the microbiota of both the oral and lung environments (Bassis et al., 2015; Fan et al., 2020), impaired cognitive abilities, and a heightened prevalence of ADHD (Rangeeth et al., 2019). It can disrupt sleep patterns (Huang & Young, 2014) and contribute to various other adverse aspects of life (Kuroishi et al., 2014). Notably, mouth breathing is prevalent among approximately 55% of children (Abreu et al., 2008; De Menezes et al., 2006). However, in the context of resistance training, nearly all individuals tend to employ oronasal or oral breathing. During sports performance, increased ventilation through the mouth may subjectively make the workload feel easier (Tong et al., 2014), but it can also result in nasal congestion (Pacheco et al., 2015) and CO_2 diminishment, which further leads to vasoconstriction and impaired blood flow (Domino et al., 1993).

Despite the importance of this topic, there is a dearth of research on the comparison between nasal and mouth breathing concerning strength performance. Only Lörinczi, et al. (2023b) have reported that in individuals who do not prefer nasal breathing during resistance training, nasal exhalation resulted in significantly lower power output compared to mouth exhalation or breath holding after inhalation, though the practical effect was minor. Notably, there is a gap in our understanding regarding the immediate effects of various breathing modes on short-term local muscle endurance performance (SLMEP) and physiological responses.

Hence, it remains uncertain whether commonly employed modes of breathing (oronasal and oral) are necessary to maintain a certain level of strength, or if pure nasal breathing, which appears to be physiologically healthier, can be equally effective. The available evidence does not address whether oral and oronasal breathing might have negative health consequences when used exclusively during resistance training.

Breathing is directly related to a human movement (Jesensky et al. 2016). However, the precise regulation and optimal practices for breathing in different situations remain unclear. Therefore, this study addresses a highly relevant, original, and current research gap, as existing scientific knowledge is insufficient. Both the scientific community and athletes alike deserve answers to questions about how, when, and why to breathe to optimise performance.

Research Question: Do various breathing modes (nasal, oral, oronasal) immediately affect short-term local muscle endurance performance and physiological responses?

Methods

2.1 Study design

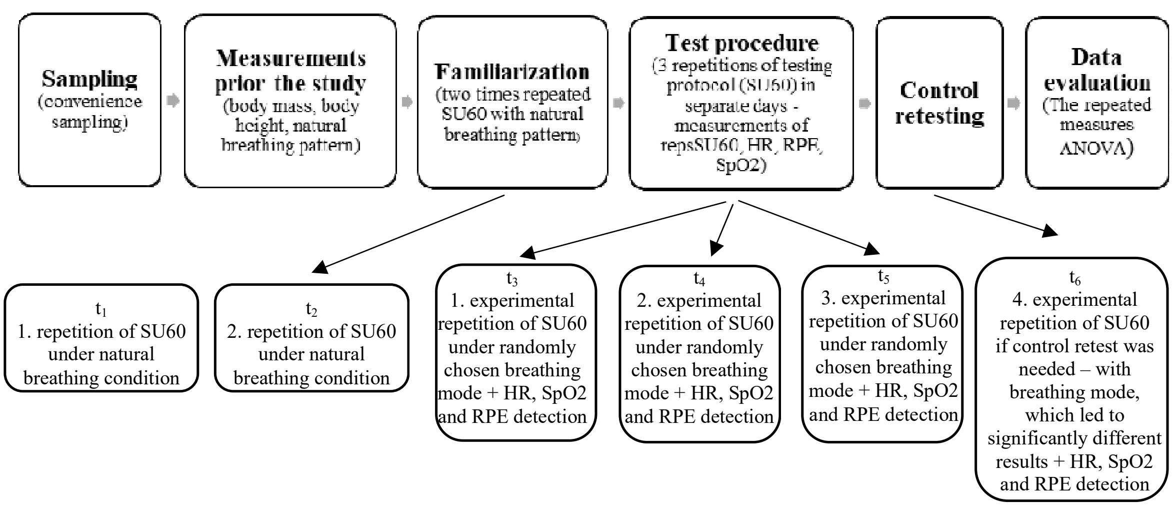

Figure 1 Study design

This experimental field study consisted of a series of carefully planned steps, including participant recruitment, pre-study assessments, two familiarization sessions, the main testing procedure, control retesting, and the subsequent data analysis (see Figure 1). Participants were recruited on a voluntary basis, utilizing convenience sampling. The pre-study assessments encompassed inquiries regarding participants' date of birth and their natural breathing patterns during resistance training, as well as measurements of body mass (using a precise scale accurate to 100 g) and body height (measured with a stadiometer accurate to 1 cm).

During the familiarization phase, participants performed the 60-second sit-up test (SU60) twice, employing their individually preferred natural breathing mode. The test protocol involved three repeated measurements of SU60, each conducted with a selected breathing mode, namely: nasal inhale + nasal exhale (NN), oral inhale + oral exhale (MM), and nasal inhale + oral exhale (NM). These modes were assigned randomly on separate testing days for each participant, following a simple randomization procedure. In addition to recording the number of repetitions in SU60 (repsSU60), other dependent variables, such as heart rate (HR), blood oxygen saturation (SpO2), and perceived exertion (RPE), were measured. The selected breathing modes (NN, NM, MM) served as the independent variables. Data analysis and the assessment of differences were conducted using the SPSS software. Ethical considerations were integral to the study's design and implementation. The experimental procedures strictly adhered to the ethical guidelines outlined in the Declaration of Helsinki 2000 and received approval from the ethics commission of the Faculty of Physical Education and Sport at Comenius University Bratislava (under number 6/2022).

Participants

A total of 110 physically active college students voluntarily participated in this study, consisting of 70 males and 40 females (refer to Table 1 for participant characteristics). The sample size was not predetermined and was established through non-probability convenience sampling. Most participants identified themselves as occasional mouth breathers, with approximately 95% of them reporting the use of oronasal and oral breathing modes during resistance training. This suggests a high probability that the majority of participants were not adapted to the pure nasal breathing mode (NN). All participants willingly agreed to participate in the study and provided oral informed consent, which was documented and witnessed by the researchers before their involvement in the study. Inclusion criteria were defined as follows: participants had to be in good health, allowing them to complete a repeated test protocol; possess at least one year of prior experience with resistance training; and demonstrate proficiency in executing the correct technique for the sit-up exercise.

Exclusion criteria encompassed the following: individuals with illnesses or medical conditions that impeded the execution of the repeated test protocol; those lacking experience in resistance training; participants unable to perform sit-ups with proper technique; and individuals displaying significantly different results after control retesting.

Procedures

Test procedures

To evaluate short-term local muscle endurance performance (SLMEP), the 60-second sit-up test (SU60) was employed. This test is recognized as a valid method for assessing abdominal SLMEP and has demonstrated excellent reliability in previous studies (Augustsson et al., 2009; Diener et al., 2009). A finding is consistent with our own familiarization measurements (ICC = 0.937; $p < 0.001$). The results of this test are quantified by the number of repetitions a participant can complete within a one-minute timeframe (repsSU60). For the analysis of physiological responses, pulse oximetry to measure blood oxygen saturation (SpO2) was utilized, employing the Viatom Oximeter PC-60FW. Heart rate (HR) was monitored using a chest strap heart rate monitor within the Polar system. The lowest recorded SpO2 and the highest HR observed during the tests were recorded. Additionally, participants' perceived exertion levels (RPE) were assessed using the Borg Scale 6–20.

Protocol procedure

The study was conducted at Comenius University Bratislava (Slovakia). The protocol procedure commenced with a familiarization phase in which participants completed SU60 twice while adhering to their natural breathing patterns. The experimental testing phase comprised three consecutive measurements of SU60 and, when necessary, control retesting. Each repetition of SU60 was performed under the selected breathing condition, with the order randomized for each participant across separate testing days. Repeated testing sessions were spaced 2 to 5 days apart. Following each SU60 test, SpO2 and HR were measured for a 30-second interval while participants remained seated. RPE was verbally diagnosed right after the test. If participants completed all three measurements but displayed significant deviations in results, a control retest was administered. Consistent warm-up protocols, testing times, and room temperatures were maintained throughout the entire protocol procedure. Throughout the research period, participants refrained from engaging in any form of resistance training. During each testing repetition, participants were instructed to exert maximal effort.

To control the independent variables, measures were implemented as follows: NN conditions were maintained by applying tape over the mouth, MM conditions were upheld using a swim clip on the nose, and NM conditions were verified through visual inspection by the examiners.

Statistical analyses

Kolmogorov-Smirnov test and Shapiro-Wilk test were used to assess normality of data distribution. The repeated measures ANOVA was employed to detect significance of differences between the results obtained under various breathing conditions (NN, NM, MM). The repeated measures ANOVA was also used to detect effect of repeated testing (to check potential improvements in performance outcomes over time). Level of significance was verified at $p < 0.05$. Effect size was expressed by partial eta squared (η^2). To regulate the family-wise error rate and determine which groups differ, a post-hoc Bonferroni correction was used. In cases of significant differences revealed by ANOVA, a parametric paired t-test was used to evaluate pairwise differences and Cohen's d was used to express effect size. SPSS program was utilized for statistical analyses.

Results

Prior Study measurements

Prior study measurements, including basic somatometry, are mentioned in the table below (see Table 1). In the context of natural breathing patterns used during resistance training, it was confirmed that the most commonly used mode is NM (80% of participants confirmed that). 15% of participants naturally use MM and 5% of participants use NN during resistance training.

Table 1 Characteristics of research sample

	decimal age (yr)	body height (cm)	body mass (kg)
men (n = 70)	22.40 ± 1.42	181.2 ± 6.34	78.22 ± 8.92
women (n = 40)	21.69 ± 1.50	167.68 ± 5.92	63.37 ± 6.60

Evaluation of the effect of repeated testing

The potential effect of repeated testing in repsSU60 was evaluated by repeated measures ANOVA from results reached among the test days 1-5 (both familiarization and experimental measurements). In both male and female groups, ANOVA revealed no significant differences among test days (men: $F(4,66) = 0.36$, $p = 0.83$; women: $F(4,36) = 1.30$, $p = 0.290$), so we can refute the potential learning effect. This fact supports the degree of internal validity of the research.

Results in SLMEP and physiological responses

ANOVA revealed no significant differences among selected breathing modes in both genders in the context of repsSU60 (men: $F(2,68) = 1.15$, $p = 0.322$; women: $F(2,38) = 1.81$, $p = 0.178$), RPE (men: $F(2,68) = 0.43$, $p = 0.654$; women: $F(2,38) = 0.83$, $p = 0.92$), and SpO2 (men: $F(2,68) = 0.84$, $p = 0.920$; women: $F(2,38) = 0.36$, $p = 0.964$) (see Table 2). In the context of repsSU60, RPE and SpO2 η^2 revealed only small to medium effect ($\eta^2 = 0.00 – 0.09$).

ANOVA confirmed significant differences among various breathing modes in HR (men: $F(2,68) = 3.62$, $p = 0.032$; women: $F(2,38) = 4.48$, $p = 0.018$), with η^2 revealing medium to large effect ($\eta^2 = 0.10 – 0.19$). A parametric paired t-test confirmed significant differences between NN and NM in the male group (140.01 ± 12.42 bpm vs. 144.37 ± 13.91 bpm; difference 4.36 bpm (3%); $p = 0.026$; $d = 0.34$) and between NN and MM in the female group (141.25 ± 10.19 bpm vs. 143.8 ± 9.46 bpm, difference 2.55 bpm (1.7%), $p = 0.047$, $d = 0.26$). In both cases, the effect size revealed only a small effect.

Table 2 Summary table of results

Group	NN	NM	MM	ANOVA		
SU60 (reps; mean ± SD)				F	p	η^2
men	53.36 ± 6.68	53.23 ± 6.15	53.80 ± 6.72	1.15	0.322	0.03
women	49.75 ± 5.99	48.68 ± 6.32	48.93 ± 6.68	1.81	0.178	0.09
HR (bpm; mean ± SD)						
men	140.01 ± 12.42	144.37 ±13.91	143.07 ± 13.51	3.62	0.032	0.10
women	141.25 ± 10.19	141.5 ±10.72	143.8 ± 9.46	4.48	0.018	0.19
RPE (score; mean ± SD)						
men	15.50 ± 1.32	15.31 ± 1.33	15.46 ± 1.38	0.43	0.654	0.01
women	15.23 ± 1.39	15.28 ± 1.09	15.33 ± 1.12	0.83	0.921	0.00
SpO2 (%; mean ± SD)						
men	98.06 ± 1.15	98.01 ± 1.19	97.99 ± 1.10	0.08	0.920	0.00
women	98.03 ± 0.29	97.95 ± 0.11	98.00 ± 1.26	0.04	0.964	0.00

Answer to the research question: Various breathing modes (NN, NM, MM) have no immediate effect on SLMEP, evaluated by SU60, and physiological responses, such as RPE and SpO2. Only minor immediate effects could have various breathing modes on HR, whereas NN can potentially lead to slightly lower values compared to NM and MM.

Discussion

This study aimed to investigate the immediate effects of various breathing modes on SLMEP and physiological responses, a subject that had not been previously explored. Results revealed that there are no significant immediate effects of the most commonly used breathing modes (NN, NM, MM) on SLMEP measured by SU60 in both males and females. The internal validity of this finding is supported by the rejected potential effect of repeated testing. Also, physiological responses, such as RPE and SpO2, were not affected by various breathing modes in both genders. While it is noteworthy that NN led to slightly lower HR after SLMEP in comparison to NM and MM, it is essential to emphasize that practically all these differences had only a minor effect. Moreover, these findings contradict those of (Recinto et al., 2017) who found significantly higher HR while nasal breathing during short-term submaximal exercise. HR could also be easily affected by various confounding variables (such as level of motivation or mental arousal etc. (Fowles, 1983), so we would not take these findings as completely authoritative. If there is a real potential for nasal breathing to cause lower physiological stress for the cardiovascular system compared to oronasal and oral breathing modes during SLMEP, explanations could be associated with higher levels of CO_2 and NO in the bloodstream, during nasally restricted breathing, which further causes vasodilatation, increased blood circulation, and better oxygenation, leading to a lower need for the heart to work in such an excess (Ali-Ahmad et al., 2003; Dallam et al., 2018; LaComb et al., 2017; Martina et al., 2012). However, since the mentioned variables were not analyzed in this study, this phenomenon cannot be confirmed unequivocally.

Despite the absence of significant performance differences, it is essential to note that a majority of participants naturally employ mouth breathing during resistance training, with approximately 80% using oronasal and 15% using oral breathing, because these modes seem to be more comfortable for them. Although many studies have highlighted the negative health consequences of chronic mouth breathing (Fraga et al., 2018; Rangeeth et al., 2019; Triana et al., 2016), the consequences of short-term use of oronasal and oral breathing modes for a restricted period of resistance training or another physical performance are unknown.

Thus, it is not unequivocally recommended to completely avoid these modes, when they ensure comfort, but rather recommend to conduct studies focused on this issue. However, it should be noted that pure nasal breathing appears to be physiologically healthier and does not compromise the outcomes of SLMEP, so participants should be encouraged to incorporate this breathing mode into their training. Our findings align with previous research (Recinto et al., 2017), indicating that during short-term, predominantly anaerobic performance, differences among various breathing modes are negligible. Breathing pattern is probably more important in longer activities with greater aerobic demand (Murlasits et al., 2023).

Additionally, our study did not reveal any differences in SpO2, and no instances of saturation deviating from the physiological norm were observed. This suggests that, regardless of the mode of breathing, continuous and adequate oxygenation is maintained during physical exertion. However, for future research, it should be noted that muscle oximetry measurements may offer a more precise assessment of oxygenation differences than pulse oximetry. Furthermore, RPE remained unaffected by the chosen breathing mode during SLMEP. The short duration of the performance, involving a limited number of muscles, likely does not induce feelings of hypoventilation, which could affect RPE. It appears that respiratory gas exchange remains sufficient and equally effective, irrespective of the mode of breathing during SLMEP. While this study did not uncover significant differences in the immediate effects of various breathing modes on SLMEP and physiological responses, its findings are valuable. Notably, the potentially healthier breathing mode, NN, was found to be equally effective as the more commonly used modes (NM, MM). Therefore, individuals may be encouraged to incorporate nasal breathing mode into their practice.

Strengths and limitations:

Strengths of this study include a diverse research sample encompassing both genders; originality in addressing an underexplored area; focus on three prevalent breathing modes; applicability to a wide active population; a controlled experimental design with repeated measurements; objective measures of HR, SpO2, and RPE; adherence to ethical guidelines; rejection of the effect of repeated testing.

Limitations of this study include: a field experiment – which does not allow controlling confounding variables at the same level as a laboratory experiment; the homogeneity of the research sample – which does not allow generalizing findings to a broader population; the research sample – the majority of participants declared using NM and MM modes during resistance training (thus are potentially not adapted to NN); differences in HR – although significant differences in HR were revealed, several uncontrolled variables could significantly affect the stability of this parameter; the use of pulse oximetry – muscle oximetry measurements would be more valuable; HR and SpO2 measures – these physiological variables were measured after the test and not during, which does not allow tracking the progress of HR in time; a focus only on immediate effects – long-term effects or adaptations to nasal breathing are unknown and could be an important area for future research; a single exercise – findings of the study pertain specifically to the SU60 exercise (it may not necessarily apply to other types of strength exercises or endurance activities); limited outcome measures – future studies could consider additional physiological and performance measures for a more comprehensive assessment (for example, respiratory quotient or EMG muscle activity); confounding variables – various uncontrolled factors such as sleep quality and the level of motivation, etc., may have influenced the results; sample size – sample size was not calculated prior to the study, and according to expected observed power, significance level and confidence intervals should be higher.

Suggestions for Future Research:

Future research is needed to validate the hypothesis that exclusive nasal breathing can be equally effective as oronasal or oral breathing in the context of resistance training and other forms of strength performance than SLMEP. Further research could also focus on verifying the immediate effects of nasal, oronasal, and oral breathing modes on SLMEP using a different test protocol while considering the limitations of this study. Furthermore, investigations should focus on the immediate effects of different breathing modes on physiological responses and the duration of the adaptation process to pure nasal breathing in various physical performance scenarios. Additional studies are required to confirm or refute the assumption that time-limited mouth breathing during strength training negatively impacts aspects of health.

Conclusion

Various breathing modes (NN, NM, MM) have no significantly different immediate impact on SLMEP and physiological responses. There were no significant variations in repsSU60, RPE, and SpO2 observed among the NN, NM, and MM modes in both genders. In some cases, NN led to significantly lower HR compared to other breathing modes, but these differences are practically small. Since there are no significant differences between various breathing modes in the context of SLMEP, individuals can choose their breathing mode based on personal preference, but the use of a potentially healthier mode (NN) seems to be more appropriate.

Declarations

Ethical approval and consent to participate

All participants were informed about the content and course of the protocol before entering the study. All participants willingly consented to their participation and provided oral informed consent to examiners. The study adhered to the ethical principles outlined in the Declaration of Helsinki 2000 and received approval from the ethics commission at the Comenius University Bratislava (Faculty of Physical Education and Sport).

Availability of data and material

The corresponding author has the right to share the datasets on rational request.

Conflicts of interest

The authors assert that they have no potential conflicts of interest related to the publication of this study.

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Author Contributions

All authors (FL, DL and DA) have actively and intellectually contributed to the work and have endorsed its publication.

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