

Effect of various breathing conditions on squat jump performance

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Abstract

Problem Statement: Currently, there is a lack of evidence regarding the influence of various breathing conditions on specific strength parameters. Several studies have primarily focused on the health aspects of breathing through the nose versus the mouth. The purpose of this study is to investigate how specific breathing conditions affect explosive power performance. **Approach:** Fifty male college students performed 5 sets of 3 repetitions of squat jumps (SJ) under three breathing conditions: exhaling through the nose (NE), exhaling through the mouth (ME), and breath hold after inhale (BH). The best performance attained under each breathing condition (SJmax) as well as the average performance of the three best attempts under each condition (referred to as SJave) were recorded. Additionally, the participants' natural breathing pattern (NBP) was identified to assess whether the best results were achieved under it. A repeated measures ANOVA method and parametric paired t-test were used to identify differences in SJmax and SJave among various breathing conditions. The effect size was evaluated using Cohen's d. The Chi-squared test was employed to establish a relationship between SJmax, SJave, and NBP. **Results:** The ANOVA analysis revealed significant differences between the selected breathing conditions in both SJmax ($p = 0.047$) and SJave ($p = 0.001$). In the context of SJmax, both ME and BH led to significantly higher results than NE ($NE < ME$, $p = 0.047$, $d = 0.29$; $NE < BH$, $p = 0.02$, $d = 0.34$). Similarly, ME and BH also achieved significantly higher SJave results ($NE < ME$, $p = 0.003$, $d = 0.45$; $NE < BH$, $p < 0.001$, $d = 0.53$). Chi-squared analysis revealed a significant relationship between NBP and both SJmax ($\chi^2 = 6.30$, $p = 0.043$) and SJave ($\chi^2 = 6.66$, $p = 0.036$). **Conclusion:** The NE breathing condition can significantly lower squat jump performance compared to ME or BH in individuals who do not use NE in their training practice. Best squat jump performance is frequently achieved under NBP. However, selected breathing conditions may have a significant, yet likely minor effect on squat jump performance.

Keywords: breathing, exhale, nose, mouth, breath hold, squat jump

Introduction

Power can be positively affected by various warm-up protocols (Fradkin et al., 2010; Miguel Silva et al., 2018), post-activation potentiation protocols (Dobbs et al., 2019; Králová et al., 2018), or supplementation (Martinez et al., 2022). Strength performance can even be affected by primary physiological needs such as sleep (Craven et al., 2022), water intake (McCartney et al., 2017), food intake (Henselmans et al., 2022), or circadian rhythms (Ayala et al., 2021; Thun et al., 2015). However, it is still unknown how power output is affected by the most basic physiological need – breathing. Breathwork has been around for centuries but is now being rediscovered as a lost art and explored scientifically (Nestor, 2021).

The issue of breathing is gaining popularity also because it is widely applicable and costless (Mendo et al., 2022). Most research on breathing examines the impact of various interventions on psychological health and stress reduction (Cunha et al., 2022; Ma et al., 2017). In sports sciences, breathing is predominantly studied in the context of endurance performance and respiratory muscle training (Bahenský et al., 2020; Hajghanbari et al., 2013; Harbour et al., 2022; Illi et al., 2012; Mackała et al., 2019). However, after James Nestor and Patrick McKeown published their bestsellers – "Breath" (Nestor, 2021) and "The Oxygen Advantage" (McKeown, 2015), a new perspective to the science of breathing was brought. Based on scientific literature, both authors consider the nose a very important organ of breathing. Nasal breathing is the key pillar of healthy breathing (Allen, 2017; McKeown & Macaluso, 2017; Swarthout, 2022; Trabalon & Schaal, 2012; Zimmer, 1994). Nasal cavities have the function of filtering, warming, and humidifying the inhaled air (Ferneck et al., 2020), which leads to prevention of colds, flu, allergic reactions, hay fever, or irritable coughing (Allen, 2017). Nasal breathing is also connected with lower water loss (Svensson et al., 2006), better diaphragm activation (Trevisan et al., 2015), spine stabilization (Kolar et al., 2010; Nelson, 2012), better oral health (Caixeta et al., 2014; Fan et al., 2020; Liu et al., 2008; Muñoz & Beltri Orta, 2014), higher sleep quality (Huang & Young, 2014), higher oxygen uptake (Sevoz-Couche & Laborde, 2022), higher levels of nitric oxide (Arnal et al., 1999), and carbon dioxide (Schleifer et al., 2002), which lead to better physiological functioning of the body (Ali-Ahmad et al., 2003; Jensen, 2004; Martina et al., 2012). Although most studies point to the negative health consequences of

mouth breathing in the long term and chronic use (Caixeta et al., 2014; Emslie et al., 1952; Fraga et al., 2018; Kuroishi et al., 2014; Liu et al., 2008), even short-term use can negatively affect human physiology (Shturman-Ellstein et al., 1978). Despite that, the idea of insufficient nasal breathing and necessity of mouth breathing in sports practice still persists (LaComb et al., 2017). Although some studies point to certain limitations of nasal breathing during sport performance (LaComb et al., 2017; Morton et al., 1995; Thomas et al., 2009), it may be equally effective when individuals adapt to it (Dallam et al., 2018; Hostetter & McClaran, 2016).

When performing maximal strength and explosive exercises, forced exhalation and the Valsalva manoeuvre are often used in practice (Hackett & Chow, 2013). These breathing conditions can positively affect the amount of isometric force compared to forced inhalation and natural breathing pattern (Ikeda et al., 2009; Li & Laskin, 2006). Forced expiration and grunting seem to lead to higher force production compared to forced inhalation or the Valsalva manoeuvre (Li & Laskin, 2006). Forced expiration is a potentially safer alternative to the Valsalva manoeuvre and is more audibly pleasing than grunting (Li & Laskin, 2006). However, the velocity, force, and peak muscle activity during tennis serves and forehand strokes are significantly enhanced when athletes are allowed to grunt (O'Connell et al., 2014).

Deep inhalation and diaphragm activation are important to create greater intra-abdominal pressure, which stabilizes the torso during exercise and helps with energy transfer between peripheries (Jesenský et al., 2016; Nelson, 2012). Intra-abdominal pressure has a positive causal effect on maximal voluntary isometric contraction torque of hip extension (Tayashiki et al., 2018). Although breath control was shown to influence intra-abdominal pressure, it does not appear to influence isometric trunk extension force in a knees bent position (Hagins et al., 2006). Furthermore, the intra-abdominal pressure produced in such efforts appears to be unrelated to the amount of force produced (Hagins et al., 2006).

The most common directions in the context of breathing for resistance training are: "breathe in" during the eccentric phase and "breathe out" during the maximal exertion or concentric phase (Hagins et al., 2006). However, it is still unknown whether to breathe through the nose or mouth. The absence of evidence regarding the effect of different breathing conditions during high-intensity single movements was the reason to conduct this study.

Purpose

The purpose of the study was to determine whether and how various breathing conditions (exhale through the nose (NE) / exhale through the mouth (ME) / breath hold after inhale (BH)) acutely affect squat jump performance (SJ).

Methods

Research Sample

In this semi-experimental study, 50 male college students (see Table 1 for characteristics) voluntarily completed a squat jump testing protocol. The sample was based on non-probability convenience sampling. All participants were recreational athletes and had previous experience with the squat jump exercise. None of the participants had NE as a natural breathing pattern (NBP) during the concentric phase of the explosive exercise. For 29 participants, NBP was ME, and for 21 participants, it was BH. The research sample consisted of individuals who do not use NE during resistance training and are therefore potentially not adapted to it.

Table 1 Characteristics of research sample

	age (yr)	height (cm)	body mass (kg)
men (n = 50)	22.50 ± 1.71	119.92 ± 7.58	77.47 ± 12.09

Protocol

The entire study was designed and conducted at the Faculty of Physical Education and Sport, Comenius University in Bratislava, Slovakia. The study was approved by the ethics commission and adhered to the ethical guidelines of the Declaration of Helsinki 2000.

During the familiarization phase, the starting squat position was established for each participant, ensuring a 90-degree angle between the thigh and lower leg in the lower position. All participants performed 5 sets of 3 repetitions of vertical jumps from the squat position (without a counter-movement and without arm-swing). The first set was done with a natural breathing regimen, while the second set was performed with the selected breathing regimens (NE, ME, BH).

The testing protocol proceeded as follows: All participants completed 5 sets of 3 repetitions of vertical jumps from an isometric squat position (without a counter-movement and arm-swing). At intervals of 5 seconds, participants were instructed to transition into the squat position from a standing position in a controlled manner, maintain that position for 3 seconds, and then execute a jump as high as possible upon receiving the examiner's signal. To ensure uniformity, a soft stopping surface was used to maintain consistent range of motion for each repetition. All conditions were kept as stable as possible, with the only variation being the breathing condition changing for each repetition in the set. The sequence of breathing conditions for each jump changed randomly

for each set. The only stipulation was that the same sequence couldn't repeat twice across all sets. The height of the squat jump was measured using Optojump.

The examiner recorded the participant's natural breathing pattern (NBP), which was established during the first set of familiarization. The best result from all series for each breathing condition (SJmax) and the average results (for each breathing condition) from the three best attempts out of the five series (SJave) were also recorded. The examiners monitored and controlled the breathing conditions. During NE and ME conditions, participants were instructed to perform forced exhalation.

Statistical analysis

Statistical analyses were conducted using the SPSS program. The Kolmogorov-Smirnov test was employed to assess the normality of the data distribution. The repeated measures ANOVA method was applied to determine whether significant differences exist in the outcomes among various breathing conditions (NE, ME, BH). Furthermore, the parametric paired t-test was utilized to assess the significance of differences between results (SJmax, SJave) achieved under the selected breathing conditions. The Chi-squared test was employed to determine whether a significant relationship exists between the NBP and the breathing condition that yielded the best results for the individual (best SJmax, best SJave). In significant cases, the effect size was evaluated by Cohen's d (Cohen, 1998).

Results

Table 2 presents a summary of the results. Using the ANOVA method, significant differences were found in both SJmax (Wilks' Lambda = 0.88; $F(1, 49) = 3.26$; $p = 0.047$; $\eta^2 = 0.12$) and SJave (Wilks' Lambda = 0.75; $F(1, 49) = 7.91$; $p = 0.001$; $\eta^2 = 0.25$) between the selected breathing conditions. ME and BH led to significantly higher SJmax and SJave compared to NE. No significant differences in results between ME and BH were found (see Table 2).

Table 2 Summary of results

NE	ME	BH	Significant differences
SJmax (cm; $\bar{x} \pm s$)			
35.9 $\pm$ 5.86	36.25 $\pm$ 5.86	36.30 $\pm$ 5.78	NE < BH*; NE < ME*
Wilks' Lambda = 0.88; $F(1,49) = 3.26$; $p = 0.047$; $\eta^2 = 0.12$			
SJave (cm; $\bar{x} \pm s$)			
34.60 $\pm$ 5.82	35.10 $\pm$ 5.78	35.15 $\pm$ 5.88	NE < ME**; NE < BH**
Wilks' Lambda = 0.75; $F(1,49) = 7.91$; $p = 0.001$; $\eta^2 = 0.25$			

In the context of SJmax, both ME and BH resulted in significantly higher results than NE (NE < ME, $p = 0.047$; NE < BH, $p = 0.02$). In both cases, Cohen's d showed only a small effect ($d < 0.5$). No significant differences between ME and BH were recorded (see Figure 1).

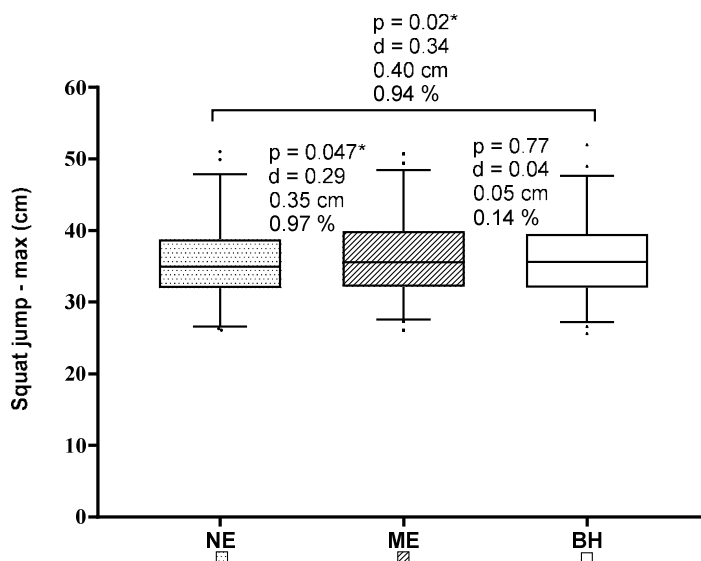


Figure 1 Differences in SJmax reached under selected breathing conditions

Regarding SJave, both ME and BH led to significantly better performance compared to NE (NE < ME, $p = 0.003$; NE < BH, $p < 0.001$). Cohen's d indicated a small effect for NE - ME ($d = 0.45$) and a medium effect for NE - BH ($d = 0.53$). No significant difference was observed between ME and BH (see Figure 2).

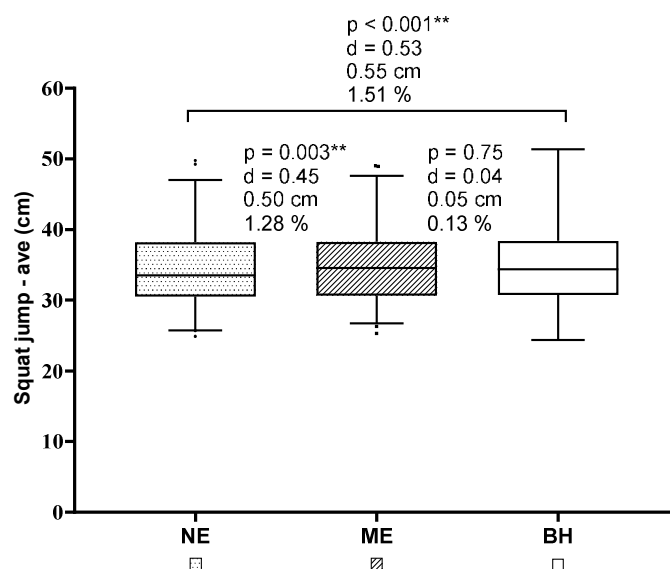


Figure 2 Differences in SJave reached under selected breathing conditions

Chi-squared test analysis revealed a significant relationship between the NBP for squat jumps and the breathing condition that resulted in the best squat jump performance for each individual. A significant relationship was confirmed between NBP and both the best SJmax ($\chi^2 = 6.30$, $p = 0.043$) and best SJave ($\chi^2 = 6.66$, $p = 0.036$). This highlights the fact that participants achieve their best results most often under their natural breathing patterns.

Discussion

Based on measurements and data analysis, it can be stated that in individuals who do not use nasal breathing while exercising (and are therefore potentially not adapted to it), the NE condition may lead to significantly lower squat jump performance compared to ME and BH. This phenomenon was confirmed at the 5% significance level for SJmax and the 1% level for SJave. However, these differences were practically very small (around 1%), and the effect size revealed only a small to medium effect. In practice, this demonstrates only a minor potential effect of breathing conditions on the power output. So even by using NE are individuals able to maintain a sufficient level of performance necessary to predominantly stimulate fast-twitch muscle fibres and the development of explosive power (Cormie et al., 2011a, 2011b). Although, there is potential that NE can negatively affect power output, it is unknown how performance would be affected if individuals were adapted to this breathing pattern.

Although nasal breathing is potentially healthier, especially in the long term (Al-Awadi & Al-Casey, 2013; Allen, 2017; Tralalon & Schaal, 2012), there is no evidence suggesting the idea that using the mouth for exhalation only during the training period can negatively affect health and physiology.

The reason BH and ME led to significantly better performance than NE cannot be clearly justified at present, as this issue is not well-studied. The best SJmax and SJave were most frequently recorded under the BH condition. This indicates that the expiratory phase is not necessary for performance support during the concentric phase of the movement. We hypothesize that by holding the breath after inhalation, individuals are better able to maintain and utilize intra-abdominal tension and core stability, allowing for better energy transfer through the body (Nelson, 2012; Tayashiki et al., 2018). A more stable punctum fixum allows the punctum mobile to work more efficiently. Since not every individual can maintain a stable intra-abdominal pressure during exhalation, it is easier for practitioners to hold their breath. This breathing principle is similar to that used in maximal strength loads—the Valsalva manoeuvre (Hackett & Chow, 2013).

Why ME led to better results compared to NE remains a theoretical question. One of the main reasons could be that none of the participants use NE as a natural breathing pattern, and a significant relationship between NBP and the best results was confirmed. Nevertheless, in some individuals, we observed the best SJmax and SJave under the NE condition. Another potential explanation may be the hypothesis that during the more pronounced exhalation facilitated by the mouth, there is a more pronounced activation of muscle fibres that are involved not only in the breathing process but also in the movement process.

Limitations of the study include a sample consisting only of men who are not accustomed to nasal breathing during explosive movements. For future studies, it would be advisable to include females and individuals who use NE as their NBP. More research is necessary to confirm or refute our findings and claims.

This study is highly original and addresses a previously unexplored issue. Its beauty lies in its simplicity, as athletes deserve to understand not only how much to exercise, eat, drink, and sleep, but also how to breathe and how the breathing process affects their athletic performance. It has been shown that breathing is an important aspect that should be considered by athletes and coaches, even during strength performance. If we understand how breathing relates to muscular work, we can assist athletes in achieving better sports performance.

Conclusion

Various breathing conditions have the potential to affect power output, but the practical effect seem to be only minor. NE can significantly lower squat jump performance in individuals who do not prefer it as their NBP. Both ME and BH lead to significantly better SJmax and SJave compared to NE. No significant differences between ME and BH were observed. Participants most frequently achieve their best results under their natural breathing patterns. Due to the lack of scientific evidence, the explanations are only theoretical. Further studies are necessary to confirm or refute these findings.

Abbreviations

NE: (nose exhale) breathing condition – exhale through the nose

ME: (mouth exhale) breathing condition – exhale through the mouth

BH: (breath hold) breathing condition – breath hold after inhale

SJ: squat jump test (vertical jump from isometric squat position, without counter-movement, without arm-swing)

SJmax: best SJ result for certain breathing condition

SJave: average SJ result for certain breathing condition (average out of 3 best attempts)

NBP: natural breathing pattern – subjectively preferred way of breathing during concentric phase of explosive movement

Conflict of interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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