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Growing a Better Airway: Rapid Maxillary Expansion, Nasal Breathing, and the Open Question of Aerobic Development in the Child and Adolescent Athlete

Karolina Kot-Ceglarek
ORCID https://orcid.org/0009-0000-3891-3559
E-mail: kot.karolina5a@gmail.com
Centrum Stomatologiczne DEMED, Wołomin, Poland

Izabela Truchel
ORCID https://orcid.org/0009-0001-6485-2435
E-mail: truchel.iza@gmail.com
Corten Dental, Warsaw, Poland

Julia Szymańska
ORCID https://orcid.org/0009-0005-2847-0105
E-mail: julia_szymanska00@interia.pl
Medical Center of The Medical University of Warsaw, Warsaw, Poland

Natalia Smyczyńska
ORCID https://orcid.org/0009-0008-8213-3531
E-mail: smyczynskanatalia@gmail.com
SZPZLO Warszawa Praga-Północ, Warsaw, Poland

Mikołaj Kubik
ORCID https://orcid.org/0009-0002-5875-4713
E-mail: mikolaj.kubik24@gmail.com
SZPZLO Warszawa Praga-Północ, Warsaw, Poland

Marta Krzyżanowska
ORCID https://orcid.org/0009-0001-2932-0337
E-mail: krzyzanowska6@gmail.com
Non-Public Healthcare Facility Mix-Med Arima, Radom, Poland

Julia Kamut
ORCID https://orcid.org/0009-0005-8630-1035
E-mail: juliakamut@gmail.com
Medical Center of The Medical University of Warsaw, Warsaw, Poland

Abstract

Background. Rapid maxillary expansion (RME) involves the widening of the maxilla and midpalatal suture. Transverse maxillary deficiency has been identified as a factor that can increase nasal airway resistance and contribute to sleep-disordered breathing (SDB) in children. However, there has been no investigation into whether fixing this issue can enhance aerobic development in young athletes.

Objective. This study aims to combine the existing research on RME and airway issues with pediatric exercise physiology to create testable hypotheses regarding nasal breathing efficiency, recovery and aerobic training capacity in young athletes.

Methods. A thorough structured narrative review was conducted, utilizing a systematic approach to evaluate literature from PubMed, Scopus, Web of Science, and Embase. The AMSTAR-2 and GRADE frameworks were applied to assess secondary syntheses.

Results. RME consistently decreases nasal airway resistance (with moderate certainty in the short to medium term). The impact on pediatric obstructive sleep apnea (OSA) is towards

improvement but remains of low to moderate significance — RME does not significantly affect the apnoea–hypopnoea index by itself, with enhancements mainly found in oxygenation and in combination treatments. This positions RME as a secondary or adjunct option. Connections to exercise efficiency and performance are weak, indirect, and somewhat null; there are currently no trials linking RME to aerobic outcomes in athletes.
Conclusion. While RME could facilitate nasal breathing and support better recovery through improved sleep, there is no substantiated evidence indicating a direct improvement in athletic performance; this highlights the need for further research within pediatric exercise physiology.
Keywords: Rapid maxillary expansion, nasal airway resistance, nasal breathing, paediatric obstructive sleep apnoea, aerobic fitness and trainability, youth athlete, exercise economy

1. Introduction

The period of childhood and adolescence represents a crucial time for developing aerobic fitness. During these years, as young people grow and mature, their capacity for oxygen uptake significantly increases. Importantly, the way they gain fitness differs in quality from adult experiences; youth aerobic fitness stands alone as a developmental concept rather than merely a smaller version of adult fitness [1,2]. For those involved in youth sports, this implies that the maturation stages where aerobic potential can be most influenced are also when various developmental factors are easiest to change [3]. Key among these factors are sleep and recovery: sufficient sleep and its consistency are vital for readiness to train, adapting to training, and performance in subsequent days, while disrupted sleep negatively impacts these areas [4]. These factors are exactly what those interested in physical culture focus on — trainability, efficiency in exercise, and recovery linked to sleep. Rather than relying on any single clinical measure, these aspects serve as the criteria for evaluating the intervention discussed in this review. Therefore, a comprehensive review of youth sports that prioritizes aerobic development must consider not only the training input but also the physiological conditions — both respiratory and restorative — that influence how the developing athlete adjusts.

One significant aspect to consider is how breathing is influenced by the chosen pathway and its associated costs. As a person exercises more intensely, their minute ventilation increases, requiring the airway to provide higher airflow with manageable effort. Although the nasal passage effectively conditions and filters incoming air, it creates most of the resistance in the upper airway. There is a well-defined oronasal switch-point, which is the threshold where a person begins to breathe through their mouth during exercise [5,6]. The location of this switch-point and how much additional airflow the nasal route can manage before reaching it are affected, in part, by the individual's fixed upper-airway structure. Children with narrow, high-arched palates often show increased nasal resistance, leading them to habitually breathe through their mouths, which is linked to a recognizable pattern of craniofacial growth [7]. For young athletes, maintaining clear nasal passages is not just a matter of comfort, but it also represents a crucial factor in achieving effective ventilation — and importantly, it is an issue that can be corrected through anatomical adjustments. This correctability makes the airway a valuable area of focus for youth-sport research instead of viewing it merely as an obstacle that must be worked around.

The correctable issue here is transverse maxillary deficiency, and the specific solution is rapid maxillary expansion (RME), which is an orthodontic technique designed to open the midpalatal suture and broaden the nasal floor and sidewalls, thus increasing the size of the nasal airway [8]. Clinically, RME is used to treat pediatric obstructive sleep apnea and sleep-disordered breathing (SDB). Current recommendations suggest it should complement the primary treatment of adenotonsillectomy rather than serve as a standalone solution [9,10].

We emphasize this intervention only after thoroughly understanding the athlete and their physiology because the orthodontist or dentist is an essential member of a youth-athlete development team, contributing alongside other specialists: the focus remains on the airway extending outward to the maxilla, never the other way around. Evidence from orthodontics regarding rapid maxillary expansion (RME) and its effect on the airway, along with findings from pediatric exercise physiology related to aerobic development, trainability, and sleep, have developed separately and without integration. There has been no inquiry into whether addressing a transverse maxillary deficiency can alleviate a mechanical barrier to nasal breathing during the critical phase when aerobic fitness is highly trainable. We refer to this combined approach as developmental-window airway orthodontics for young athletes: timing interventions on the transverse airway to coincide with both the maxillary sutural expansion phase and the aerobic trainability phase, while assessing outcomes based on youth sports performance—such as exercise efficiency, sleep-based recovery, and trainability—instead of relying solely on the apnoea–hypopnoea index (AHI) as a clinical measure.

The connection between rapid maxillary expansion (RME) and lower nasal airway resistance, along with broader nasal structures, is well established, though it is limited to a short- to medium-term period. There is moderate evidence indicating that RME enhances nasal breathing, with this improvement persisting for at least approximately 11 months; however, the long-term effects (over several years) are still unclear [11]. The link between RME and the severity of sleep-disordered breathing (SDB) in children is inconsistent and only moderately certain. The subsequent connection—from breathing pathways to exercise efficiency to athletic performance—remains weak, indirect, and somewhat negligible: controlled experiments have shown no significant improvement in efficiency or VO_2max when comparing nasal to oral breathing [12,13], and nasal dilation does not enhance performance in cycling time trials [14]. Additionally, no studies have established a connection between RME and any performance or aerobic development outcomes. It is crucial to differentiate the craniofacial-mechanical evidence from broader wellness claims; this distinction is treated as essential, not merely a side note.

To facilitate this mapping, we present three research questions:

RQ1. Does RME consistently lower nasal airway resistance and decrease the severity of pediatric SDB, and how strong and direct is the evidence supporting these claims?

RQ2. What mechanisms might explain how reduced nasal resistance and better sleep could affect aerobic development, exercise efficiency, and training adaptations in young athletes?

RQ3. What is the true level of evidence linking RME to athletic performance, and what types of pediatric exercise physiology study designs are required to investigate this?

2. Methodology

2.1 Design and rationale

This work is offered as a structured narrative review featuring critical analysis, intentionally refraining from being classified as a PRISMA-registered systematic review or a new meta-analysis. The approach stems from the aim of integrating two well-established yet previously disconnected areas of research — the orthodontic studies on rapid maxillary expansion (RME) and upper-airway biology, alongside the pediatric and adolescent exercise-physiology literature focusing on aerobic development, respiratory function during exercise, and recovery during sleep — rather than reassessing either field. The solid evidence linking RME to airway effects is extensively compiled in existing systematic reviews, meta-analyses, network meta-analyses, umbrella reviews, and overviews of reviews [8,9,11,15,16,17], while the area of youth physiology is grounded in respected narrative and consensus reviews [1,2,3,4]. Employing a new screening process on this varied and two-domain body of work — and detailing identification, screening, and inclusion counts from a search that was not conducted as a single reproducible protocol — would misrepresent the essence of the work. Transparency is achieved by outlining the information sources and eligibility criteria in this section, and where applicable in the Results, by revisiting the counts and effect estimates provided by the secondary studies included in this review.

2.2 Information sources

Four databases were consulted through a narrative approach: PubMed/MEDLINE, Scopus, Web of Science, and Embase.

2.3 Synthesis approach

The synthesis process followed a sequence — starting from mechanism to clinical, then psychosocial, and finally economic aspects. It merged narrative interpretation with a structured table format. Estimates of effect from earlier reviews are presented again along with their confidence intervals and evaluations, without combining them into a new figure. Importantly, the two robust areas of study (RME → nasal airway resistance and anatomy; RME → pediatricSDB severity) are kept distinct from the weaker or absent area (breathing route → exercise economy → athletic performance), ensuring the clear strength gradient — whether strong, indirect, weak, null, or absent — is maintained rather than obscured. Additionally, the total lack of any trial connecting RME to any athletic or aerobic development outcome is recognized as a significant finding in itself.

2.4 AI

AI was utilized for two specific purposes in this research. Text analysis of clinical reasoning narratives to identify linguistic patterns associated with specific logical fallacies. Assistance in refining the academic English language of the manuscript, ensuring clarity, consistency, and adherence to scientific writing standards. AI tools were used for additional linguistic refinement of the research manuscript, ensuring proper English grammar, style, and clarity in the presentation of results. It is important to emphasize that all AI tools were used strictly as assistive instruments under human supervision. The final interpretation of results, classification of errors, and conclusions were determined by human experts in clinical medicine and formal logic. The AI tools served primarily to enhance efficiency in data processing, pattern recognition, and linguistic refinement, rather than replacing human judgment in the analytical process.

3. Results

The results are organized in a gradient, covering various aspects such as the youth aerobic-development window (§3.1), the robust mechanistic aspect of RME and nasal airway resistance (§3.2), the significant clinical aspect of RME and pediatric SDB (§3.3), along with the weak or missing link between breathing pathways and exercise efficiency and performance (§3.4), and the subsequent psychosocial and economic factors (§3.5). This way, the authentic strength gradient ranging is consistently maintained at each level. Figure 1 provides a summary of the entire causal sequence, categorized by evidence status.

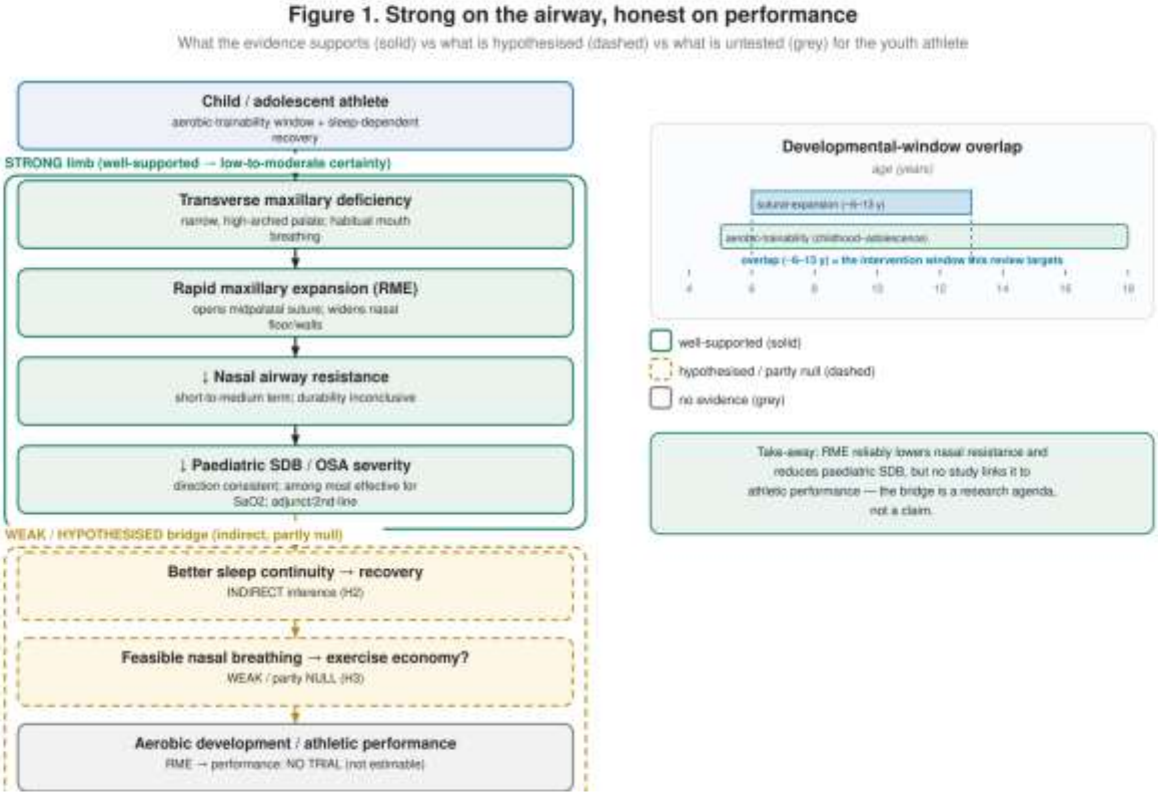

Figure 1. The review highlights a causal link, classified according to the reliability of evidence. A robust airway connection (transverse maxillary deficiency → RME → lower nasal airway resistance; moderate certainty) leads to a less certain and only directional decrease in pediatric sleep-related breathing issues — the controlled AHI for RME alone shows no change, with

improvements primarily seen in oxygenation and combination treatments — thus, the solid green frame indicates a range from well-supported to low-to-moderate certainty instead of suggesting a consistent strength. A proposed/partly-null connection (improved sleep and recovery → possible nasal breathing → efficiency in exercise; dashed amber) points to an unverified outcome (RME → athletic performance; grey — no existing trial). The maxillary sutural-expansion phase of childhood (illustrative, ~6–13 y) coincides with the developmental window for aerobic training — the period this review focuses on. This is a conceptual diagram; the degree of certainty is outlined in Figure 3 and Table 3.

3.1 The youth aerobic-development window

During childhood and adolescence, there is a significant period of growth where aerobic fitness develops quickly, and young athletes learn how to adapt their aerobic capabilities. Peak oxygen uptake serves as the key indicator of youth aerobic fitness. In children, this preferred physiological term replaces the adult term "VO_2max," as reaching a maximum effort plateau is often not achievable. Throughout growth, peak oxygen uptake enhances steadily due to increases in body size, heart dimensions, blood volume, and oxygen transport capacity, as well as the development of systems involved in oxygen movement and usage. It is essential to recognize that youth aerobic fitness represents its unique developmental phase rather than being simply a lesser form of adult fitness. The method of expressing peak oxygen uptake is important; dividing it by body mass can lead to misleading comparisons between individuals and along developmental lines, perpetuating lasting misconceptions about how children's cardiorespiratory fitness evolves.Therefore, any approach aimed at incorporating airway interventions in youth sports should start with an accurate understanding of the developmental biology linked to aerobic function instead of using adult references.

The development of aerobic fitness is accompanied by the more debated issue of how trainable aerobic capacity is — specifically, how much and during which developmental stages structured training can boost peak oxygen uptake beyond just natural growth and maturation. The idea of a "window" during maturation where training has a greater impact on aerobic improvements is widespread but lacks solid empirical backing: there is ongoing debate in youth exercise physiology about whether younger children truly have a lower trainability than adolescents or adults, and how much the observed maturational effects are influenced by issues related to measurement, scaling, and the design of studies [1]. In fact, the timing, strength, and even the reality of a distinct trainability window are some of the most significant unanswered questions in the field of youth aerobic fitness [3]. This section does not settle this issue; it simply frames the window as the developmental backdrop for assessing a transverse-airway intervention in this review, noting that this same growth phase also introduces considerable spontaneous maturation changes — a point that will be relevant as we make before-and-after comparisons.

Sleep and recovery play crucial roles in how young athletes adapt during this period, and they should be a primary focus in discussions about their development, not an afterthought. Sufficient sleep duration and, very importantly, uninterrupted sleep are key factors in ensuring recovery, readiness for training, and the effective consolidation of training gains. In contrast, limited or broken sleep hinders these processes and negatively impacts the daytime functioning essential for high-quality training [4]. For young athletes, this is particularly significant: the same developmental years that support aerobic growth also come with increased sleep needs, so any disruption in sleep continuity poses a risk to the physiological pathway through which training translates into adaptations. Recognizing sleep as a critical outcome — rather than just a lifestyle factor — is vital, as it is the means through which any sleep-related breathing issues could potentially influence aerobic development.

So, why should a respiratory or airway issue be significant for young athletes during this crucial time? Exercise significantly increases the demand for ventilation: as the intensity of work rises, minute ventilation must also increase to support gas exchange, with the airway needing to provide that airflow with a manageable amount of breathing effort. Children actually ventilate more than adults at equivalent metabolic levels, evident from their higher ventilatory equivalents, while their respiratory systems are still growing in size and efficiency. In this developing system, resistance in the upper airway and the method of airflow contribute to the overall work needed for breathing as ventilation increases. It is based on these physiological considerations, and solely them at this point, that nasal patency and airway structure become relevant topics in the physiology of exercise for youth.

A key characteristic of how we breathe during exercise makes it possible to view breathing as a physiological factor: the switch from nasal to oronasal breathing. While at rest or during light activity, breathing mainly happens through the nose. However, as the demand for ventilation increases, there comes a consistent point where people start to use their mouths, transitioning to oronasal breathing. This change helps reduce the effort needed to move air through the nose.During physical activity, the way ventilation is split between nasal and oral pathways changes with the intensity of exercise. As the requirement grows, the contribution from the mouth increases, while the share from the nose decreases.This discussion of the switch-point and oronasal partitioning serves just as background information: it highlights the specific moment when nasal breathing shifts, laying the groundwork for how future discussions regarding nasal airway resistance in young athletes should be framed and evaluated.

Collectively, these threads outline the real concerns of this review — enhancements in aerobic fitness and its potential for improvement, recovery during sleep, and the breathing physiology of active children.

3.2 The strong limb — RME, nasal airway resistance and anatomy

Among all the connections that exist between the maxilla and the development of youth aerobic capacity, the one being discussed here is both the most powerful and straightforward: rapid maxillary expansion (RME) effectively enlarges the nasal structure and decreases resistance in the nasal airway. For young athletes, where the nasal pathway significantly influences the overall effort required for breathing, this provides the essential mechanical basis for subsequent factors like sleep, recovery, and efficiency. Thus, it's crucial to clearly identify what this aspect supports and what its documented boundaries are.

The correctable cause

A transverse maxillary deficiency, characterized by a narrow and high-arched palate, limits the cross-sectional area of the nasal cavity just above it. This narrower pathway leads to increased nasal airway resistance for any given airflow. Children who display this anatomical feature often resort to mouth breathing as a habit, and this relationship has a clinically recognizable pattern: the systematic review and meta-analysis of [7] shows that children who habitually breathe through their mouths exhibit a noticeable pattern of altered facial bone development. This aligns with the long-standing observation that the way we breathe and the growth of the craniofacial structure are closely linked. What the findings demonstrate is a clear, mechanically logical focus: a bony constriction that, notably, can be corrected while still growing. This is the anatomical issue that RME aims to fix.

The intervention effect

RME utilizes a sideways orthopedic force that pulls apart the two maxillary sections at the midpalatal suture. Since the lateral nasal walls are part of the maxillary structure, opening this suture causes the nasal floor to expand and the lateral walls to move outward, thereby increasing the size of the front part of the nasal cavity. The combined evidence showing a significant functional change in this context is unusually substantial for a question in orthodontics. The umbrella review of [8], which examines systematic reviews about RME and the nasal and oropharyngeal structures and breathing functions in children and adolescents, along with the overview by [17] that looks at orthopedic treatments and upper airway enlargement, leads to a consistent conclusion: RME enhances the width and openness of the nasal cavity while lowering nasal airway resistance in the short to medium term. For the anatomical effects and short to medium-term functional results, the evidence is rated as moderate in reliability.

The application of this method is limited by the biology of the suture. In older adolescents whose midpalatal suture is starting to fuse, traditional tooth-borne expansion is not as effective. According to the systematic review by [26], miniscrew-assisted rapid palatal expansion (MARPE) can offer similar benefits for the upper airway in these developing patients. This is noted as a limited device variant of the same method rather than a separate assertion.

A caution for interpretation: variability in measurement.

Any combined statement regarding "decreased nasal resistance" should be considered with the methods used to measure it, as the existing techniques do not easily translate into each other. Rhinomanometry provides a functional resistance by measuring the relationship between pressure and flow, while acoustic rhinometry estimates cross-sectional areas and volumes based on reflected sound, offering a geometric perspective. Imaging-derived cross-sections reflect static structures. The consensus report of [25] on standardizing acoustic rhinometry and rhinomanometry highlights that these methods address related, yet different questions and necessitate careful, consistent data collection for valid comparisons. Therefore, reviews that mix results from both methods end up merging functional and geometric metrics, which increases apparent variability and reduces the accuracy — although not the overall trend — of the combined findings. This variability is noted as a formal limitation in §5.

In a thorough long-term systematic review by [11], which focused on whether RME has enduring effects on airway size and breathing, a cautious conclusion was reached: there is moderate support indicating that RME enhances the conditions for nasal breathing, and this improvement can be expected to last for at least about 11 months after treatment. In contrast, the evidence regarding nasal-cavity volume is inconsistent and varies with the methods used — while cone-beam computed tomography (CBCT) often shows no significant increase in nasal cavity size, other imaging techniques, like radiographic width and acoustic rhinometry, indicate positive results. (The term "low methodological quality" in that review refers to four studies that were excluded, not to its conclusion about breathing.) This distinction is crucial for the entire review. It allows for a statement regarding breathing that is moderately certain but time-limited — RME enhances the conditions for nasal breathing and reduces measured resistance reliably during the first year after expansion — while it refrains from claiming a guaranteed, lifelong benefit because the effectiveness beyond that medium-term period wasn't proven. As a result, the confidence in a long-term (multi-year) breathing benefit is less than the moderate confidence associated with the medium-term outcomes.

Delimiting the claim

Two key boundaries ensure the integrity of this limb. Firstly, the evidence presented focuses on changes in the anatomy and function of the airway rather than on athletic performance; the subsequent aspects related to exercise efficiency and performance are discussed separately (§3.4) and are considerably less robust. Secondly, it is crucial to clearly differentiate this craniofacial-mechanical research from the trending wellness practices surrounding "nasal-breathing" and "mouth-taping," which promote advantages while disregarding the anatomical mechanisms manipulated by RME. The two concepts are distinct, and the strength of the current argument relies on this distinction.

To sum up, this limb is the most well-supported in the overall argument. Transverse maxillary deficiency likely increases nasal resistance and is linked to a mouth-breathing dentofacial pattern [7]. RME facilitates the opening of the midpalatal suture and expands the nasal floor and lateral walls, providing converging evidence with moderate certainty that nasal airway resistance decreases and nasal airflow improves in the short to medium term [8,17]. This also applies to cases involving sutural fusion through MARPE [26]. However, this finding should be viewed with caution due to measurement variability [25]. The enhancements in nasal breathing are moderately certain and appear to be stable for around 11 months, yet their long-term durability (over multiple years) is still uncertain and does not establish RME as a lifelong remedy for breathing issues [11].

3.3 The strong-direction limb — RME and paediatric obstructive sleep apnoea / sleep-disordered breathing

After confirming that rapid maxillary expansion (RME) effectively increases the width of the nasal airway and reduces resistance in that airway over a short to medium term, the next question for growing athletes is whether this anatomical change leads to a noticeable drop in paediatric sleep-disordered breathing (SDB), which disrupts sleep and hampers nighttime recovery. The evidence on this matter supports a consistent direction, yet it requires careful interpretation since the most commonly referenced effect sizes come from uncontrolled studies.

In contrast, comparisons that account for natural variations tell a more nuanced story. Highlighting this difference is the main focus of this subsection.

The uncontrolled pre/post signal

A thorough meta-analysis carried out by Camacho and colleagues [9] indicates significant improvement within a group of children with transverse maxillary deficiency and obstructive sleep apnoea (OSA) who underwent RME. In the subgroup with shorter follow-up, the apnoea–hypopnoea index (AHI) dropped from 8.9 to 2.7 events per hour, a reduction of around 70%. In a different subgroup with longer follow-up (more than three years and starting from a different baseline), the AHI decreased from 7.1 to 1.5 events per hour, which is roughly 79%. When expressed as standardized effects, the combined AHI standardized mean difference was −1.54 — indicating a substantial effect — and the enhancement in the lowest recorded oxygen saturation (LSAT) reflected a standardized mean difference of +1.74. At first glance, these statistics are impressive and position RME as an effective treatment.

Two important qualifications should be noted. First, a complete cure—defined as an AHI below one event per hour—occurred in only around 25.6% of children with available data. This means that while many children showed improvement, they were not fully cured; RME helped reduce the severity levels but did not normalize the condition for most. Secondly, and more crucially, these figures are primarily uncontrolled pre/post estimates: each child was assessed against their own baseline rather than being compared to an untreated group. Because the treatment period coincides with a time of significant craniofacial growth and the well-documented tendency for pediatric SDB to improve on its own, a pre/post analysis cannot distinguish the effects of the appliance from simply aging. Therefore, the extent of the uncontrolled reduction should be seen as a maximum estimate of the actual effect, rather than an accurate measure of what RME adds on top of natural progression—a limitation that the meta-analysis itself recognizes.

The controlled correction

This is where the network meta-analytic evidence serves as a crucial, stabilizing finding and deserves to be highlighted instead of being overshadowed by the initial pre/post data. In their synthesis of controlled comparisons across orthodontic appliances for pediatric OSA, Yu and colleagues found that RME alone did not lead to a statistically meaningful reduction in AHI compared to control: the average change was +0.02 events per hour (95% confidence interval −1.72 to 1.75), indicating no significant effect. Therefore, the substantial uncontrolled reduction noted by Camacho and colleagues is not supported for RME alone once spontaneous growth and resolution are taken into account—this is the very confounding variable that the pre/post design fails to address. The honest conclusion is that natural craniofacial development and spontaneous resolution of SDB likely exaggerate the uncontrolled estimates (Figure 2).

Importantly, the same analysis reveals that effective combinations were identified. When RME was used with adenotonsillectomy, there was a mean AHI reduction of −5.13 events per hour (95% CI −7.50 to −2.76), while combining RME with a mandibular advancement appliance resulted in an AHI reduction of −3.79 (95% CI −5.21 to −2.37). Non-expansion methods also showed potential—mandibular advancement resulted in −2.18 (95% CI −3.48 to −0.89) and myofunctional therapy yielded −2.45 (95% CI −4.76 to −0.14)—with modest between-study variation ($I^2 \approx 32.6\%$). This pattern makes sense internally: the greatest benefits occur when RME is used alongside a procedure that targets the main obstructive factor (most often adenotonsillar hypertrophy), as opposed to using expansion alone.

The second network meta-analysis conducted by Lin and colleagues [16] supports and clarifies these findings across 14 studies involving 1,064 participants. Adenotonsillectomy was found to be the most effective method for lowering AHI, while RME was recognized as one of the best approaches for enhancing oxygen saturation (SaO_2). Differences in the oxygen desaturation index (ODI) were often not significant, and complete resolution of OSA was achieved infrequently with any single treatment. Together, both network meta-analyses agree on a detailed hierarchy: adenotonsillectomy is the most effective intervention on AHI, RME is highly effective for oxygenation and serves as a part of combination therapy, and normalization is rare regardless of the method used. The finding related to oxygenation is particularly important in the context of youth athletes discussed in this review, as it is the nighttime desaturation and associated arousals — instead of the AHI alone — that are most likely to disrupt sleep continuity and the overnight recovery necessary for aerobic adaptation.

Longitudinal support and clinical context.

The pooled syntheses are reflected in the primary longitudinal studies. An early significant demonstration by Cistulli and his team [21] showed that RME could be effective for treating OSA in carefully chosen adult patients.Additionally, the prospective pediatric studies by Villa and colleagues at 12 months [19] and 36 months [20] indicated that improvements in SDB were maintained over the medium term. However, it is important to note that these are primarily small, non-randomized series; they suggest a sustained positive trend but do not invalidate the null controlled effect of RME alone on the AHI.

The clinical recommendations align with an additional role for RME. The guideline from the American Academy of Pediatrics [10] identifies adenotonsillectomy as the primary treatment for childhood OSA. The Childhood Adenotonsillectomy Trial [22], the key randomized study, demonstrated that adenotonsillectomy was more effective in alleviating symptoms and improving behavior compared to a watchful waiting approach. In relation to this standard, RME should not be seen as the main solution but rather as a supplementary or secondary option — particularly valid when transverse maxillary deficiency is the major phenotype or when used in combination with adenotonsillectomy [27]. This perspective aligns with what the controlled network meta-analysis results would suggest and helps to prevent overstating the findings that uncontrolled data might imply.

Synthesis verdict

The findings across a meta-analysis and two network meta-analyses consistently show that RME has a positive effect on pediatric SDB. This effect is most evident in improving oxygen levels (SaO_2), especially when paired with a procedure that addresses the main blockage. However, the reliability of this evidence ranges from low to moderate. It mainly stems from small, often non-randomized groups that use varied definitions of SDB and lack sufficient controlled studies. Additionally, the reported decrease in AHI without control may be exaggerated due to natural craniofacial growth and the spontaneous resolution of SDB; when RME is assessed alone, its effect on AHI does not show significance. For young athletes, this means that RME could help decrease the severity of SDB and support oxygenation during sleep recovery, but it should be seen as a supplementary approach rather than a standalone solution. The strength of the evidence is more about consistent outcomes than exactness or reliable internal comparisons of individual results. This nuanced conclusion—pointing to a consistent trend alongside genuine uncertainty regarding its impact—serves as a solid base for the following discussion on recovery-oriented theories and is intentionally more cautious than simply looking at the headline pre/post reduction figures would suggest. Table 1 provides a direct comparison of uncontrolled and controlled estimates.

Table 1. RME and paediatric OSA/SDB: controlled vs uncontrolled effect estimates.

Source	Design	Comparison	Effect (95% CI)	Note (uncontrolled vs controlled)
[9]	SR/MA (17 studies, 314 children)	Within-arm pre/post (RME)	AHI 8.9→2.7/hr (≈70%, ≤3 y); 7.1→1.5/hr (≈79%, >3 y); AHI SMD −1.54; LSAT SMD +1.74; cure (AHI <1/hr) 25.6% (of those with calculable data)	**Uncontrolled** pre/post, no comparator; magnitude an upper bound, likely inflated by spontaneous growth/resolution
[15]	SR + network MA (11 studies, 595 patients; I^2 ≈ 32.6%)	Controlled, mean AHI difference vs control	RME alone +0.02 (−1.72 to 1.75), NS; RME+adenotonsillectomy −5.13 (−7.50 to −2.76); RME+MAA −3.79 (−5.21 to −2.37); MAA −2.18 (−3.48 to −0.89); MFT −2.45 (−4.76 to −0.14)	**Controlled** — RME *alone* null; benefit concentrated in combinations
[16]	SR + network MA (14 trials, 1,064 participants)	Controlled, ranking of interventions	Surgery (adenotonsillectomy) best for AHI; RME	**Controlled** — adjunct role; normalisation uncommon

			among the most effective for lowest SaO_2; ODI comparisons often NS; complete resolution rare	whatever the modality
[19] / [20]	Prospective cohorts (12- and 36-month follow-up)	Longitudinal pre/post (RME)	SDB improvement maintained over the medium term	**Uncontrolled, small, non-randomised** — direction-supporting persistence, no comparator

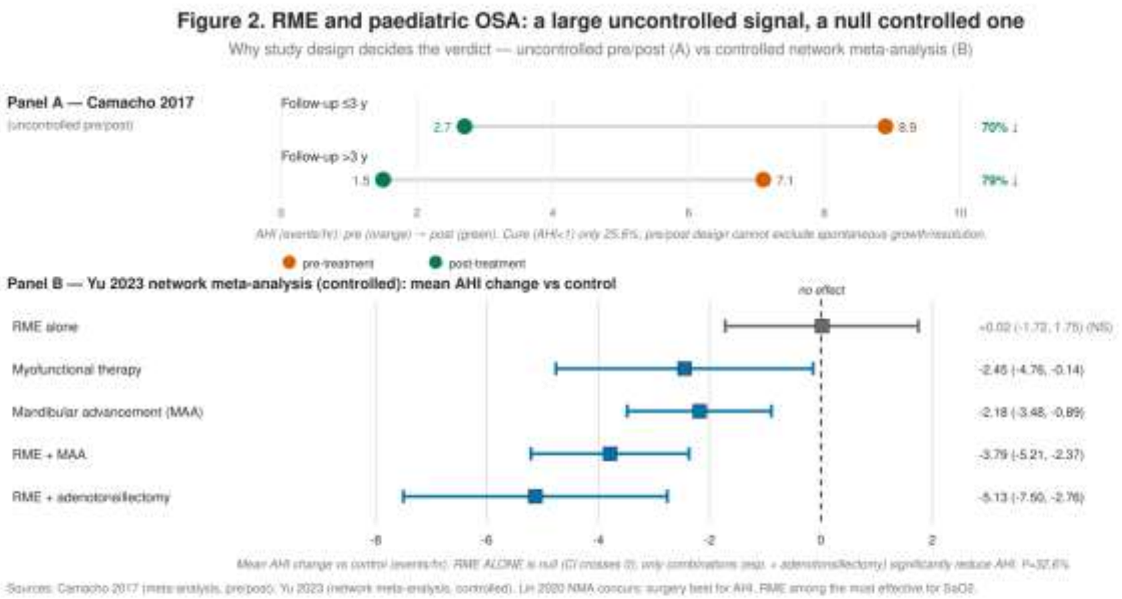

Figure 2. RME and pediatric OSA: a significant uncontrolled indicator, a controlled one that shows no effect. Panel A: uncontrolled pre/post apnoea–hypopnoea index (AHI) from [9] (8.9→2.7/hr, ~70%, ≤3 y follow-up; 7.1→1.5/hr, ~79%, >3 y; only 25.6% of those with calculable data experienced complete recovery) — this design does not rule out spontaneous improvement or resolution. Panel B: controlled network meta-analysis [15], average change in

AHI compared to control — RME alone shows no effect (+0.02, 95% CI −1.72 to 1.75; the interval crosses 0), while combinations (notably RME + adenotonsillectomy, −5.13 [−7.50, −2.76]) prove effective. [16] agrees: surgery is most beneficial for AHI, and RME is one of the top methods for SaO_2. Values are as reported; they have not been re-pooled.

3.4 The weak link — breathing route, exercise economy, and performance

The idea that the route of breathing — whether nasal or oral — noticeably enhances exercise efficiency or athletic performance is supported by shaky, inconsistent evidence, and in its best cases, it's essentially null. Even more critically, the key question this review seeks to explore — if rapid maxillary expansion (RME) positively affects athletic or aerobic development outcomes — hasn't been directly evidenced at all.

The intermediate evidence: breathing route and economy

First, let's tackle the intermediate question, which is easier to examine than the RME question, yet still lacks strong evidence: does regular or required nasal breathing provide an advantage in efficiency or capacity? [12] studied recreational runners after they underwent a lengthy period of intentional nasal-restricted training, comparing nasal and oral breathing. This research recorded changes in metabolic and ventilatory responses with nasal breathing — including modified ventilatory equivalents and breathing patterns — but found no significant improvement in maximal oxygen uptake or noticeable performance gains. This finding is revealing: although the body adapts to the breathing route, this adaptation does not lead to a higher aerobic limit. [13] directly investigated the capacity aspect by examining maximal oxygen consumption for both oral and nasal breathing. The results showed no meaningful differences in VO_2max between the two methods. Together, these studies arrive at the same conclusion — the breathing method changes how ventilation occurs but does not impact aerobic capacity.

If improvements in the breathing route could be achieved simply by increasing nasal airflow, one would expect a performance boost. [14] specifically looked into this and discovered that neither internal nor external nasal widening made any difference in cycling performance during a 20-km time trial. In essence, expanding the nasal passage did not lead to quicker times — a finding that challenges the notion that nasal breathing limits performance during intense exercise. Collectively, studies [12], [13], and [14] represent a small but consistent body of evidence that suggests breathing routes do not enhance performance. Additionally, these studies focused on adults or recreational athletes rather than young athletes, further limiting the applicability of the findings to youth (a limitation discussed in §5).

The critical gap: an empty cell.

There is no trial that connects RME — or any type of maxillary expansion — to outcomes related to athletic performance or aerobic development. The evidence is absent. The sequence suggested by the strong limbs — RME → lower nasal resistance → viable nasal breathing → improved economy → safeguarded aerobic development — relies on assumptions at every step. Presenting the anatomical certainties of §3.2 or the directional SDB signal from §3.3 as if they imply a performance outcome would create a conclusion that is not reflected in the data. The claim available is purely conditional: while RME might enable more efficient nasal breathing, this remains a possibility worth exploring — but it is still a hypothesis, not a confirmed result. Table 2 displays the uncertain versus ambiguous intermediate evidence next to that empty cell.

Table 2. Breathing route and exercise economy/performance: the weak/absent limb.

Source	Intervention/contrast	Outcome	Result/direction
[12]	Nasal vs oral breathing after habituated nasally-restricted training (recreational runners)	VO_2max / physiological economy	No meaningful VO_2max or performance benefit; ventilatory adjustments without an aerobic gain (null/equivocal)
[13]	Oral vs nasal breathing	Maximal oxygen consumption (VO_2max)	No significant difference between conditions (null)
[14]	Internal or external nasal dilation vs control	20-km cycling time-trial performance	No improvement in time-trial performance (null)
RME → athletic performance / aerobic development	None tested	Athletic-performance / aerobic-	**NO STUDY — not estimable** (the empty cell)

		development endpoint	

It is quite possible that the effect of a better breathing pathway is truly minimal — insignificant enough not to impact a developing athlete — or that any minor effect is overshadowed by a significant confounding factor present in this group: spontaneous craniofacial growth. During the RME window, children are naturally growing, irrespective of any interventions. The palate, airway, and aerobic capacity all follow their unique developmental paths; thus, distinguishing a slight device effect from this background is something that many uncontrolled pre/post studies in the SDB literature [9] fail to achieve. The accurate interpretation is not "RME likely enhances performance, but the studies just haven't captured that"; rather, it is "the intermediate evidence shows no effect, direct evidence is lacking, and a true-null result remains a genuine possibility. "

The physiological limit: the transition from oral to nasal breathing

A physiological observation connects the null results to the anatomy, clarifying why any advantage from the nasal route is inherently limited. The nasal pathway does not provide ventilation indefinitely. While at rest and during low-intensity activities, people breathe through their noses, a specific oronasal transition occurs when ventilation increases, leading to a gradual reliance on mouth breathing to meet airflow requirements [5]. Research by [6] has measured this balance between nasal and oral breathing during exercise, revealing that as physical exertion rises,mouth breathing becomes a larger part of total ventilation. This has clear implications for our current discussion: even if the airway is optimized through RME, the nasal contribution can only last until the point where mouth breathing starts to dominate, which occurs at levels far below those needed for competitive sports. Thus, any efficiency gain associated with nasal breathing is fundamentally limited—it is greatest at submaximal intensities where nasal breathing prevails, and it fades as the intensity increases and oronasal breathing becomes necessary. This does not dismiss the potential benefits of nasal breathing at lower intensities; instead, it outlines its limits, which is another reason for asserting that the performance argument should remain conditional and speculative rather than definitive.

3.5 Psychosocial and economic dimension

The argument for addressing pediatric SDB does not rely on the performance debate, making it crucial to separate the two discussions: the psychosocial and economic factors are based on the well-established aspects of SDB, rather than the unverified efficiency argument. With this perspective, these factors represent some of the most justifiable reasons for a youth-athlete development team to focus on airway health.

Psychosocial: daytime function beyond SDB

Paediatric SDB leads to issues with attention, mood, behavior, and overall quality of life during the day. Research has shown that addressing this condition can lead to improvements in these areas. In the Childhood Adenotonsillectomy Trial, Marcus and his team [22] found that children with obstructive sleep apnea experienced enhancements in neurobehavioural aspects and quality of life when they underwent early adenotonsillectomy instead of just waiting.While this trial focuses on a primary surgical solution rather than RME, it should not be taken as proof for expansion; its significance is more limited to demonstrating that lessening the burden of SDB can result in observable benefits in daytime functioning and behavior, which any effective airway treatment might also achieve. The guidelines on paediatric-OSA [10] place these outcomes in the context of everyday management, and [27] recognizes that dental and orthodontic options, including RME, can also play supportive roles within this framework. Particularly for young athletes, the advantage of better sleep is not merely an increased VO_2max but rather enhanced daily functioning: improved focus during training, better mood control, and more enjoyment in sports—all essential for commitment and long-term engagement, where sleep significantly influences performance [4]. This argument focuses on sleep and recovery, and it should only be pushed as far as the evidence on SDB allows.

Economic: interceptive timing within the growth window.

The economic aspect is better understood as a matter of timing rather than just a financial estimate, and this review does not provide any cost figures due to the lack of reliable data. The reasoning focuses on the developmental period. RME takes advantage of a specific midpalatal suture, making it a limited-time opportunity; addressing a transverse deficiency within the growth phase is important while correction is still feasible from an orthopedic perspective. This timing also coincides with the crucial childhood period when aerobic development is at its peak. The economic imbalance follows this logic: recognizing the narrow palate/mouth-breathing phenotype during a standard health check is low-cost, while neglecting a transverse deficiency might later require more complex orthodontic, surgical, or orthognathic solutions, and untreated sleep-disordered breathing brings additional challenges. If interceptive expansion during this period even slightly enhances the airway, the opportunity cost may favor early detection. This is a timing argument, suggesting that early intervention for a correctable issue is generally better than dealing with its later effects, presented in a conditional context rather than as a clear demonstration of cost savings.

Honest qualifications

This dimension is limited by two key qualifications. To start, the psychosocial and economic studies referenced here are less robust and indirect compared to the solid anatomical and clinical data available, and many of the related connections are complicated: for instance, nasal obstruction in children often occurs alongside allergic rhinitis and malocclusion in ways that don't clearly imply causation [28]. Therefore, any improvements in quality of life cannot be solely linked to airway width. Additionally, it is crucial to note that none of this translates into performance improvements. Although enhanced daytime function, mood, and enjoyment in sports are real benefits and may help encourage participation in training, they result from reduced sleep-disordered breathing (SDB) and should not suggest an aerobic or competitive advantage, which §3.4 indicates as unverified. The defensible assertion is limited and should be clearly stated: addressing pediatric SDB offers recognized benefits for daytime functioning and quality of life, and because of developmental timing, early intervention is a sensible approach. However, both claims rest solely on the SDB aspect, leaving the performance issue exactly where §3.4 positioned it—unresolved and unexplored. The complete gradient of evidence strength throughout the causal chain is illustrated in Figure 3.

Table 3. Evidence-strength map across the causal chain.

Causal link	**Best evidence**	**Direction/estimate**	**Certainty (GRADE-style)**
Transverse maxillary deficiency → nasal resistance	[7] (SR/MA)	Narrow, high-arched palate and habitual mouth breathing accompany elevated nasal resistance and an altered dentofacial pattern	Low-to-moderate

RME → nasal resistance / anatomy (short-to-medium term)	[8] (umbrella review); [17] (overview of SRs)	↓ nasal airway resistance; ↑ nasal-cavity width and patency	Moderate
RME → durable breathing improvement	[11] (long-term SR)	Moderate evidence that nasal-breathing conditions improve, stable ≥~11 mo; nasal-cavity-*volume* evidence mixed (CBCT null vs positive radiograph/acoustic rhinometry); multi-year durability uncertain	Moderate to ~11 mo; long-term uncertain
RME → paediatric SDB / AHI (direction)	[9] (SR/MA); [15], [16] (network MAs)	↓ SDB severity and ↑ SaO_2 in direction; RME-alone controlled AHI effect null; benefit in combinations	Low-to-moderate
SDB reduction → sleep/recovery → aerobic trainability	[4]; [1] (separate literatures)	Plausible protective pathway via sleep-dependent recovery	Indirect
Breathing route → exercise economy	[12]; [13]; [14]	No meaningful economy, VO_2max or time-trial benefit	Weak-null
RME → athletic performance	No study	Not estimable	Absent / not estimable

Note: certainty labels are GRADE-informed descriptive categories (moderate / low-to-moderate / low / indirect / weak-null / absent), mixing formal GRADE tiers with descriptive terms for links that fall outside the formal GRADE ladder.

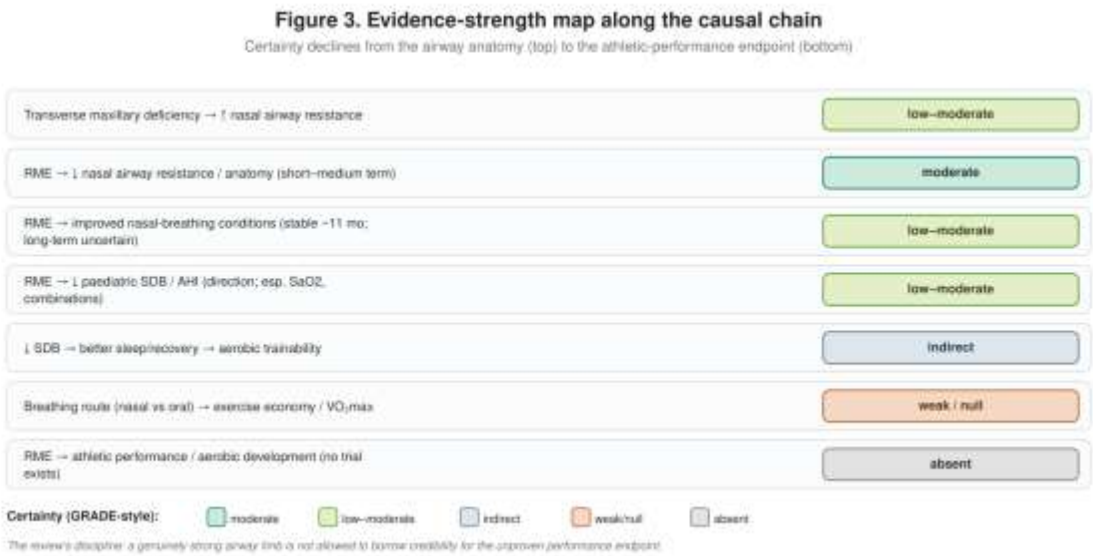

Figure 3. Evidence-strength map along the causal chain. GRADE-style certainty for each link, declining from the airway anatomy (moderate) through the paediatric-SDB direction (low-to-moderate) and the indirect sleep→recovery→trainability inference, to the weak/null breathing-route→economy evidence and the absent, not-estimable RME→performance endpoint. The map enforces the review's discipline: a strong airway limb does not lend credibility to the unproven performance endpoint. Corresponds to Table 3.

4. Discussion

The significance of linking the orthodontic RME–airway research to exercise physiology for children and young people is not found in a new effect assessment, but rather in a testable redefinition: evaluating RME against developmental outcomes in youth—such as the feasibility of nasal breathing, recovery during sleep, and capacity for aerobic training—during the overlap of the maxillary-sutural-expansion and aerobic-trainability periods, instead of relying solely on the clinical apnea-hypopnea index. This new perspective is valuable only if it rigorously acknowledges what the evidence can and cannot support. Three distinct findings should be differentiated throughout this discussion. The connection from RME to nasal airway resistance is well established in the short to medium term.The link from RME to pediatric sleep-disordered breathing shows some agreement in direction but carries low to moderate certainty and is best interpreted as an adjunct or secondary position. Meanwhile, the relationship between breathing route, exercise economy, and performance is weak, indirect, and somewhat insignificant, with no study tyingRME to any athletic or aerobic development outcome. Therefore, the contribution presents a clear differentiation of strong, weak, and absent evidence (Table 3), which translates into three testable hypotheses—one for each limb, reflecting well-supported, indirect, and genuinely weak evidence, articulated with a clear testing design and a possibility for a "no" outcome. These hypotheses align with the review's research questions: H1 looks into whether a mechanical exposure exists and can be corrected (RQ1), H2 examines the potential mechanisms for aerobic development linked to sleep and recovery (RQ2), and H3 investigates the actual strength of direct performance evidence and the designs necessary to validate it (RQ3). This reframing is also notably separate from the "nasal-breathing/mouth-taping" wellness trend: the craniofacial assertion is based on a fixable anatomical issue and on compiled orthodontic data, not on promises of performance, viewing the lack of performance data as a research aim rather than a gap masked by hopeful assumptions.

4.1 H1 — "The nasal-resistance ceiling hypothesis"

Transverse maxillary deficiency creates a mechanical limit on nasal airflow. Rapid maxillary expansion (RME) helps by widening the nasal floor and side walls, which results in reduced nasal airway resistance and increases the nasal-breathing capacity during lower-intensity exercise. This is the most direct and solid link in the relationship. Evidence from systematic reviews supports the cause — a narrow, high-arched palate and the tendency to breathe through the mouth, which is associated with a specific dentofacial structure [7]. Moreover, the intervention effect, where RME opens the midpalatal suture leading to measurable decreases in nasal resistance and greater nasal-cavity width, is consistently observed in an umbrella review [8] and a comprehensive overview of systematic reviews [17]. Two honesty checks clarify this assertion. First, it's not clear how long the breathing benefits last: there is moderate evidence indicating that RME enhances conditions for nasal breathing, and this benefit seems stable for about 11 months.However, findings on nasal-cavity volume are unclear (with CBCT often showing negligible volume changes) and long-term durability remains questionable [11]. Thus, the well-supported claim is practical, focusing on the short to medium term. Second, nasal resistance is assessed through methods that cannot be converted into one another (like rhinomanometry, acoustic rhinometry, and imaging), meaning standardization of measurements is essential for any testing. The physiological implication of this hypothesis is intentionally conservative: it suggests that reducing the fixed nasal component of upper-airway resistance delays the point at which mouth breathing becomes necessary. This delay — rather than any subsequent efficiency or performance enhancement — is what H1 seeks to investigate, explaining why the hypothesis is limited to the measurements of resistance and switch-point.

Test / Falsification: This study, which includes a control group and examines youth with transverse deficiency, evaluates standardized rhinomanometric nasal resistance [25] and the oronasal switch-point — the point at which participants naturally begin to breathe through their mouths during a specific minute ventilation [5,6] — while using a structured incremental submaximal protocol. Our first hypothesis (H1) suggests that RME leads to a reduction in nasal resistance and an increase in the switch-point to a higher minute ventilation. This hypothesis will be disproven if neither of these changes exceeds measurement error.

4.2 H2 — "The developmental-window / SDB-recovery hypothesis"

Addressing maxillary constriction during the critical childhood period for aerobic training may lessen sleep-disordered breathing, a condition that disrupts sleep and hinders overnight recovery and adaptation. This, in turn, helps protect the quality of aerobic development and training. Evidence strongly supports the link between SDB reduction and outcomes: a focused meta-analysis [9] and two network meta-analyses [15,16] indicate that maxillary expansion leads to a decrease in pediatric OSA severity and improved oxygen levels. It is important to note, however, that this correlation does not equate to a robust controlled effect of RME alone. In fact, findings from network meta-analysis show that RME used as the sole treatment hasn't produced a significant reduction in the apnea-hypopnea index(AHI), with improvements mainly observed when it is combined with other methods [15]. Adenotonsillectomy continues to be the primary option, while RME is viewed as a secondary or supportive treatment [10,16].Importantly, the assumption that less SDB helps enhance trainability through improved sleep-dependent recovery is reasonable but indirect; it relies on the fact that sleep and recovery are key factors for adaptation [4] during a developmental phase when aerobic fitness is clearly reliant on maturation [1], and doesn't rest on any recovery results measured post-RME. Consequently, the initial idea (SDB reduction) is more robust than its outcome (protected trainability), and care must be taken to not confuse the two: while there is strong evidence that expansion helps reduce SDB severity, this alone does not prove that a child's overnight recovery or their response to a training period improves as a consequent effect. It is this final assertion that the research design below aims to clarify.

Test / Falsification: This involves a planned controlled trial, which could either be randomized or use a watchful-waiting control to account for natural craniofacial growth and the spontaneous resolution of sleep-disordered breathing (SDB) in young athletes experiencing transverse deficiency and mild SDB. The study will integrate polysomnography and actigraphy along with next-morning recovery indicators (such as sleep efficiency, nighttime heart-rate variability [HRV], resting/submaximal heart rate, and training-readiness/rating of perceived exertion [RPE]), all monitored throughout a specific training period. Hypothesis 2 (H2) anticipates that the RME group will exhibit a decrease in AHI and enhanced sleep continuity/recovery indicators when compared to the control group; this hypothesis will be disproven if improvements in sleep/recovery are not significantly different from the control after accounting for spontaneous resolution.

4.3 H3 — "The hypothesis concerning breathing-route economy (the truly weak link)"

By facilitating consistent nasal breathing, RME has the potential to enhance ventilatory and physiological efficiency during submaximal exercise. This point is acknowledged as the genuine weak link: the available direct evidence is sparse, largely indirect, and somewhat inconclusive, which is why H3 should be viewed as a hypothesis-generating statement rather than a definitive assertion. The underlying assumption — that the breathing method influences efficiency or maximum oxygen uptake — lacks solid support: studies comparing nasal and oral breathing show no significant advantage in VO_2max and provide unclear effects on efficiency [12,13]. Additionally, attempts to boost nasal flow via nasal dilation do not yield benefits in time-trial performance [14]. No research has directly linked RME to any indicators of efficiency or performance, making each inference from anatomy or clinical sleep-disordered breathing to athletic performance an extrapolation. The legitimate counterpoint — that any efficiency effects are minimal or overwhelmed by natural growth and spontaneous resolution of sleep-disordered breathing — deserves proper consideration. This is the reason the design outlined below focuses on equivalence rather than just superiority. Any remaining advantage of habitual nasal breathing likely pertains more to air conditioning and filtration, the effort involved in breathing at submaximal levels, or the sleep and sleep-disordered breathing connections that H2 addresses, rather than a significant improvement in efficiency or maximum oxygen uptake. This is why H3 is considered the weakest hypothesis and is posed as a question instead of an expectation.

Test / Falsification: this involves a within-subject crossover analyzing submaximal efficiency (steady-state VO_2 at fixed workloads plus VO_2max) while enforced nasal breathing is compared to oronasal breathing before and after RME, with a predetermined smallest worthwhile difference and an equivalency framework; the transparently pre-registered expectation is no significant gain in efficiency. Thus, H3 will only be supported if a post-RME improvement in efficiency exceeds the smallest worthwhile difference; otherwise, it will be disproved, reflecting a design meant to assert a negative outcome.

4.4 Touchpoints for Screening

Cautious screening is the careful outcome of disciplined translation, rather than a strict performance requirement. Current health assessments for young athletes already evaluate injury and illness risks, and they could incorporate an affordable craniofacial/airway screening touchpoint. This would involve detecting a narrow, high-arched palate and the tendency to breathe through the mouth [7], followed by referrals for orthodontic, ENT, or sleep evaluations if sleep-disordered breathing features are present [10]. The rationale behind this approach is to safeguard recovery during sleep for developing athletes [4]—a logical practice that aligns with existing hypotheses, placing orthodontists as valuable members of the youth-athlete development team. It should be noted that this is not an evidence-based assertion claiming that expansion enhances performance, as there is no direct data to support this. The purpose of the screening is clear: it recognizes a correctable anatomical issue along with a potential sleep-related impact that merits clinical evaluation, without suggesting an improvement in aerobic capacity. This touchpoint stands apart from the wellness trend of mouth-taping or nasal breathing, which fails to address the anatomical cause and exaggerates the benefits. The touchpoint proposed here serves as a referral suggestion grounded in craniofacial and sleep-related evidence, rather than a performance enhancement strategy.

4.5 Research Agenda in Pediatric Exercise Physiology

The main output required is the agenda that populates the blank space. Focus areas include: controlled RME trials involving young athletes assessed based on youth-development indicators such as the oronasal switch-point, submaximal economy, sleep continuity/recovery, and trainability, instead of only considering the AHI [9,15]; watchful waiting as a counterpoint to accommodate natural craniofacial growth and self-resolving SDB; standardized nasal-resistance measurements to eliminate variations in methods; equivalently framed economy crossovers designed to highlight a pre-determined minimum worthwhile difference; timed windows with designs that analyze suture patency and capitalize on the overlap of two crucial developmental phases [3]; and consistent pre-registration to prevent optimistic reporting, aligning with endpoints related to sleep and recovery in young athletes [4]. These trials should differentiate effects of RME on its own from those of RME used in combination, ensuring that the supportive role is verified rather than presumed. Additionally, they should categorize participants by maturation to allow for direct examination of developmental-window principles instead of deducing them. This agenda serves, not as a performance assertion, but as a valuable contribution: it transforms a genuine lack of evidence into a clear, actionable plan tailored for the pediatric exercise physiology field.

5. Limitations

There are multiple limitations affecting the inferences presented, largely stemming from the separation of strong, weak, and absent limbs. The most significant issue is the extrapolation from anatomy/clinical-SDB to sport performance: existing evidence supports that anatomical (nasal resistance) and clinical (SDB severity) aspects are well-established, but using this information for understanding youth's aerobic development, efficiency, or trainability is merely an inference rather than proven fact. Secondly, the connection between the intermediate breathing route and economy is not strong; comparisons of nasal versus oral breathing reveal no notable benefits to VO_2max or economy [12,13], and nasal dilation does not improve time-trial performance [14] — additionally, no studies have shown a relationship between RME and any endpoint in athletic or aerobic development, indicating that the performance limb is lacking rather than just weak. Thirdly, the potential confounding effects of natural craniofacial growth and the spontaneous resolution of SDB are important: much of the evidence for RME-OSA comes from uncontrolled pre/post data [9], and these confounding factors are highlighted within the RME-OSA meta-analyses — via network meta-analysis, the controlled effect of RME alone on AHI was found to be negligible [15] — thus, while there is a trend, the certainty around it is just low to moderate. Fourth, there is no established long-term durability: moderate evidence suggests that RME enhances conditions favorable to nasal breathing for at least approximately 11 months, yet findings about nasal cavity volume are inconsistent (CBCT often indicates no significant increases), and long-term durability remains uncertain [11], limiting the strong limb to the short to medium term. Fifth, the measurement of nasal resistance varies: rhinomanometry, acoustic rhinometry, and imaging-derived cross-sections don't correlate well [25], which hampers pooled certainty and cross-study comparisons. Sixth, the evidence around SDB is largely derived from small, non-randomized studies with inconsistent definitions of SDB and a scarcity of controlled trials, and much of it fails to separate the effects of RME alone from those of RME in combination [15,16], making it difficult to determine the isolated impact of expansion from the available data. Seventh, some of the breathing-route physiology is based on studies involving adults or recreational exercisers rather than youth athletes, limiting its relevance to the target group, and the unique developmental biology that characterizes youth aerobic fitness cannot just be assumed to align with adult findings. Eighth, the pathway surrounding recovery and trainability in H2 is inferred from disparate literatures

— one discussing SDB reduction and the other focusing on sleep-dependent adaptation — with no studies connecting these aspects in young athletes, thus making the relationship a well-reasoned hypothesis rather than one based on observed results.

6. Conclusion

Rapid maxillary expansion reliably increases the width of the maxilla and decreases nasal airway resistance over the short to medium term [8,17]. It also lowers the severity of pediatric SDB according to a meta-analysis and two network meta-analyses [9,15,16], though ratings of certainty are low to moderate. Therefore, it is best viewed as an adjunct or second-line approach rather than a primary solution [10]. This suggests that RME could potentially aid in developing nasal breathing and improving sleep recovery for growing athletes. However, direct performance benefits remain uncertain: the connection between breathing route and economy is weak and somewhat unproven [12,13,14], and no research has linked RME to improvements in athletic performance or aerobic development. Any existing effects may only be slight and can be indirectly influenced by sleep and recovery [4], or affected by natural craniofacial growth and spontaneous resolutions of SDB [9,15]. This serves as an important reminder and distinguishes this synthesis from the mouth-taping wellness trend. The evidence supporting breathing benefits is moderate and seems to hold steady for about 11 months; however, its long-term effectiveness (over several years) has not yet been demonstrated [11].Thus, the contribution is not a new assertion of effectiveness but a rethinking—focusing on developmental-window orthodontics for airways assessed against youth development milestones, and coordinated with the times when sutural expansion and aerobic training are beneficial. This is paired with three testable hypotheses, careful screening measures, and a research agenda in pediatric exercise physiology aimed at conducting controlled, appropriately timed RME trials focusing on youth development outcomes [1,3]. For those involved in youth sports, the main takeaway is clear: prioritize sleep protection and ensure nasal breathing capabilities in developing athletes, and treat the controlled trial—not the appliance itself—as the most significant deliverable. In summary: robust in terms of airway benefits, candid regarding performance outcomes.

Declarations

Author Contributions

Conceptualization: Karolina Kot-Ceglarek, Julia Szymańska, Julia Kamut

Methodology: Mikołaj Kubik, Karolina Kot-Ceglarek, Marta Krzyżanowska

Software: Julia Szymańska, Julia Kamut, Mikołaj Kubik, Natalia Smyczyńska

Check: Karolina Kot-Ceglarek, Marta Krzyżanowska

Formal analysis: Julia Kamut, Marta Krzyżanowska, Natalia Smyczyńska

Investigation: Julia Szymańska, Karolina Kot-Ceglarek

Resources: Julia Szymańska, Mikołaj Kubik, Marta Krzyżanowska

Data curation: Karolina Kot-Ceglarek, Marta Krzyżanowska, Natalia Smyczyńska

Writing - rough preparation: Mikołaj Kubik, Marta Krzyżanowska, Natalia Smyczyńska

Writing - review and editing: Karolina Kot-Ceglarek, Julia Szymańska

Visualization: Karolina Kot-Ceglarek

Supervision: Julia Kamut, Mikołaj Kubik, Natalia Smyczyńska

Project administration: Mikołaj Kubik, Marta Krzyżanowska, Karolina Kot-Ceglarek

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Conflict of Interest

The authors declare no conflict of interest.

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Declaration of Generative AI Use

Generative AI tools were used to assist with drafting and organization of the manuscript. The authors reviewed and edited all AI-assisted content and take full responsibility for the integrity, accuracy and final content of the work.

References

1. Armstrong N. Pediatric aerobic fitness and trainability. *Pediatr Exerc Sci.* 2017;29(1):8–13. doi:10.1123/pes.2017-0012. PMID: 28271801.
2. Armstrong N, Welsman J. Youth cardiorespiratory fitness: evidence, myths and misconceptions. *Bull World Health Organ.* 2019;97(11):777–782. doi:10.2471/BLT.18.227546. PMID: 31673193.
3. Armstrong N. Top 10 research questions related to youth aerobic fitness. *Res Q Exerc Sport.* 2017;88(2):130–148. doi:10.1080/02701367.2017.1303298. PMID: 28402178.
4. Walsh NP, Halson SL, Sargent C, et al. Sleep and the athlete: narrative review and 2021 expert consensus recommendations. *Br J Sports Med.* 2021;55(7):356–368. doi:10.1136/bjsports-2020-102025. PMID: 33144349.
5. Niinimaa V, Cole P, Mintz S, Shephard RJ. The switching point from nasal to oronasal breathing. *Respir Physiol.* 1980;42(1):61–71. doi:10.1016/0034-5687(80)90104-8. PMID: 7444224.
6. Wheatley JR, Amis TC, Engel LA. Oronasal partitioning of ventilation during exercise in humans. *J Appl Physiol (1985).* 1991;71(2):546–551. doi:10.1152/jappl.1991.71.2.546. PMID: 1938727.
7. Zhao Z, Zheng L, Huang X, Li C, Liu J, Hu Y. Effects of mouth breathing on facial skeletal development in children: a systematic review and meta-analysis. *BMC Oral Health.* 2021;21(1):108. doi:10.1186/s12903-021-01458-7. PMID: 33691678.
8. Garrocho-Rangel A, Rosales-Berber MÁ, Ballesteros-Torres A, et al. Rapid maxillary expansion and its consequences on the nasal and oropharyngeal anatomy and breathing function of children and adolescents: an umbrella review. *Int J Pediatr Otorhinolaryngol.* 2023;171:111633. doi:10.1016/j.ijporl.2023.111633. PMID: 37421834.
9. Camacho M, Chang ET, Song SA, et al. Rapid maxillary expansion for pediatric obstructive sleep apnea: a systematic review and meta-analysis. *Laryngoscope.* 2017;127(7):1712–1719. doi:10.1002/lary.26352. PMID: 27796040.

10. Marcus CL, Brooks LJ, Draper KA, et al; American Academy of Pediatrics. Diagnosis and management of childhood obstructive sleep apnea syndrome. *Pediatrics.* 2012;130(3):576–584. doi:10.1542/peds.2012-1671. PMID: 22926173.

11. Baratieri C, Alves M Jr, de Souza MM, de Souza Araújo MT, Maia LC. Does rapid maxillary expansion have long-term effects on airway dimensions and breathing? *Am J Orthod Dentofacial Orthop.* 2011;140(2):146–156. doi:10.1016/j.ajodo.2011.02.019. PMID: 21803251.

12. Dallam GM, McClaran SR, Cox DG, Foust CP. Effect of nasal versus oral breathing on VO_2max and physiological economy in recreational runners following an extended period spent using nasally restricted breathing. *Int J Kinesiol Sports Sci.* 2018;6(2):22–29. doi:10.7575/aiac.ijkss.v.6n.2p.22.

13. Morton AR, King K, Papalia S, Goodman C, Turley KR, Wilmore JH. Comparison of maximal oxygen consumption with oral and nasal breathing. *Aust J Sci Med Sport.* 1995;27(3):51–55. PMID: 8599744.

14. Adams CM, Peiffer JJ. Neither internal nor external nasal dilation improves cycling 20-km time trial performance. *J Sci Med Sport.* 2017;20(4):415–419. doi:10.1016/j.jsams.2016.08.018. PMID: 27637570.

15. Yu M, Ma Y, Xu Y, et al. Orthodontic appliances for the treatment of pediatric obstructive sleep apnea: a systematic review and network meta-analysis. *Sleep Med Rev.* 2023;72:101855. doi:10.1016/j.smrv.2023.101855. PMID: 37820534.

16. Lin SY, Su YX, Wu YC, Chang JZ, Tu YK. Management of paediatric obstructive sleep apnoea: a systematic review and network meta-analysis. *Int J Paediatr Dent.* 2020;30(2):156–170. doi:10.1111/ipd.12593. PMID: 31680340.

17. Bellon M, Boutin F, Haddad R, Frapier L. Effectiveness of orthopaedic treatments on the enlargement of the upper airways: overview of systematic reviews. *Int Orthod.* 2023;21(2):100745. doi:10.1016/j.ortho.2023.100745. PMID: 36871416.

18. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ.* 2021;372:n71. doi:10.1136/bmj.n71. PMID: 33782057.

19. Villa MP, Malagola C, Pagani J, et al. Rapid maxillary expansion in children with obstructive sleep apnea syndrome: 12-month follow-up. *Sleep Med.* 2007;8(2):128–134. doi:10.1016/j.sleep.2006.06.009. PMID: 17239661.

20. Villa MP, Rizzoli A, Miano S, Malagola C. Efficacy of rapid maxillary expansion in children with obstructive sleep apnea syndrome: 36 months of follow-up. *Sleep Breath.* 2011;15(2):179–184. doi:10.1007/s11325-011-0505-1. PMID: 21437777.

21. Cistulli PA, Palmisano RG, Poole MD. Treatment of obstructive sleep apnea syndrome by rapid maxillary expansion. *Sleep.* 1998;21(8):831–835. doi:10.1093/sleep/21.8.831. PMID: 9871945.

22. Marcus CL, Moore RH, Rosen CL, et al; Childhood Adenotonsillectomy Trial (CHAT). A randomized trial of adenotonsillectomy for childhood sleep apnea. *N Engl J Med.* 2013;368(25):2366–2376. doi:10.1056/NEJMoa1215881. PMID: 23692173.

23. Shea BJ, Reeves BC, Wells G, et al. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. *BMJ.* 2017;358:j4008. doi:10.1136/bmj.j4008. PMID: 28935701.

24. Guyatt GH, Oxman AD, Vist GE, et al; GRADE Working Group. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. *BMJ.* 2008;336(7650):924–926. doi:10.1136/bmj.39489.470347.AD. PMID: 18436948.

25. Clement PA, Gordts F; Standardisation Committee on Objective Assessment of the Nasal Airway, IRS, and ERS. Consensus report on acoustic rhinometry and rhinomanometry. *Rhinology.* 2005;43(3):169–179. PMID: 16218509.

26. Prévé S, García Alcázar B. Interest of miniscrew-assisted rapid palatal expansion on the upper airway in growing patients: a systematic review. *Int Orthod.* 2022;20(3):100657. doi:10.1016/j.ortho.2022.100657. PMID: 35752557.

27. Ngiam J, Cistulli PA. Dental treatment for paediatric obstructive sleep apnea. *Paediatr Respir Rev.* 2015;16(3):174–181. doi:10.1016/j.prrv.2014.11.002. PMID: 25600076.

28. Occasi F, Perri L, Saccucci M, et al. Malocclusion and rhinitis in children: an easy-going relationship or a yet to be resolved paradox? A systematic literature revision. *Ital J Pediatr.* 2018;44(1):100. doi:10.1186/s13052-018-0537-2. PMID: 30134958.