

Article

Impact of Virtual Reality Immersion on User Engagement and Performance During Gamified Respiratory Muscle Training

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Abstract

Inspiratory Muscle Training (IMT) is a well-established intervention for enhancing respiratory strength; however, its clinical efficacy is frequently compromised by low adherence and high dropout rates due to the repetitive nature of traditional protocols. While screen-based gamified biofeedback is the most common digital training approach, these non-immersive (NI) conditions often lead to split attention and lack the controlled, private environments necessary for optimal engagement and exercise quality. This study evaluated the impact of immersion level on respiratory performance and user experience by comparing two conditions in gamified Virtual Reality (VR) environments: fully immersive (FI) and NI. The IMT was performed using an instrumented threshold load device, where real-time mouth pressure drove gamified environments designed to guide respiratory patterns. The results demonstrate that perceived effort and fatigue remained consistent across immersion levels; however, the FI condition provided a higher level of immersion despite a reported reduction in breathing control. Notably, 73% of participants found the FI condition more motivating, with higher scores in focus (60%), user preference (63%), and efficacy (40%). Crucially, increased task complexity widened the performance gap between immersion levels. In scenarios requiring higher respiratory muscle workload, significant differences emerged in breathing regulation, specifically regarding the inspiratory duty cycle, favoring the NI condition. Specifically, the NI condition exhibited a higher inspiratory duty cycle and higher scores compared to the FI condition. These findings suggest that while FI significantly boosts user motivation, the synergy between the head-mounted display (HMD) and the physical demands of the threshold device may disrupt respiratory regulation during high-effort tasks. This highlights a critical design trade-off between immersion levels and physiological precision that must be addressed in the development of future digital pulmonary interventions.



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1. Introduction

Inspiratory Muscle Training (IMT) is a highly effective technique for enhancing the strength and endurance of the respiratory musculature [1]. It consists of loaded breathing maneuvers through a mechanical device comprising a unidirectional valve that creates a inspiratory resistance, forcing the subject to make a more significant effort to overcome

the resistive load. While IMT is a proven technique for improving mucus clearance and reducing shortness of breath in Chronic Obstructive Pulmonary Disease (COPD) and asthma patients, its benefits extend to a broad spectrum of populations. For instance, in clinical cohorts such as those with multiple sclerosis [2], or in physically active populations, including aging adults [3] and athletes [4], IMT serves as a tool to enhance respiratory efficiency, delay fatigue, and improve exercise capacity. Furthermore, research demonstrates that IMT is equally effective for general healthy adults, in whom it has been shown to increase diaphragm thickness, lung volumes, and overall exercise capacity [5]. Furthermore, IMT is a straightforward, cost-effective, and safe intervention that can be performed at home using conventional flow-dependent resistive or pressure-threshold devices [6,7]. Despite these advantages, therapy adherence remains a significant challenge; studies show consistently low engagement [8] and withdrawal rates of 10–20% in pulmonary rehabilitation programs [9]. This dropout rate is often attributed to the monotonous and repetitive nature of the training, which typically requires 4–6 sessions per week over 3 to 12 weeks, and is further exacerbated by the absence of real-time auditory or visual biofeedback in conventional mechanical devices.

To address the limitations inherent in traditional IMT and standard respiratory protocols, such as spirometry maneuvers and diaphragmatic breathing, several biofeedback-based solutions have been developed. For instance, studies by [10,11] introduced electromyographic (EMG) biofeedback, utilizing visual and auditory cues to enable users to voluntarily modulate respiratory muscle tension. Further innovations include visual respiratory biofeedback focused on abdominal excursion [12] and visual feedback of abdominal pressure generated by an air-resistive training device positioned on the chest, which provides external resistance during inhalation to strengthen respiratory muscles [13]. Advancements in sensing and display technologies have enabled more sophisticated biofeedback systems designed to enhance user engagement, performance, and long-term adherence. A prominent trend involves gamified biofeedback, where physiological signals, such as airflow temperature and chest excursion, control gameplay in real time [14]. Examples include a gamified inhaler device that guides the rhythm and depth of inhalation while providing instantaneous performance feedback for children [15], and a system using a temperature sensor to detect inhalation/exhalation signals and provide real-time feedback on a screen [16]. Additionally, mobile solutions have been developed to guide and evaluate slow-paced breathing exercises by using the device's microphone to detect respiratory phases [17].

All previously mentioned solutions utilize non-immersive interfaces, typically relying on computer or smartphone screens for visual feedback. In fact, this remains the most common modality in game-based respiratory interventions for pulmonary rehabilitation [18]. However, these platforms are highly susceptible to external distractions; in home settings, ambient family activity can interfere, while in clinical environments, the inherently busy atmosphere can be disruptive. Such environmental noise may diminish breath awareness, making patients more prone to inefficient respiratory patterns. Furthermore, traditional screen-based setups lack the spatial isolation necessary to create a controlled sense of privacy, which is essential for maintaining the high level of concentration required for precise task execution. Immersive technologies, particularly VR, can mitigate these drawbacks through full visual occlusion. This facilitates a complete perceptual decoupling from the physical surroundings, eliminating external visual stimuli and fostering an environment of undivided attentional focus. Additionally, by enveloping the user in a virtual space, these systems can reduce the social inhibition or self-consciousness often associated with using rehabilitation devices in public or semi-public settings.

Despite the potential benefits of integrating immersive technologies, such as HMDs, and gamification into respiratory muscle training, to our knowledge, no studies have yet reported on the integration of fully immersive (FI) interfaces with mechanical valve-based IMT. Most existing gamified immersive solutions involving breathing maneuvers are designed for diaphragmatic breathing to promote relaxation [19–22] or enhance a correct breathing pattern [23] and typically rely on external sensors, such as chest belts, to monitor respiratory phases; these maneuvers differ significantly in frequency and intensity from those required in IMT and do not use a mechanical valve. This research gap likely stems from a lack of empirical evidence comparing exercise quality and user preference between FI and NI solutions for IMT. The present study addresses this gap by evaluating the impact of immersion level on respiratory performance and user experience, specifically comparing two interfaces: a FI VR setup and a NI screen-based system. These environments guide personalized breathing exercises for respiratory muscle strengthening via a pressure-threshold device [24] consistent with conventional IMT protocols. In both setups, respiratory mouth pressure serves as the primary biofeedback parameter to control the dynamics of two dedicated exergames.

2. Materials and Methods

2.1. Participants

Thirty participants (14 male and 16 female; age: 26 ± 7.6) were recruited from the Center for Research and Advanced Studies (CINVESTAV), Mexico. All participants were naïve to respiratory muscle training and had no prior experience using a pressure-threshold device. Participants were randomly allocated either to the Sky Snack ($n = 15$, 6 male, 9 female; age = 26.8 ± 8.2) or Ocean Obstacle ($n = 15$, 8 male, 7 female; age = 25.1 ± 7.1) game group upon enrollment. The sample size for each group was determined through a power analysis using G*Power software (version 3.1.9.7). For each group, we conducted a 2×5 repeated-measures ANOVA, where the factors were the immersion level (2 levels) and the exercise block (5 levels). Assuming a moderate effect size of 0.25, a significance level of $\alpha = 0.05$, and a statistical power of $1 - \beta = 0.85$, a sample size of $n = 15$ per group was calculated to be sufficient to detect significant differences. Regarding digital familiarity, 6 participants reported some experience with VR technologies. All subjects were in good respiratory health with no history of pulmonary disease. The experimental protocol was fully explained to all participants, who provided written informed consent prior to enrollment. Furthermore, the study was conducted according to the principles of the Helsinki Declaration.

2.2. Gamified Inspiratory System

It comprises an instrumented inspiratory threshold valve and an IMT application (see Figure 1). The valve (from Respironics, Inc., Murrysville, PA, USA) is electronically equipped for measuring mouth-respiratory airflow pressure. Furthermore, it provides inspiratory flow resistance (threshold load), which can be mechanically set within 9 and 41 cmH₂O. The mouth-pressure data is used as a real-time command signal to control the vertical motion of the game's main character (the higher the mouth pressure, the higher the main character's movement).

The IMT application guides users through a series of breathing exercises, including controlled respiratory pauses, via two distinct exergames: Sky Snack and Ocean Obstacle [24]. The application was run in a laptop and the exergames were displayed through an Oculus Quest 2 headset (FI VR condition) or a laptop screen (NI screen-based condition). The application features adjustable difficulty levels and customizable respiratory

parameters, such as respiratory cycle duration and duty cycle, to tailor the training to individual requirements.



Figure 1. Experimental setups for respiratory muscle training: (A) the NI screen-based interface and (B) the FI VR interface.

For this study, both games were configured with a 5.5-s respiratory cycle to facilitate training at a respiration rates of 11 breaths per minute [25]. However, Sky Snack was designed with a lower workload relative to the Ocean Obstacle game. Specifically, Sky Snack was configured with a 33% duty cycle, while Ocean Obstacle utilized a 40% duty cycle.

The training protocol was structured into five blocks of 12 consecutive breathing maneuvers each, separated by 1-min rest intervals. Consequently, the total duration of each gameplay session was approximately 23 min. Prior to each session, the system was calibrated to the device's pressure-threshold; participants performed a forced inhalation to overcome the resistance, assisted by real-time visual feedback provided via an on-screen progress bar.

2.3. Measurements

Outcome measures comprised objective physiological data and subjective user feedback. Objective metrics included the duty cycle and the game score achieved during each exercise block. Duty cycle, defined as the proportion of the total respiratory cycle dedicated to inhalation, indicates how participants modulate their inhalation duration in response to system guidance. The game score, proportional to the number of fruits collected in Sky Snack and inversely proportional to the number of collisions with obstacles in Ocean Obstacle, serves as a direct indicator of the precision with which participants modulated their inhalation to control the game character. Consequently, the duty cycle reflects inhalation duration, while the score reflects inhalation precision.

Subjective metrics were gathered via two instruments: a post-condition questionnaire and a final comparative questionnaire administered at the conclusion of the study (detailed in Table 1 and Table 2, respectively). Items were adapted from validated instruments addressing presence [26], muscle fatigue [27], user experience [28], and usability [29]. These items were selected to ensure the instrument remained concise, minimizing cognitive load for participants immediately following the physical exertion of the training, and were structured with a balance of positive and negative phrasing to reduce response-set bias.

For the post-condition questionnaire, we employed a 5-point Likert scale to assess five user experience (UX) factors (usability, physical exertion, respiratory control, immersion, and overall experience). Responses for each subject are scored from one ("Not at all" or "Very low") to five ("Very much" or "Very high"), with negative items reverse-coded. The final score for each construct was obtained by averaging the responses, with higher scores consistently reflecting a more positive user experience. It should be noted that this instrument was used as an exploratory tool to capture user feedback in this specific

human–machine interaction context; therefore, individual constructs were evaluated independently, and formal psychometric validation or internal consistency assessments were not conducted.

This final assessment evaluated breathing control, focus, engagement, and future use preference through a forced-choice task among three options: NI, FI, or both levels. The answers were evaluated as percentages of participants choosing one of the three options.

Table 1. Questions of the post-session questionnaire.

Item	Question
1	How easy was to use the Gamified inspiratory system? (U)
2	How clear and immediate was the feedback provided by the system regarding your breathing performance? (U)
3	What level of effort did you perceive in your diaphragm during the exercises? (P)
4	Did you experience fatigue or discomfort in your diaphragm or other respiratory muscles? (P)
5	Were you able to maintain a controlled and steady breathing pattern throughout the training? (C)
6	How smooth and uninterrupted was your breathing pattern with the system? (C)
7	How much did the system facilitate your breathing performance? (I)
8	How much distraction did you perceive during the session? (I)
9	How would you describe your experience with the system? (Ex)
10	How much the gamified interface keep you motivated throughout the session? (E)

U: Usability, P: Physical exertion, C: Respiratory Control, I: Immersion, and Ex: Overall experience.

Table 2. Questions of the final questionnaire.

Item	Question
1	Which of the two interfaces did you find more effective for performing the exercises? (E)
2	Which of the two interfaces allowed you to focus on your breathing and the use of the valve? (F)
3	Which of the two interfaces did you find more attractive or motivating for performing the training? (A)
4	In which interface would you like to repeat the training? (R)

E: More effective, F: Better focus, A: Engagement Level, R: Preference to repeat.

2.4. Experimental Protocol

The experiment utilizes a within-subjects design to evaluate the influence of immersion level on respiratory exercise quality, UX and participant preference. Specifically, the experiment compares a gamified FI VR setup against an NI screen-based gamified condition; see Figure 1. In both conditions, participants interact with the gamified interface using an instrumented inspiratory threshold valve. In the FI VR condition, the game is viewed through an Oculus Quest 2 headset (Figure 1B), whereas in the NI condition, it is displayed on a laptop screen (Figure 1A).

Participants were randomly assigned to either the Sky Snack ($n = 15$) or the Ocean Obstacle group ($n = 15$) upon enrollment. Each participant completed the experimental protocol in a single session. The task involved performing respiratory exercises through their assigned game. Participants completed the training under both NI and FI conditions, with the order of conditions counterbalanced to control for potential order effects. Each session lasted approximately 40 min per condition, with a 30-min break between conditions.

In each condition, participants were advised to perform the breathing exercises while sitting comfortably in a chair, with their arms resting on a table, with their necks in an upright position, and both feet flat on the floor. They were also instructed to emphasize the use of their diaphragm and to ensure that their abdomen “sticks out” during each inspiratory manoeuvre.

Prior to start the experiment, maximum inspiratory pressure ($P_{I_{max}}$) was measured with participants in a sitting position, using a nose clip and a handheld respiratory pressure meter equipped with a disposable tube-type mouthpiece and a two-way bacterial filter [24]. Following the recommendations in [30], participants performed three $P_{I_{max}}$ maneuvers starting from residual volume and were encouraged to improve their performance via real-time visual feedback on the device screen. To ensure data quality, only acceptable measurements were recorded, and the highest value was selected for the final $P_{I_{max}}$ calculation. This $P_{I_{max}}$ value was then used to calibrate the threshold valve load, which was set to 20% of the participant's maximum capacity in both sessions.

Before beginning the study, participants completed a questionnaire regarding their history with respiratory muscle training, VR technologies, and pulmonary diseases. To ensure a comprehensive evaluation of the user experience, both the post-session and final comparative questionnaires were administered once both experimental conditions had been completed. Upon completion of the questionnaires, the experimenter interviewed participants to identify any instances of simulator sickness or discomfort and to allow for open-ended participant feedback.

2.5. Statistics

Statistical analysis was conducted using RStudio (version 2025.09.2). The normality of the data distribution was assessed using the Shapiro–Wilk test. Given the non-normal distribution of all performance metrics, non-parametric tests were employed for all subsequent analyses.

A Scheirer–Ray–Hare test was employed as a non-parametric alternative to a two-way ANOVA to investigate the main effects of immersion level (FI vs. NI) and the exercise block (comprising 5 blocks), as well as their interaction. For post-hoc analysis, a paired Wilcoxon signed-rank test was used to compare outcomes between experimental conditions, with p-values adjusted using the Bonferroni correction. Additionally, a one-sample Wilcoxon signed-rank test was implemented to compare measured outcomes against target values, with results reported using a 95% confidence interval for the median difference. For all statistical evaluations, a significance threshold of 0.05 was established.

3. Results

All 30 recruited participants successfully completed the experiment. Although two participants experienced transient dizziness following sudden head movements, they reported no further discomfort after remaining seated and stationary for a short period. Notably, participants' performance and or questionnaire responses remained consistent regardless of their prior experience with VR technology.

3.1. Objective Measures

The mouth pressure profiles for a single subject during a representative interval of both games are illustrated in Figure 2. These profiles are representative of the trends observed across the entire study group, where similar respiratory patterns were recorded. These profiles compare respiratory performance across FI and NI conditions, demonstrating six distinct breathing cycles, characterized by a pressure decrease from baseline during the inhalation phase. Specifically, baseline pressures were maintained at approximately 882 cmH₂O for Sky Snack (see Figure 2a) and 884 cmH₂O for Ocean Obstacle (see Figure 2b). During inhalation, these values decreased and triggered the game mechanics, specifically, the movement of the main character, before returning to and stabilizing at the initial baseline throughout the exhalation phase.

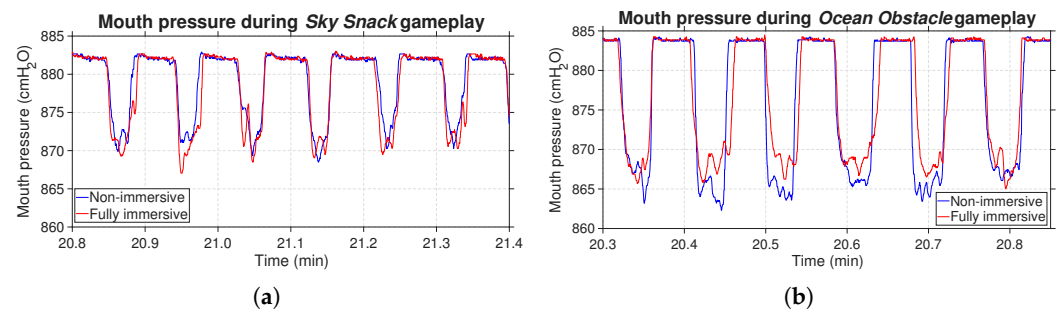


Figure 2. Mouth pressure recorded during: (a) Sky Snack and (b) Ocean Obstacle gameplay, comparing the FI (red solid line) and the NI conditions (blue solid line).

A comparison of the two games reveals that the pressure in Sky Snack dropped approximately 13 cmH₂O from baseline, whereas Ocean Obstacle required a more pronounced drop of approximately 19 cmH₂O. Additionally, the inhalation phase was shorter in Sky Snack compared to Ocean Obstacle, suggesting that the latter imposes a higher respiratory difficulty.

The pressure profiles in Sky Snack were highly consistent across both conditions. In contrast, during Ocean Obstacle gameplay, the inhalation phase associated with the FI condition exhibited a smaller amplitude compared to the NI counterpart. This indicates that FI might influence the user's breathing control during more demanding respiratory tasks.

The average inspiratory duty cycle, segmented by block and condition for each game, is presented in Figure 3. Each graph also includes a solid red line representing the target inspiratory duty cycle for the respective game.

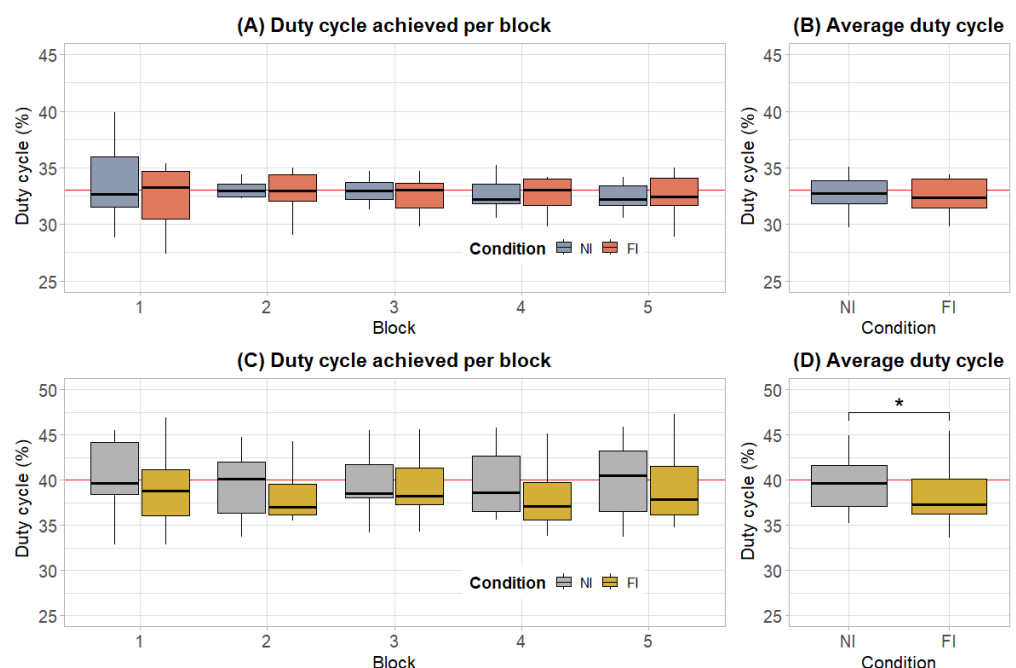


Figure 3. Average inspiratory duty cycle across the fully immersive (FI) and non-immersive (NI) conditions during Sky Snack (A,B) and Ocean Obstacle (C,D) gameplay. Graphs (A,C) show performance across blocks, while (B,D) represent the overall average duty cycle. The solid red lines represent the target inspiratory duty cycles: 33% for the Sky Snack game and 40% for Ocean Obstacle. The horizontal line with asterisk (*) denote statistically significant difference ($p < 0.05$).

To assess the influence of exercise block (blocks 1–5) and immersion level (NI vs. FI), a Scheirer–Ray–Hare test was applied to the duty cycle data. In the Sky Snack game, neither exercise block ($H(4) = 1.03$, $p = 0.91$) nor immersion level ($H(1) = 3 \times 10^{-5}$, $p = 0.99$)

yielded significant main effects. For Ocean Obstacle, exercise block did not yield significant main effect ($H(4) = 1.6$, $p = 0.81$); however, the immersion level did yield a significant main effect ($H(1) = 4.53$, $p = 0.033$). A post hoc analysis yielded that for the Ocean Obstacle game, the duty cycle was significantly higher in the NI condition compared to the FI condition ($p = 0.03$). No significant interaction between block and immersion was detected for either game ($p > 0.05$).

A one-sample Wilcoxon signed-rank test was used to evaluate under each condition the average duty cycle achieved against the respective targets for each game. For Sky Snack, participants' performance did not significantly deviate from the 33% target in either the FI condition with a median of 32.88% (CI: 32.28%, 33.53%) ($V = 1397$, $p = 0.73$) or NI condition with a median of 32.79% (CI: 32.37%, 33.26%) ($V = 1216$, $p = 0.36$). Similarly, for Ocean Obstacle, the duty cycle under the NI condition yielded a median of 39.81% (CI: 38.94%, 40.76%), demonstrating no significant deviation from the 40% target ($V = 1347$, $p = 0.68$). In contrast, a significant discrepancy was observed under the FI condition (median = 38.29%, CI: 37.37%, 39.36%), where the achieved duty cycle was significantly lower than the target ($V = 854$, $p = 0.003$).

The average score achieved across blocks and the overall score for both Sky Snack and Ocean Obstacle are displayed in Figure 4. Each graph also includes a solid red line representing the maximum possible score per block for each game (400 for Sky Snack and 2000 for Ocean Obstacle).

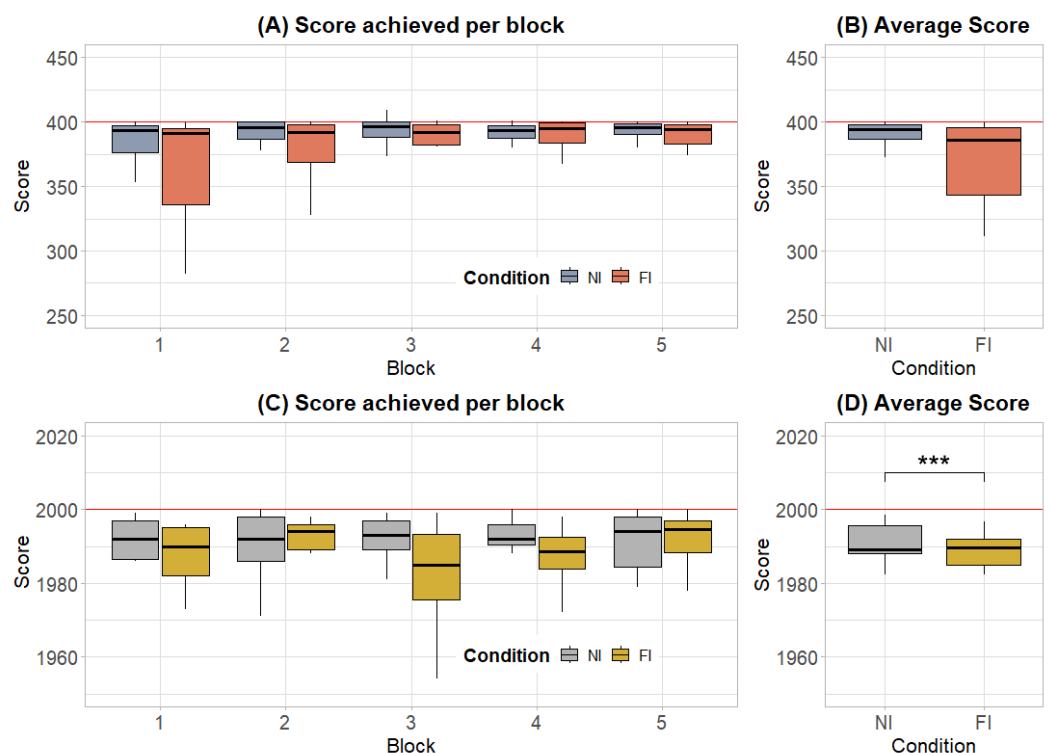


Figure 4. Average score achieved across the fully immersive (FI) and non-immersive (NI) conditions during Sky Snack (A,B) and Ocean Obstacle (C,D) gameplay. Graphs (A,C) show performance across blocks, while (B,D) represent the overall average score. The solid red lines indicate the maximum possible score per block. The horizontal line with asterisks (***) denote statistically significant difference ($p < 0.001$).

To assess the influence of exercise block (blocks 1–5) and immersion level (NI vs. FI) on score data, a Scheirer–Ray–Hare test was applied. In the Sky Snack game, neither the immersion level ($H(1) = 2.9$, $p = 0.09$) nor the exercise block ($H(4) = 3.45$, $p = 0.48$) yielded significant main effects. For Ocean Obstacle, the exercise block did not have

a significant effect ($H(4) = 2.01, p = 0.73$); however, the immersion level exerted a significant main effect ($H(1) = 10.52, p = 0.001$). No significant interaction between block and immersion was detected for either game ($p > 0.05$). A post hoc analysis yielded that for the Ocean Obstacle game, the averaged score achieved under the NI condition was significantly higher than that achieved under the FI condition ($p = 0.001$).

A one-sample Wilcoxon signed-rank test was used to compare the performance scores achieved in each condition against the theoretical maximum for each game (see Figure 4B,D). Across all games and conditions, participants' scores deviated significantly from the maximum possible value. In the FI condition, participants achieved a median score of 379.5 (CI: 361.5, 389.5; $V = 54.5, p < 0.001$) for Sky Snack and 1985 (CI: 1979.5, 1988.5; $V = 0, p < 0.001$) for Ocean Obstacle. Similarly, in the NI condition, medians reached 389.5 (CI: 385, 393; $V = 40, p < 0.001$) for Sky Snack and 1991.5 (CI: 1989, 1993; $V = 0, p < 0.001$) for Ocean Obstacle.

3.2. Subjective Measures

Results from the post-session questionnaire are presented in Figure 5. Participants perceived no significant differences between the FI and NI conditions regarding usability ($V = 418, p = 0.63, r = 0.074$) or overall experience ($V = 542, p = 0.14, r = 0.23$). Similarly, ratings for physical exertion ($V = 417, p = 0.62, r = 0.075$) and respiratory control ($V = 404, p = 0.46, r = 0.134$) remained consistent across conditions. Conversely, participants reported a significantly higher level of immersion in the FI condition compared to the NI condition ($V = 717, p < 0.001, r = 0.63$), demonstrating a large effect size for this dimension.

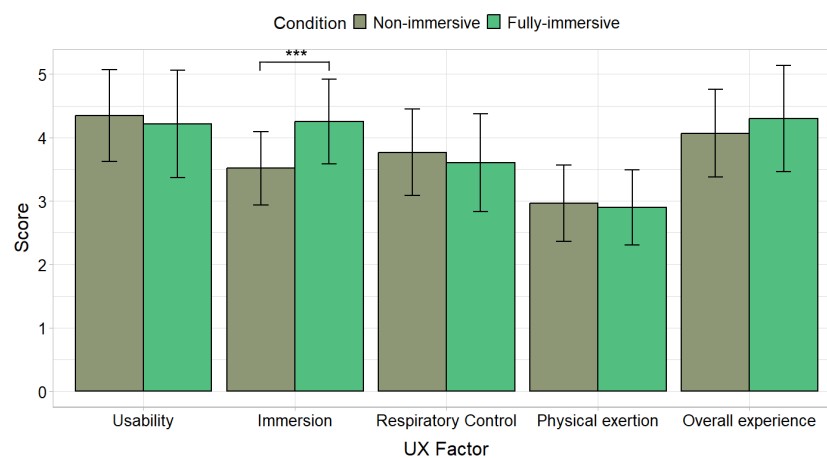


Figure 5. Post-session questionnaire results. The horizontal line with asterisks (***) denote statistically significant difference ($p < 0.001$).

The results of the final comparative questionnaire are summarized in Figure 6, which illustrates participant preferences across four key dimensions: Efficacy, Focus, Motivation, and Preference. Overall, the FI condition was identified as the superior environment for psychological and engagement factors. In contrast, the NI condition was consistently the least preferred option in all dimensions. Motivation yielded the most significant disparity, with 73% of participants selecting the FI condition. This suggests a strong correlation between the level of immersion and the user's drive to engage with the system. Regarding Focus and Preference, the distributions were similar, with the FI condition emerging as the primary choice (60% and 63%, respectively). However, nearly one-third of the cohort (27%) indicated that both conditions were equally effective or preferred, highlighting a perceived value in the versatility of the two approaches. In terms of Efficacy, 43% of participants reported that both conditions were equally effective for the task, while 40% favored the FI

condition, and only 17% favored the NI condition. Notably, all participants with previous experience in VR technology consistently favored the FI condition, reporting higher levels of motivation, preference and focus, along with an increased ability to maintain focus throughout the task.

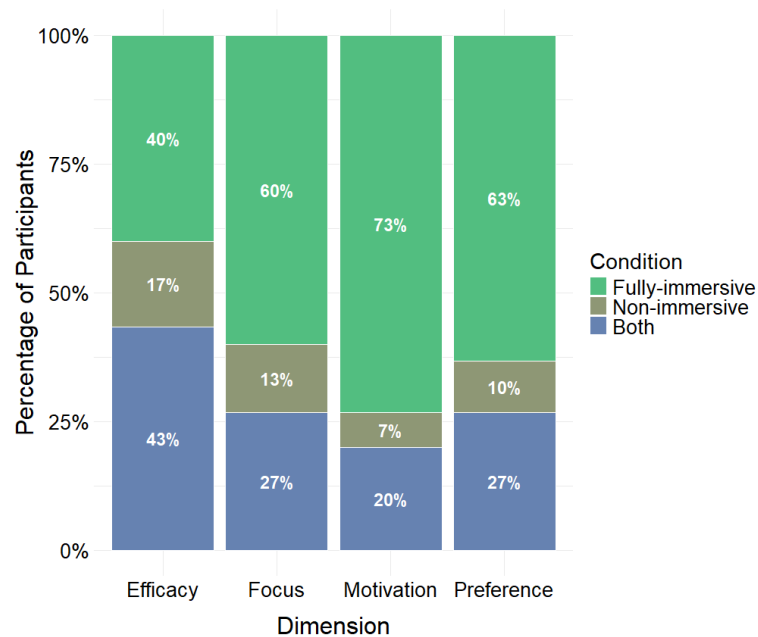


Figure 6. Results of the final comparative questionnaire assessing participant responses across four psychological and functional dimensions (Efficacy, Focus, Motivation, and Preference) comparing FI, NI, and both conditions.

4. Discussion

The results demonstrate that the inspiratory duty cycle remained consistent across exercise blocks for both games, suggesting that gamified feedback effectively supported stable inspiratory durations throughout the training. Although duty cycle measurements did not differ significantly between immersion conditions during Sky Snack, a notably lower duty cycle was observed in the FI condition compared to the NI condition during Ocean Obstacle. Regarding performance relative to target duty cycles, participants adhered closely to the 33% target across both conditions. However, maintaining the 40% target proved more challenging in the FI condition. Similarly, performance (see Figure 4), which reflect the pressure-modulation precision required for character control, were lower in the FI condition than in the NI condition exclusively during Ocean Obstacle. Furthermore, when assessed against maximum achievable values, performance remained significantly constrained under both immersion levels, indicating that the task requirements themselves pose a substantial challenge to achieving peak precision, regardless of the immersion modality. Collectively, these findings suggest that both the precision and temporal stability of respiratory regulation may be challenged by the combined demands of the fully immersive environment, the use of the HMD, and high-duty-cycle targets. This performance decay occurs despite participants reporting higher levels of focus and motivation (see Figure 6) and without a significant increase in perceived physical exertion. This suggests that the enthusiasm elicited by the immersive environment may divert the cognitive resources required for physiological regulation, aligning with previous research demonstrating that the combination of FI VR environments and physical interfaces can lead to reduced task accuracy and performance [31].

While high intrinsic motivation immersive VR-based exercise is recognized as a positive factor for user participation, enjoyment, and positive experiences [32–35], our results

highlight a complex trade-off between psychological engagement and motor performance. Although FI VR breathing exercises foster greater motivation, a key factor for long-term adherence in home-based augmented reality frameworks [36], the data suggest that this heightened engagement does not necessarily translate to improved inspiratory performance during high-duty-cycle IMT. This discrepancy implies that high levels of immersion may impose an additional cognitive load that competes for attentional resources, potentially hindering precise motor execution. These findings align with previous studies on VR-based relaxation and breathing techniques, which are consistently reported as more enjoyable and effective for stress relief, yet often yield no significant performance gains over traditional approaches [33,37]. Ultimately, these results emphasize that immersion does not guarantee optimal attentional allocation; instead, it creates a trade-off scenario where the benefits of increased motivation must be balanced against the potential for cognitive interference in motor precision.

This paradox is further reflected in the participants' subjective evaluations across the dimensions of efficacy, focus, motivation, and preference (Figure 6). While the NI condition was consistently the least favored across all categories, a comparative analysis reveals that the FI condition is the most robust strategy for maximizing user engagement. This is particularly pronounced in the motivation dimension, where 73% of participants favored the immersive condition and 20% valued both, resulting in a 93% positive reception for immersive technology. These findings indicate that, despite recognizing the functional efficacy of the NI approach (collectively 60% for NI and Both), participants predominantly perceived the FI condition as providing superior intrinsic motivation, which is essential for ensuring long-term adherence to respiratory muscle training. Overall 90% of the sample expressed a positive disposition toward the integration of immersive technology, derived from a combination of direct preference for FI (63%) and the acknowledgement of the complementarity of both systems (27%). Consequently, FI VR emerges as a powerful tool to enhance the training experience, mitigating the impact of observed challenges in inspiratory precision during high duty cycle IMT.

Limitations

A notable limitation of this study is that the findings may not be directly generalizable to clinical populations with respiratory pathologies, such as COPD. While the training protocol proved effective in our cohort, patients with pulmonary disease often exhibit distinct physiological constraints, such as higher levels of fatigue and compromised respiratory control, which were not represented in this study. Therefore, these results should be interpreted with caution when applied to rehabilitative settings, underscoring the need for further validation in clinical populations.

Regarding the methodology, although the questionnaire items were adapted from established literature, the instrument was not subjected to a formal psychometric validation process. Consequently, these subjective results should be viewed as preliminary indicators of user experience and interpreted with caution.

5. Conclusions

This study evaluated the impact of immersion level on the efficacy of a gamified Inspiratory Muscle Training (IMT) protocol, comparing a fully immersive VR environment against a traditional screen-based system. Our findings demonstrate that immersive VR serves as a key facilitator for psychological engagement, significantly surpassing the non-immersive interface in terms of user motivation, focus, and preference. With a cumulative 90% of participants responding positively to the integration of VR technology, it emerges

as a robust strategic approach to address the low adherence and high dropout rates that typically hinder traditional respiratory interventions.

However, the results also reveal a critical trade-off between psychological immersion and physiological precision. Despite reported higher levels of focus and motivation, participants exhibited decreased inhalation precision and duration in the fully immersive condition, particularly during high-workload scenarios. Notably, this decay in performance occurred without a corresponding increase in perceived physical exertion, suggesting that the immersive experience may either displace the attention required for precise respiratory regulation or impose a higher cognitive load.

In conclusion, these findings suggest that the choice between modalities could be guided by specific training goals. The FI interface appears to be a viable tool for fostering long-term adherence and motivation, which might be particularly beneficial when the primary objective is to encourage consistent practice. Conversely, the NI approach could remain preferable in scenarios where absolute precision and duration is the critical requirement, especially for shorter, more focused sessions. These findings provide a vital foundation for the development of next-generation digital therapeutics that aim to harmonize high user engagement with respiratory control performance.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of Center for Rehabilitation and Special Education (CREE-DIF) from Saltillo, Mexico (Eoo1-2021, 9 September 2021).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data is contained within the article. Further inquiries can be directed to the corresponding author.

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Abbreviations

The following abbreviations are used in this manuscript:

IMT	Inspiratory Muscle Training
FI	fully immersive
NI	non-immersive
VR	Virtual Reality
HMD	head-mounted display

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