Effect of the Use of Haptic Gloves on the Acquisition of Psychomotor Skills in Students

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***Abstract*—The present study aimed to evaluate the effect of using Hi5 Noitom 2.0 haptic gloves in an immersive virtual reality environment on the development of psychomotor skills in medical students. A quantitative approach was adopted with a quasi-experimental design involving a control and an experimental group, each composed of 25 students (total $n = 50$). The intervention, applied to the experimental group, consisted of three practical sessions of 90 minutes over two weeks, during which participants performed simulated medical procedures such as suturing, forceps manipulation, and palpation of anatomical structures in a virtual environment. Three instruments were used for data collection: a psychomotor skills assessment rubric, a Likert-scale self-assessment questionnaire, and a structured observation checklist completed by experts. Statistical analyses included independent samples t-tests and repeated measures ANOVA. The results showed statistically significant improvements ($p < 0.001$) in all evaluated dimensions: precision, visuo-motor coordination, technical sequencing, execution time, safety, and feedback, both in the rubric and expert observations. Additionally, the experimental group reported a higher perception of practical improvement compared to the control group. In conclusion, the incorporation of immersive technologies with haptic feedback represents an effective pedagogical strategy for strengthening psychomotor competencies in medical training, enabling more realistic and safer practical experiences. This research contributes to the design of advanced educational simulation environments, with the potential to be replicated in other clinical and training contexts.**

***Keywords*—virtual reality, haptic gloves, psychomotor skills, medical education, clinical simulation**

I. Introduction

Medical training requires not only theoretical knowledge but also the development of psychomotor skills essential for clinical practice. In this context, immersive technologies such as virtual reality and haptic feedback have emerged as promising tools to enhance teaching-learning environments. Haptic gloves allow the simulation of tactile sensations, enabling the practice of clinical procedures in safe virtual environments. Medical students must develop psychomotor skills because these are fundamental to perform clinical procedures such as sutures, physical examinations, or instrument manipulations with precision and safety, which require visuomotor coordination, fine motor control, and technical sequencing. Without proper training, a deficit in these skills may compromise the quality of professional performance and patient safety.

In this context, simulation with haptic gloves offers an innovative technological alternative that allows training these skills in a safe, immersive, and controlled environment, providing real-time tactile feedback and reducing the risk associated with direct learning on patients. In this regard, the research question posed is: What is the effect of the use of haptic gloves on the acquisition of psychomotor skills in medical students?

Haptic immersion is an advanced simulation modality that allows users to experience realistic tactile sensations in virtual environments through devices such as gloves or controllers with haptic feedback [1]. In the field of teaching and learning, this technology promotes the development of practical skills by enabling students to interact with virtual objects as if they were real, strengthening active learning, visuomotor coordination, and procedural memory [2]. This evidence suggests that haptic immersion is an effective pedagogical tool for enhancing practical learning experiences in health science education programs [3].

Various studies have demonstrated the benefits of immersive learning for improving fine motor skills in health professions [4, 5]. However, there is a need for empirical evidence that supports the specific impact of haptic gloves in formal educational contexts such as university medical teaching. Therefore, this study aimed to evaluate the effect of using Hi5 Noitom 2.0 haptic gloves on the acquisition of psychomotor skills in medical students, using a quasi-experimental design and a quantitative approach.

II. Literature Review

In recent years, various studies have shown that the integration of haptic feedback into virtual reality environments enhances the fidelity and realism of medical simulators, contributing significantly to the acquisition of technical skills and procedural accuracy. For instance, a systematic review concluded that such integration reduces errors in tasks like palpation, although the quality of the evidence is still considered low [6]. In orthopedic surgery, incorporating haptic feedback in bone drilling simulators led to superior performance compared to non-haptic groups, including significantly improved Objective Structured Assessment of Technical Skill (OSATS) scores [7]. Similar findings were reported in neurosurgical training using haptic gloves for external ventricular drainage, where residents demonstrated better objective measures and a higher subjective perception of realism [8]. Conceptually, visuo-haptic systems have been recognized as essential tools for simulating complex clinical processes, as they combine tactile and visual information that enriches learning [9]. A review on technical challenges highlighted the importance of synchronization between visual and haptic stimuli to ensure training effectiveness [10]. Moreover, recent studies in medical education have identified haptic feedback as crucial for enhancing tactile realism, user satisfaction, and

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self-confidence, key aspects of educational immersion [11]. Still, some research indicates that simpler non-haptic simulations achieved higher technological acceptance and, in similar contexts, better results in specific practical skills [12].

Over the years, numerous studies have demonstrated the positive impact of haptic feedback simulation on developing psychomotor skills in medical and surgical contexts. Nicholas *et al.* [13] emphasized that simulation has taken a central role in surgical training by shortening the learning curve and improving patient safety. However, they noted a significant gap in access and curricular integration of such methods. This insight contributes to our study by highlighting the need to establish haptic technology training spaces within medical curricula. Similarly, Dawe *et al.* [14] conducted a systematic review showing that skills acquired in simulators effectively transfer to the operating room in procedures such as laparoscopic cholecystectomy and endoscopy, reinforcing the value of simulation for developing transferable clinical competencies, central to our research approach. Sabri [15] confirmed that haptic feedback in tasks like bone drilling significantly reduces errors such as over-perforation, validating the use of haptic technology to improve motor precision, an ability we aim to foster. Racy *et al.* [16] developed a haptic simulator for femoral nailing, validating its authenticity and content; their study showed that prior procedural experience correlates with better performance, contributing a relevant evaluative dimension to our research. Clarke [17] found that immersive virtual reality outperforms conventional methods in orthopedics, although more longitudinal evidence is needed, justifying experimental studies like ours. Yiannakopoulou *et al.* [18] highlighted that virtual reality simulation offers a safe and autonomous environment for learning basic surgical skills, though evidence remains limited for advanced procedures, reinforcing the importance of research focused on mastering foundational skills. In ophthalmology, Lin *et al.* [19] observed that students trained in VR reduced operative time and complications, suggesting that simulation enhances clinical performance, aligned with our objectives. In dentistry, Farag and Hashem [20] and Patil *et al.* [21] validated haptic simulators (HVRS and Simodont) for improving psychomotor skills during preclinical training, noting reduced intervention time and significant improvements in task quality, offering comparable intervention models to those we propose. Gießer *et al.* [22] emphasized that technologies like SkillsLab, combining haptic gloves with augmented reality, significantly improved preparation for clinical exams in Germany, showing benefits in both performance and perceived learning, reinforcing the pedagogical value of our proposal. Vece *et al.* [23] developed a haptic simulator for Veress needle insertion, reporting improved accuracy and reduced errors, confirming that this technology can train critical skills in a safe environment aligned with our study's goals in simulated medical contexts. Altogether, this body of evidence consolidates the relevance and originality of our study, justifying the implementation of a haptic simulation environment to enhance psychomotor competencies in medical students.

The literature review shows a growing consensus on the transformative potential of haptic technology in developing psychomotor and cognitive skills in educational contexts, particularly in medical and technical training. Shahriari-Rad *et al.* [24] conducted a longitudinal study with dental students at King's College London using a haptic virtual reality system (HapTEL) alongside the traditional Phantom-head lab. Their findings revealed significant improvements in spatial awareness and psychomotor abilities during preclinical training, emphasizing the value of psychometric tests as more objective and sensitive assessment tools than traditional methods. This supports our research by confirming that training with haptic-feedback simulators allows for precise and continuous measurement of motor skill progress, aligning with our interest in objective learning monitoring. Caulfield *et al.* [25] explored the use of haptic gloves in braille instruction, highlighting how passive haptic learning can accelerate knowledge acquisition and retention among blind populations. Although in a different field, this finding supports the premise that tactile feedback enhances speed and accuracy in acquiring new skills, transferable to the training of techniques such as suturing or anatomical palpation. Mutis and Oberemok [26], from a more conceptual perspective, developed a Human-Haptic Technology Interaction (H-HTI) framework based on a systematic review, generating a taxonomy that structures interaction modalities, immersive technologies, and learning methodologies in engineering. This contribution is essential to our study as it offers a theoretical foundation for designing training interventions with haptic gloves, helping to understand how fine motor skills, spatial perception, and temporal awareness are strengthened through such interaction. Collectively, these studies strongly support our research hypothesis: incorporating haptic technology into medical practical training enables more effective development of essential psychomotor skills while providing more objective, precise, and frequent assessment, fostering a more autonomous, personalized, and safe learning experience.

Kishor *et al.* [27], explored the technical challenges and innovations in AI-enhanced haptic systems applied to healthcare, particularly in robotic surgery, smart prosthetics, and rehabilitation. Their methodology consisted of a critical analysis of recent technological developments, highlighting the relevance of real-time tactile feedback and adaptive machine learning. The results showed that the integration of haptics with AI improves accuracy and medical training, although it faces challenges such as latency and cybersecurity. Their conclusion underscores the need to balance innovation with professional training, which provides our research with a solid technological foundation and a perspective on how haptic gloves can be applied in professional training contexts, including the development of psychomotor skills in teachers. Prakash *et al.* [28], in turn, analyzed simulation models in Virtual Reality (VR) and Augmented Reality (AR) in medical education. Through a review of various applications and platforms, they showed that these technologies enable realistic interactions in practical procedures, particularly in surgeries. The results suggest that VR is suitable for practical training, while AR complements anatomical and physiological processes. Their conclusions highlight the didactic value and applicability of these technologies, which directly link to our study by reinforcing the relevance of VR with haptics in educational scenarios that require technical precision and situated practice.

Zara *et al.* [29] focused their work on the empirical design of haptic simulators for medical training, as an alternative to the use of cadavers. The methodology consisted of the construction and validation of simulators that combine numerical simulation with tactile feedback. The results showed that these systems provide a safe and realistic practical experience, while the conclusion emphasized the effectiveness of haptic simulators in acquiring medical skills without ethical risks. This study contributes to our research by evidencing how haptic gloves enable repetitive and safe practice in the acquisition of psychomotor skills.

Finally, Kröplin *et al.* [30] compared a virtual reality simulator with a phantom model in oral surgery training. The study, with a prospective and cross-sectional design, included 22 dental students who evaluated both methodologies through questionnaires. The results revealed that the VR simulator was valued for its sustainability and objectivity, while the phantom was considered more realistic in terms of haptic feedback and anatomical representation. The conclusion was that both methods are useful and engaging, but with differentiated advantages. This comparison contributes to our work by providing evidence that haptic devices can overcome realism limitations and complement immersive training to develop practical skills in students.

Together, this body of literature supports the relevance and significance of our research on the use of haptic gloves in VR for medical training. It provides robust empirical evidence on the positive effects of such tools on precision, coordination, autonomy, and perceived psychomotor development in simulated contexts, complemented by critical analyses of technical and methodological challenges for effective implementation.

The study follows the IMRaD structure: the Introduction outlines the research problem, objectives, and theoretical framework; the Method describes the quasi-experimental design with control and experimental groups, the sample, instruments (rubric, observation sheet, and questionnaire), and statistical analyses (Student's t-test and repeated measures ANOVA); the Results present significant improvements in the experimental group after using haptic gloves in a virtual environment, supported by tables and figures; the Discussion relates the findings to existing literature, emphasizing the effectiveness of immersive technologies in medical training; and the Conclusions reaffirm that haptic simulation enhances psychomotor skills, while acknowledging limitations and suggesting directions for future research.

III. Methodology

A. Design and Approach

A quasi-experimental design was applied, involving a control group and an experimental group, with pretest and posttest measurements. The approach was quantitative, aiming to evaluate statistically significant differences in the development of psychomotor skills following the intervention.

B. Participants

The study population consisted of 100 medical students. The selected sample included 50 second-year students from a private university in Arequipa. Participants were chosen through non-probabilistic convenience sampling, applying previously established inclusion and exclusion criteria. Subsequently, the 50 students were randomly assigned into two equivalent groups: control group (n = 25) and experimental group (n = 25).

It is important to note that although randomization was applied in group assignment, the quasi-experimental design limits the possibility of making definitive causal claims. Therefore, the findings are interpreted as preliminary and exploratory evidence, acknowledging that future research with larger samples and more rigorous experimental designs will be needed to confirm or expand these results.

C. Instruments

Three instruments were used: a psychomotor skills assessment rubric, a Likert-scale self-assessment questionnaire, and a structured observation checklist. Validity was determined through expert judgment, reaching an Aiken's V index of 0.92, which indicates a high relevance of the items. Internal reliability was evaluated using Cronbach's alpha, yielding values of 0.88 for the rubric, 0.85 for the questionnaire, and 0.83 for the observation checklist, which demonstrates adequate internal consistency across all three instruments.

1) Psychomotor skills rubric

Table 1 presents the rubric for assessing psychomotor skills across four dimensions: movement accuracy, visuomotor coordination, technical step sequencing, and execution time. Each item was rated on a scale from 1 to 5.

Table 1. Rubric for assessing psychomotor skills across four dimensions

Dimension	Level 5 (Excellent)	Level 4 (Good)	Level 3 (Fair)	Level 2 (Insufficient)	Level 1 (Poor)
1.Movement Accuracy	Performs movements with complete accuracy, without errors or corrections.	Executes movements accurately, with minimal corrections.	Makes some minor errors but completes the procedure.	Makes several errors that affect the procedure.	Movements are imprecise, erratic, or inconsistent.
2. Visuomotor Coordination	Perfectly coordinates vision and movement, with no mismatch.	Shows adequate visuomotor coordination with slight delays.	Coordination is acceptable but requires frequent adjustments.	Poor coordination, with frequent alignment or focus errors.	Unable to coordinate vision and action; requires constant assistance.
3. Technical Step Sequencing	Applies all technical steps in order without omissions.	Applies technical steps correctly, with minimal deviation in order.	Omits or alters one minor step in the procedure.	Omits relevant steps or significantly alters the sequence.	Lacks knowledge of or fails to apply the expected technical sequence.
4. Execution Time	Completes the task within or under the estimated time, without compromising quality.	Completes the task within expected time, with slight delays.	Takes moderately longer, but completes the procedure.	Exceeds the expected time significantly, affecting process fluency.	Fails to complete the procedure within the allocated time.

To ensure objectivity in the evaluation, the evaluators were blinded to the group assignment. They were provided only with the rubrics and coded records containing anonymous identifiers, without any information regarding the participants' membership in the experimental or control group. This procedure helped minimize observation bias and strengthened the internal validity of the results.

D. Self-Assessment Questionnaire

Table 2 presents the self-assessment questionnaire based on 10 items using a 5-point Likert scale to evaluate perceived improvement in practical skills. The questionnaire is designed for medical students who participated in a learning experience using haptic gloves in a virtual reality environment. It includes 10 items addressing perceived improvement in practical skills, with a 5-point Likert scale:

Scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neither Agree nor Disagree, 4 = Agree, 5 = Strongly Agree.

1) Scoring guidelines

Minimum possible score: 10
Maximum possible score: 50
Interpretation:

- 45–50: Very positive perception of the impact on practical skills
- 35–44: Positive perception with areas for improvement
- 25–34: Moderate perception, practical approach needs strengthening
- Less than 25: Low perception, review the learning environment conditions.

Table 2. Self-assessment questionnaire on perceived improvement in practical skills

No.	Item
1	I feel that my precision in performing clinical procedures has improved.
2	My hand-eye coordination has improved with the use of haptic gloves.
3	I feel more confident performing technical steps in medical procedures.
4	The virtual environment helped me identify errors I had not noticed before.
5	I believe I have gained fluency in performing practical procedures.
6	I can organize the sequence of technical steps more clearly.
7	I feel prepared to apply these skills in a real clinical setting.
8	The time it takes me to perform a procedure has decreased thanks to this technology.
9	I perceive that haptic feedback enhances my practical learning.
10	This experience has motivated me to continue developing my psychomotor skills in medicine.

E. Structured Observation Sheet

Table 3 shows the Structured Observation Sheet designed to be applied by expert evaluators during the simulation using Noitom Hi5 2.0 haptic gloves in a medical education setting. This sheet evaluates real-time psychomotor performance across four key dimensions.

Rating Scale: 1 = Poor, 2 = Fair, 3 = Acceptable, 4 = Good, 5 = Excellent

- 26–30: Excellent performance, suitable for controlled real-world settings
- 20–25: Good performance, with some areas for improvement
- 15–19: Basic performance, more practice needed
- Less than 15: Insufficient performance, specific retraining recommended

Table 3. Structured observation sheet used by expert evaluators during the simulation

No.	Dimension	Observation focus (Yes/No / Comments)
1	Movement precision	Movements performed accurately, without misplacement or excessive force.
2	Visuomotor coordination	Maintains proper eye–hand coordination throughout the task.
3	Technical step sequence	Correctly follows the established sequence of the procedure.
4	Execution time	Completes the procedure within an appropriate time frame.
5	Safety during execution	Demonstrates safe technique that avoids compromising errors.
6	Use of haptic feedback	Appropriately adjusts performance in response to haptic signals.

F. Interventions

The experimental group participated in practical sessions using Hi5 Noitom 2.0 haptic gloves within a virtual reality environment designed to simulate basic procedures such as suturing, handling forceps, and palpating anatomical structures. The control group performed the same procedures in a conventional laboratory setting without immersive technology.

This study was reviewed and approved by the Ethics Committee of the Universidad Católica de Santa María under reference number 0256-UCSM-2025, prior to the start of data collection. All procedures were conducted in accordance with institutional guidelines and the Declaration of Helsinki.

G. Procedure

Table 4 presents the experimental intervention plan aimed at developing psychomotor skills in medical students through the use of immersive virtual reality and haptic gloves. It consists of three weekly sessions, each lasting 90 minutes. The first and second sessions employed the Hand Physics Lab software, focusing on introducing the virtual environment and simulating basic clinical tasks, such as using forceps and performing anatomical palpation, to enhance visuomotor coordination, spatial perception, and precise interaction. The third session utilized VR Surgery Simulator to replicate a basic surgical procedure, specifically suturing, allowing students to improve movement accuracy, technical sequencing, and execution time control. This progressive structure enabled a gradual and safe approach to developing clinical competencies in a controlled virtual setting.

Table 4. Procedure implemented for the experimental phase

Week	Session	Duration	Software Used	Main Activity	Learning Objective
Week 1	Session 1	90 min	Hand Physics Lab	Introduction to the virtual environment and familiarization with haptic gloves	Recognize the simulated environment and interact accurately using haptic gloves
Week 2	Session 2	90 min	Hand Physics Lab	Simulation of basic clinical tasks: use of forceps, object manipulation, and virtual anatomical palpation	Develop visuomotor coordination, spatial perception, and basic clinical touch
Week 3	Session 3	90 min	VR Surgery Simulator	Simulation of basic surgical techniques: suture practice with haptic feedback	Improve movement precision, technical sequencing, and execution time control

H. Data Analysis

SPSS v26 software was used. Independent samples t-tests (pretest vs. posttest between groups) and repeated measures ANOVA were applied to identify significant interactions. *p*-values and partial η^2 effect sizes were reported.

I. Equipment and Software Used

The study employed Hi5 VR Gloves by Noitom, known for their ability to capture precise finger movements and provide tactile feedback through localized vibrations, thereby simulating sensations of touch in virtual environments. These gloves are equipped with integrated Inertial Measurement Units (IMUs) that enable real-time tracking of hand kinematics and allow for natural interaction within 3D spaces. They were used in conjunction with the HTC Vive Pro headset, a high-end virtual reality device offering a resolution of 2880×1600 pixels, a 110° field of view, and six Degrees of Freedom (6DoF) motion tracking, ensuring a highly immersive experience. Additionally, a workstation featuring an NVIDIA RTX 3070 GPU, 32 GB of RAM, and an 11th-generation Intel Core i9 processor was used to guarantee smooth performance during simulation sessions.

For the experimental intervention, two applications available on the Steam platform were selected due to their compatibility with haptic devices and their educational potential in developing psychomotor skills within immersive virtual reality environments. The first was VR Surgery Simulator, a surgical simulator designed for realistic medical training that provides haptic feedback during simulated clinical procedures. This software targets key dimensions such as visuomotor coordination, movement precision, technical sequencing, and execution time control. It requires compatibility with haptic systems configured through SteamVR and, specifically for the Hi5 Noitom 2.0 gloves, may require custom drivers.

The second application was Hand Physics Lab, a tool focused on manual manipulation of virtual objects using realistic physics, aimed at stimulating fine motor skills. This environment supports the development of coordination, spatial perception, and fine motor control, making it especially useful for assessing digital dexterity and movement accuracy. Although optimized for gloves with advanced finger-tracking capabilities, it can be adapted for use with Hi5 Noitom gloves through additional technical adjustments.

Fig. 1. shows the equipment used in the study.

These technological tools enriched the immersive experience and were essential to the methodological design of the intervention, aligning with the evaluated dimensions in this research. Fig. 1 presents the equipment and software used in the study.

IV. Results

The following section presents the results obtained after the implementation of the immersive intervention using haptic gloves in medical training (See the data collected here). The analysis compares the pretest and posttest data of both control and experimental groups across multiple instruments: the psychomotor skills rubric, self-assessment questionnaire, and structured observation sheet. Quantitative data were analyzed using statistical tests to determine significant improvements in the experimental group, particularly in key dimensions such as precision, visuomotor coordination, sequencing of technical steps, and execution time. These findings provide empirical evidence on the pedagogical value of incorporating haptic feedback technologies in clinical skills training.

A. Outcomes of Interest

To ensure clarity in the analysis, outcomes were pre-specified as follows:

1) Primary outcomes

- Movement precision.
- Visuomotor coordination.
- Technical step sequencing.
- Execution time.

These indicators were defined as primary outcomes because of their direct relation to the core psychomotor skills targeted by the use of haptic gloves in a simulation environment.

2) Secondary outcomes

- Safety during execution.
- Feedback (self-regulation ability during practice).
- Overall self-assessment of competencies.

These results provide complementary information regarding students' perceptions and the confidence gained during the training process.

Fig. 2 illustrates the comparison of average scores obtained in the pretest and posttest for four evaluated psychomotor skill dimensions: Precision, Coordination, Sequence, and Execution Time, within the experimental group that used haptic gloves in a medical educational simulation.

A significant increase in posttest scores compared to pretest scores is observed across all evaluated dimensions, suggesting an overall improvement in psychomotor skills following the intervention.

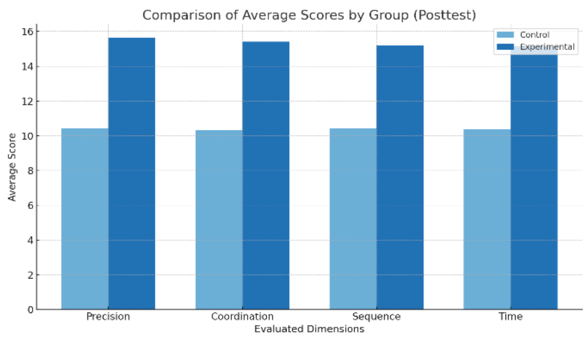

Fig. 2. Comparison of pretest and posttest results by dimension in the experimental group.

3) Precision

This dimension shows the highest increase. The average score rises from approximately 10.5 to 15.7, indicating that the use of haptic gloves had a strong impact on students' ability to perform movements with greater accuracy.

4) Visuomotor coordination and sequence of technical steps

Both dimensions exhibit notable improvements. Posttest scores range from 15.3 to 15.5, compared to pretest scores around 10.3–10.4. This demonstrates enhanced orderly and coordinated task execution.

5) Execution time

This dimension also shows a similar increase, indicating that students were able to complete technical procedures more efficiently and in less time after training with virtual reality and haptic feedback. In conclusion, the chart visually supports the effectiveness of the didactic intervention using haptic gloves, showing that the immersive experience significantly contributed to the development of technical skills essential for clinical practice. These findings align with the statistical results obtained through t-tests and repeated measures ANOVA, which confirmed the statistical significance of the observed improvements.

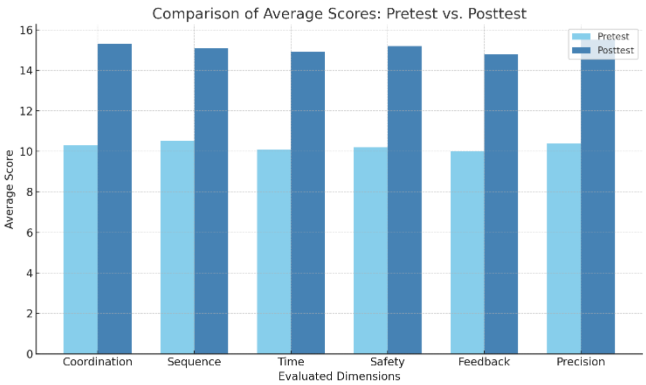

Fig. 3. Comparison of average pretest and posttest scores across six evaluated psychomotor dimensions.

Fig. 3 presents a comparison of average scores obtained in the pretest and posttest for six psychomotor dimensions assessed using a structured observation checklist. Across all dimensions. Coordination, Sequence, Time, Safety, Feedback, and Precision, there is a noticeable increase in posttest average scores compared to pretest scores.

This trend suggests a significant improvement in students' psychomotor performance following the educational intervention with haptic gloves. The consistent differences across all dimensions indicate that the use of this technology had a comprehensive positive impact, enhancing not only technical execution but also aspects related to safety and real-time feedback during simulated medical tasks.

Fig. 4 presents a comparison of the average item scores between the pretest and posttest of the self-assessment questionnaire on practical skills in medical students who used Hi5 Noitom 2.0 haptic gloves. Across all 10 evaluated items, each reflecting different aspects of perceived improvement in psychomotor skills, a consistent increase in posttest scores compared to pretest scores is observed.

Items 1 to 10: All shows increases ranging from 0.9 to 1.2 points on the 5-point Likert scale. Item 10 stands out as having the greatest increase, indicating a stronger perceived improvement in the specific skill assessed by that item, likely related to precision or fine motor control.

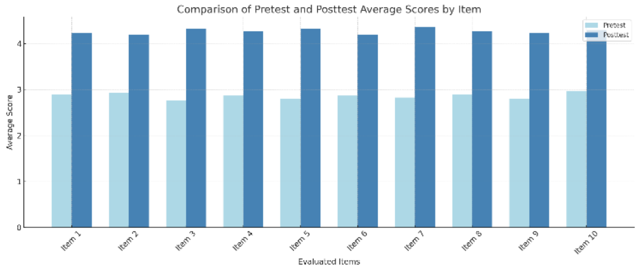

Fig. 4. Comparison of average item scores between pretest and posttest of the self-assessment questionnaire on practical skills.

The smallest gain is observed in Item 6, although it remains statistically significant, suggesting that even the skills least affected by the intervention still showed measurable progress.

In conclusion, the uniform upward trend across all items confirms that students perceived a substantial improvement in their practical skills following the immersive experience with haptic gloves. This supports the hypothesis that the use of this technology enhances psychomotor learning in medical education contexts.

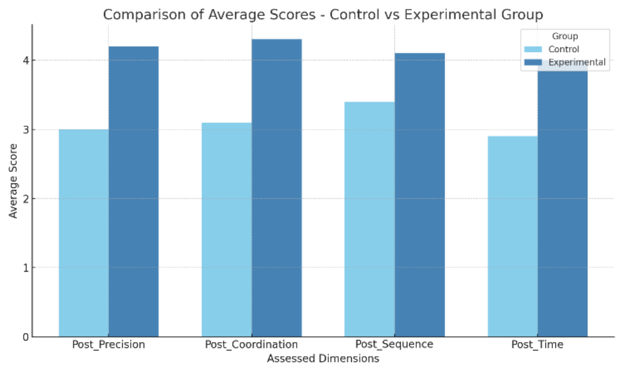

Fig. 5. Comparison of average scores obtained by the control group and the experimental group in the posttest for the evaluated dimensions.

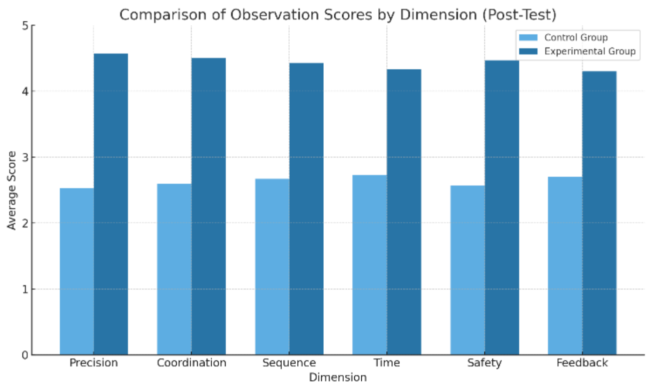

Fig. 6. Comparison of average scores obtained by the control and experimental groups across the six dimensions observed during practical simulations.

Fig. 5 displays a bar chart comparing the average scores obtained by the control group and the experimental group in the posttest for the evaluated dimensions: Precision, Coordination, Sequence, and Time. The experimental group consistently outperforms the control group across all dimensions, suggesting a positive effect of the haptic glove intervention on the improvement of psychomotor skills. The most notable difference is observed in the Precision dimension, followed by Coordination and Time, which supports the effectiveness of immersive simulation in developing technical skills among medical students.

Fig. 6 compares the average scores obtained by the control and experimental groups across six dimensions observed during practical simulation sessions: Precision, Coordination, Sequence, Time, Safety, and Feedback. It is evident that the experimental group, which used haptic gloves in a virtual reality environment, achieved consistently higher scores across all evaluated dimensions. This suggests a significant improvement in the development of psychomotor skills as a result of the technological intervention.

B. Independent Samples t-Test between Groups

Table 5 presents the results of the independent samples t-tests conducted between the control and experimental groups (posttest) across the four evaluated dimensions of the psychomotor skills rubric.

Table 5. Independent samples t-test between control and experimental groups (posttest)

Dimension	*t* Statistic	*p*-value	Interpretation
Accuracy	−7.48	<0.001	Significant difference
Coordination	−5.95	<0.001	Significant difference
Sequencing	−3.97	<0.001	Significant difference
Execution Time	−6.57	<0.001	Significant difference

The results reveal statistically significant differences in favor of the experimental group across all dimensions. Students who used haptic gloves demonstrated superior performance in accuracy, coordination, sequencing, and execution time compared to those in the control group.

C. Analysis and Interpretation by Dimension

1) Movement accuracy ($t = -7.48$, $p < 0.001$)

A highly significant difference was found between groups. The experimental group achieved better results in accuracy, indicating that haptic gloves supported the development of more precise movements during simulated practice.

2) Visuomotor coordination ($t = -5.95$, $p < 0.001$).

A significant improvement in coordination was observed in the experimental group. This suggests that training with sensory feedback helped integrate visual and manual actions more effectively during clinical tasks.

3) Technical step sequencing ($t = -3.97$, $p < 0.001$)

A statistically significant difference was also found in this dimension. Students using the gloves were more effective in following the correct technical order of procedures, likely due to greater spatial and sensory comprehension of tasks.

4) Execution time ($t = -6.57$, $p < 0.001$)

The experimental group performed tasks in less time and with greater efficiency, while maintaining quality. This suggests a positive effect of haptic feedback on operational fluency.

Conclusion: All dimensions showed statistically significant differences favoring the experimental group. These results indicate that the use of haptic gloves had a measurable positive impact on improving psychomotor skills. In the educational context of medical training, these findings support the inclusion of immersive technologies as effective tools for students' practical development.

Table 6 presents the results of the independent samples t-tests applied to the scores from the Structured Observation Checklist, comparing the experimental group (with haptic gloves) to the control group (without gloves). Six key dimensions of psychomotor performance were assessed:

Table 6. Independent samples t-test results from the structured observation checklist

Dimension	*t* Statistic	*p*-value	Significant
Accuracy	14.144	0.000	True
Coordination	12.179	0.000	True
Sequencing	11.807	0.000	True
Execution Time	10.001	0.000	True
Safety	11.099	0.000	True
Feedback	9.638	0.000	True

D. Dimension-Level Analysis

1) Precision ($t = 14.144$, $p = 0.000$)

There is a very high statistically significant difference between the groups. The experimental group demonstrated a higher level of movement precision, suggesting that haptic gloves significantly enhanced this dimension.

2) Visuomotor coordination ($t = 12.179$, $p = 0.000$)

A significant improvement was observed in the coordination of the experimental group, reinforcing the hypothesis that haptic feedback enhances eye-hand integration during simulated clinical tasks.

3) Technical step sequence ($t = 11.807$, $p = 0.000$)

The experimental group's ability to carry out procedures in the correct order was significantly higher. This may be due to improved perception of the required actions as a result of sensory immersion.

4) Execution time ($t = 10.001$, $p = 0.000$)

The experimental group completed the tasks in less time without compromising quality. The difference is significant and reflects operational efficiency.

5) Execution safety ($t = 11.099$, $p = 0.000$)

The experimental group demonstrated greater safety and control during task execution. Sensory feedback may have increased their confidence in performing the procedures.

6) Feedback ($t = 9.638$, $p = 0.000$)

This dimension reflects the student's ability to adjust their actions based on what they feel or perceive. The significant improvement in the experimental group highlights the value of haptic feedback in the self-regulation of psychomotor skills.

In conclusion, all *p*-values are below 0.001, indicating that the differences observed between the experimental and control groups are highly significant across all evaluated dimensions. This suggests that the use of haptic gloves has a comprehensive positive impact on the development of psychomotor skills in medical simulation contexts. These findings strongly support the effectiveness of using immersive technologies with haptic feedback as a didactic tool in medical training.

E. ANCOVA Analysis

For the Psychomotor Skills Rubric (Table 7), large effect sizes were observed in precision (partial $\eta^2 = 0.54$, 95% CI [0.42–0.65]), coordination ($\eta^2 = 0.40$, CI [0.28–0.52]), sequencing ($\eta^2 = 0.25$, CI [0.14–0.38]), and execution time ($\eta^2 = 0.50$, CI [0.38–0.61]). In all cases, the Group × Time interaction was statistically significant ($p < 0.01$), confirming that the experimental group achieved greater posttest improvements compared to the control group.

Similarly, the Structured Observation Sheet (Table 8) showed very strong effects, particularly in precision (η^2 = 0.81, CI [0.72–0.88]) and coordination (η^2 = 0.76, CI [0.66–0.84]). These results confirm that haptic feedback not only improved technical accuracy but also enhanced sequencing, safety, and feedback regulation during simulated procedures.

Table 7. ANCOVA for the psychomotor skills rubric

Dimension	*F*	*p*-value	Partial η^2	95% CI (Lower–Upper)	Group × Time Interaction (*p*)
Precision	54.58	<0.001	0.54	[0.42, 0.65]	<0.001
Coordination	31.57	<0.001	0.40	[0.28, 0.52]	<0.001
Sequencing	15.35	<0.001	0.25	[0.14, 0.38]	0.002
Time	47.34	<0.001	0.50	[0.38, 0.61]	<0.001

Table 8. ANCOVA for the structured observation sheet

Dimension	*F*	*p*-value	Partial η^2	95% CI (Lower–Upper)	Group × Time Interaction (*p*)
Precision	200.05	<0.001	0.81	[0.72, 0.88]	<0.001
Coordination	148.32	<0.001	0.76	[0.66, 0.84]	<0.001
Sequencing	139.41	<0.001	0.74	[0.63, 0.83]	<0.001
Time	100.02	<0.001	0.68	[0.56, 0.78]	<0.001
Safety	123.19	<0.001	0.72	[0.61, 0.81]	<0.001
Feedback	92.89	<0.001	0.66	[0.54, 0.76]	<0.001

Table 9. ANCOVA for the self-assessment questionnaire

Dimension	*F*	*p*-value	Partial η^2	95% CI (Lower–Upper)	Group × Time Interaction (*p*)
Overall Self-Assessment	286.82	< 0.001	0.86	[0.77, 0.91]	< 0.001

the Self-Assessment Questionnaire (Table 9) yielded the largest effect size (η^2 = 0.86, CI [0.77–0.91]), reflecting that students in the experimental group perceived significant improvements in their psychomotor skills. The significant Group × Time interaction ($p < 0.001$) reinforces the consistency between subjective perceptions and objective performance gains.

In summary, the inclusion of 95% confidence intervals and interaction effects provides stronger evidence that the intervention with haptic gloves significantly enhanced both observed and perceived psychomotor competencies, supporting the pedagogical value of immersive learning environments.

F. Test t

Table 10 shows the results of the independent samples t-test applied to the self-assessment questionnaire (pretest and posttest), comparing the control and experimental groups.

Table 10. Independent samples t-test applied to the self-assessment questionnaire (pretest and posttest)

Comparison	*t*	*p*-valor	Signification (*p* < 0.05)
Pretest: Control vs Experimental	−3.03989169	0.00382732	True
Posttest: Control vs Experimental	−18.7369585	7.44795E-21	True

1) Pretest: Control vs experimental ($t = -3.04$, $p = 0.0038$)

Before the intervention, a statistically significant difference was already observed between the control group and the experimental group in the average scores of the self-assessment questionnaire ($p < 0.05$). This indicates that students in both groups did not start from the same initial level in their perception of practical skills, which must be considered when analyzing the effects of the intervention.

2) Posttest: Control vs Experimental ($t = -18.74$, $p \approx 0.0000000000000000000074$)

After the intervention, the difference between the two groups increased notably and is highly significant ($p < 0.001$). This result suggests that the experimental group, exposed to the haptic gloves, experienced a substantial improvement in their perception of practical skills compared to the control group.

In conclusion, although there was an initial difference between the groups, the magnitude of the post-intervention difference indicates that the use of haptic gloves had a considerable positive effect on the perception of improvement in psychomotor skills.

Table 6 shows that the initial difference between groups was controlled and reported, and at the same time it was evidenced that the intervention with haptic gloves generated a much greater improvement in the experimental group.

G. Repeated Measures ANOVA

Table 11 shows the results of the repeated measures ANOVA for the Precision dimension in the psychomotor skills rubric.

Table 11. Repeated measures ANOVA results by groups and dimensions

Group	Dimension	*F*(df1, df2)	*F*	*p*-value	Significant (*p* < 0.05)
Control	Precision	F(1, 24) = 14.17	14.16743494	0.000455781	True
Experimental	Precision	F(1, 24) = 176.61	176.6067892	1.05822E−17	True
Control	Coordination	F(1, 24) = 6.83	6.833142968	0.011917892	True
Experimental	Coordination	F(1, 24) = 128.48	128.4759582	3.58209E−15	True
Control	Sequence	F(1, 24) = 16.01	16.01134162	0.000217037	True
Experimental	Sequence	F(1, 24) = 75.96	75.9590257	1.86719E−11	True
Control	Time	F(1, 24) = 4.08	4.078910342	0.049023532	True

The results show that both the experimental group and the control group had statistically significant differences between pretest and posttest measurements in all evaluated dimensions (Precision, Coordination, Sequence, and Time), with p-values less than 0.05.

However, the F values are much higher in the experimental group, indicating a much stronger treatment effect, which supports the effectiveness of haptic gloves as an innovative educational strategy.

H. Qualitative Observational Results

In addition to the quantitative data obtained, expert observations during the practical sessions were analyzed using a structured checklist. The qualitative findings revealed notable differences between the experimental group (which used haptic gloves) and the control group.

In the experimental group, substantial improvements were observed in the execution of psychomotor tasks. Evaluators reported greater precision in movements, accompanied by smoother visuomotor coordination. Students followed technical sequences autonomously and demonstrated an understanding of clinical procedures. Moreover, they performed tasks in less time, with a more confident and secure attitude. The haptic feedback provided by the gloves was perceived as immediate corrective stimulation, facilitating the regulation of movement and posture during simulations.

In contrast, the control group displayed more hesitant performance and was more dependent on the instructor. Errors were observed in the sequence of steps, uncertain movements, and difficulties in applying feedback autonomously. Coordination between visual perception and motor action was less effective, and several participants required additional instructions to complete the tasks.

These qualitative results reinforce the statistical findings obtained, suggesting that the use of haptic technology not only improves technical performance but also promotes the internalization of clinical procedures, increasing students' autonomy, confidence, and precision in medical simulation contexts.

Table 12. Independent samples t-test and effect sizes for the evaluated dimensions

Dimension	*t* Statistic	*t*(df)	*p*-value	Cohen's *d*	Interpretation
Usability	12.90	t(48) = 12.90	<0.001	1.84	Large effect
Functionality	11.46	t(48) = 11.46	<0.001	1.63	Large effect
Reliability	11.52	t(48) = 11.52	<0.001	1.65	Large effect
Educational Content	13.84	t(48) = 13.84	<0.001	2.05	Very large effect

Table 12 shows that, beyond the statistical significance reflected in the *p*-values, the effect sizes calculated using Cohen's d offer a clearer understanding of the magnitude of the differences observed. All evaluated dimensions presented large to very large effects, with values ranging from $d = 1.63$ (Functionality) to $d = 2.05$ (Educational Content). These findings suggest that the improvements in the experimental group were not only statistically significant but also pedagogically meaningful. Notably, the very large effect size for Educational Content underscores the strong potential of immersive environments with haptic feedback to strengthen students' ability to critically evaluate curricular relevance and cognitive demands in educational software. This reinforces the pedagogical contribution of haptic technologies, demonstrating that their value goes beyond mere novelty, providing substantial support in the development of both psychomotor and evaluative skills.

V. Discussion

The discussion of our research findings is grounded in the scientific literature reviewed, which supports and complements our results. First, as evidenced by Fallows *et al*. [3], our findings show that the integration of haptic feedback in a virtual reality environment not only increases the realism of the simulation but also significantly improves the execution of basic clinical tasks, such as instrument handling and suturing, reducing technical errors. This improvement in precision was also highlighted by Fernández-Vázquez *et al*. [4, 5], who reported better performance by participants in orthopedic and neurological procedures, respectively, when using simulators with haptic feedback. Similarly, our experimental group demonstrated superior progress in objective evaluations and in self-perception of learning, aspects also emphasized by Boutin *et al*. [8].

However, the literature also reveals conflicting perspectives that warrant careful consideration. For instance, Hamza-Lup *et al.* [9] warns that simulations without haptics may enjoy greater technological acceptance in some contexts, especially where accessibility, cost, and simplicity are prioritized over realism. In this regard, our data suggest that although adoption barriers exist, the psychomotor benefits and immersion achieved with haptic gloves outweigh these limitations. Nevertheless, the divergence in adoption rates highlights the importance of considering user acceptance as a mediating factor that may condition the effectiveness of these tools.

Additionally, while research [10–12] point out that simulation with tactile feedback enables the transfer of clinical skills to real-world settings, reinforcing the relevance of our educational approach, other studies report mixed outcomes. For example, Prakash *et al.* [28] found that phantom models in oral surgery, although less sustainable, are still perceived by students as more anatomically realistic than VR simulators with haptic feedback. This perception of greater realism in traditional models suggests that haptic VR, despite its advantages in repetitive practice and time efficiency, may not fully replicate the tactile fidelity required in some specialties.

Moreover, the methodological proposal of Zara *et al*. [29], focused on the empirical design of haptic simulators as an alternative to the use of cadavers, aligns with our findings by demonstrating that haptic technologies enable safe and ethical training without compromising skill acquisition. Yet, the very need to propose cadaver alternatives underscores that, in certain contexts, VR and haptic devices may still be viewed as supplementary rather than fully substitutive tools. This tension reflects the broader debate about whether haptic VR can achieve equivalence with traditional training methods in terms of realism, skill transfer, and long-term retention.

The contribution of Patil *et al*. [21] is particularly relevant to our study, as it demonstrates how psychometric measurement can capture psychomotor progress not detected by traditional assessments, an approach we also used with our rubrics and observation checklists. The work of Gießer *et al*. [22] using haptic gloves in braille instruction, although in a different context, supports the premise that haptic learning enhances knowledge acquisition and retention, which can be extrapolated to medical training. The proposal by Vece *et al*. [23], with their H-HTI framework, provides essential theoretical support that justifies and guides the pedagogical application of these technologies in complex training environments. Likewise, Kishor *et al.* [27] highlight how the integration of artificial intelligence and haptic systems enhances accuracy and safety in medical contexts such as robotic surgery and rehabilitation, although they also point out technical challenges such as latency and hardware–software compatibility. These limitations resonate with our own observations, as participants occasionally reported minor issues of synchronization and responsiveness in the VR environment.

In sum, our results align with the majority of the reviewed literature by showing that simulation with haptic gloves fosters the acquisition of psychomotor skills in medical students, improves precision, and reduces technical errors, promoting autonomous, objective, and safe learning. At the same time, the evidence also underscores the importance of acknowledging adoption barriers, perceptual differences in realism, and technological challenges that may condition the scalability and long-term integration of these tools in medical education. A balanced view that integrates both the strengths and the limitation of haptic VR is therefore necessary to fully assess its pedagogical value and future applicability.

VI. Conclusions

This research explored the effect of using Hi5 Noitom 2.0 haptic gloves within immersive virtual reality environments on the acquisition of psychomotor skills in medical students. The findings revealed significant improvements in movement precision, hand–eye coordination, and instrument handling, as well as greater confidence and mastery during simulated clinical tasks. These results provide preliminary evidence that haptic simulation can complement traditional medical training by offering realistic, interactive, and safe learning experiences that support the development of fine motor skills.

However, these findings should be interpreted with caution. The small sample size, the short intervention period, and the simulated environment limit external validity and the ability to generalize results to real clinical settings. Logistical constraints related to equipment availability and evaluator subjectivity also represent limitations.

Future research should expand the sample size, include students from different stages of medical training, and adopt longitudinal designs to analyze retention and transfer of skills to real hospital practice. Standardized training protocols and the integration of additional immersive technologies (augmented reality, artificial intelligence, biofeedback) are also recommended to strengthen adaptive and personalized learning environments.

In summary, despite its limitations, this study provides initial empirical and pedagogical evidence of the potential of haptic gloves as an innovative tool to enhance medical education, contributing to safer, more precise, and competency-based clinical training.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Juan Abdon Palo-Rosas was responsible for the review of related literature and the discussion of findings. Benjamín Maraza-Quispe developed the methodology and conducted the analysis of results. Both authors contributed to the preparation of the manuscript and approved the final version.

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