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Influence of practical and clinical experience on dexterity performance measured using haptic virtual reality simulator

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Abstract

Introduction: Development of dexterity, hand-eye coordination and self-assessment are essential during the preclinical training of dental students. To meet this requirement, dental simulators have been developed combining virtual reality with a force feedback haptic interface. The aim of this study was to assess the capability of the VirTeaSy© haptic simulator to discriminate between users with different levels of practical and clinical experience.

Materials and Methods: Fifty-six volunteers divided into five groups (non-dentists, 1st/3rd/final-year dental students, recent graduates) had three attempts to prepare an occlusal amalgam cavity using the simulator. Percentages of volumes prepared inside (%IV) and outside (%OV) the required cavity, skill index and progression rate, referring to the evolution of skill index between trials 1 and 3, were assessed. The dental students and recent graduates completed a questionnaire to gather their opinions about their first hands-on experience with a haptic simulator.

Results: The results showed no significant difference between the groups at the first attempt. Following the third attempt, the skill index was improved significantly. Analysis of progression rates, characterised by large standard deviations, did not reveal significant differences between groups. The third attempt showed significant differences in skill index and %IV between 1st-year undergraduate dental students and both non-dentists and recent dental graduates. The questionnaire indicated a tendency for dental operators to consider the simulator as a complement to their learning and not a substitute for traditional methods.

Conclusion: This study did not show the ability of a basic aptitude test on VirTeaSy© haptic simulator to discriminate between users of different levels of expertise. Optimisations must be considered in order to make simulation-based assessment clinically relevant.

KEYWORDS
dental education, haptic simulation, preclinical skills, restorative dentistry, virtual reality

1 | INTRODUCTION

Current medical education is based on a combination of assimilation of knowledge and acquisition of skills,[1] commonly involving the SODOTO (See One, Do One, Teach One) model.[2] Successive steps of observing a gesture or technique and then practical realisation in real conditions are a widely accepted sequence for learning in medical training. Once the techniques have been observed, students must replicate them under supervision to ensure that there is no risk to patients.[3] Clinical training in dentistry is based on constant and regular practice to acquire and strengthen these motor skills.[4] At the beginning of their clinical practice, students must treat their first patients even though they have not yet fully acquired all of their clinical skills. Clinical practice has to be taught on real patients to enable future oral healthcare professionals to develop their skills. Current clinical teaching therefore consists of mentoring students interacting with patients. Although this approach must ensure the well-being and safety of patients, it may result in discomfort, a risk of complications and prolonged treatment for patients. The benefit/risk ratio represents a fundamental ethical tension in health education. To overcome this issue, simulation-based learning has emerged as a relevant tool to develop the knowledge, behaviour and skills of healthcare professionals, whilst protecting patients from risk.[3]

In the 1990s, the creation of haptic arms (or force feedback arms) heralded the era of virtual reality simulation. Simulators were developed in various medical fields, such as cardiology, intensive care and surgery.[5] Many companies produced sophisticated high-fidelity mannequins with options to meet the expectations of students and healthcare professionals. Several studies have shown this technology to be useful, proving that the motor skills acquired on a virtual reality simulator can be transferred to a real-world setting.[6]

In dentistry, physical simulators have long been the benchmark in preclinical training to develop manual dexterity. Based on technologies developed in the aeronautical industry and in surgical medicine, prototypes of dental haptic simulators were developed in the early 2000s.[6] Virtual simulation is increasingly used in dental schools around the world as it promotes student autonomy, improves preclinical practice thanks to improved realism and provides objective assessment of students.[1,4] It has appeared in different areas, such as restorative dentistry, periodontology,[7] endodontics,[8] implantology[9] and maxillofacial surgery.[10] Moreover, working on a virtual simulator avoids the ethical and health problems associated with the use of samples (extracted teeth, cadavers, etc.) that require the prior consent of the donor.

Amongst the haptic simulators available on the market, three are mainly used in dentistry: Simodont® (2009, Netherlands), PerioSim© (2009, USA) and VirTeaSy Dental© (2011, France).[6,11] They allow students to apply theoretical concepts to preclinical practice through simulated clinical experience. Despite their many advantages, these innovative tools do not allow complete clinical training, as they do not offer the possibility of performing all the operating phases of treatment (eg dam placement, restoration placement, etc.) and clinical reflection and reasoning is not entirely solicited with this technology. Studies evaluating medical simulation training have demonstrated that, although 90% of emergency medicine residency programs use simulation technology, there is no definitive evidence to determine whether simulation has a real impact on behaviour, performance or clinical skills.[12–16]

As many dental disciplines, restorative dentistry requires high manual dexterity, tactile sensitivity and hand-eye coordination. Haptic simulators are said to be the educational tool of the future for this teaching because of their clinical realism. If these new tools accurately simulate clinical reality, it would seem logical that the initial performance of users on the simulators should depend on their level of experience. We therefore hypothesised that users with prior practical or clinical experience in dentistry should achieve better outcomes in terms of dexterity performance on the proposed simulated exercises than users who were novices or without any experience in dental practice.

The aim of this work was to assess the capability of the VirTeaSy© haptic dental simulator to discriminate between users with different levels of prior experience, using a clinical simulation exercise based on the preparation of an occlusal amalgam cavity. The secondary objective was to investigate the progression of performance after repetitions of the exercise.

2 | MATERIALS AND METHODS

In accordance with the University Hospital of Bordeaux (France) procedures, this research was submitted to the Ethics Committee of the University Hospital of Bordeaux (France). The submission to publication of this work was approved. The study was conducted at the University School of Dentistry of Bordeaux (Bordeaux University, France) in 2020.

2.1 | Hardware and interfaces

The VirTeaSy© haptic dental simulator (VirTeaSy, HRV Simulation, Changé, France) consists of a computer connected to two screens, a touch screen control system allowing access to the interface and a screen to view three-dimensional images, a plastic contra-angled handpiece connected to force feedback arm device (Geomagic Touch X Haptic Device Morrisville, Geomagic Inc., Morrisville, NC, USA) to transmit the tactile sensations, 3D glasses, a 3D mouse and a foot pedal to control the handpiece (Figure 1). The tactile sensations pre-selected in the software were maintained. The density values were 3.00 g/cm^3 for enamel, 2.22 g/cm^3 for dentin and 0.78 g/cm^3 for carious tissue.

The software interface (VirTeaSy Dental V.0) was accessible on the control touch screen. A navigation module was used to manage user accounts, present and access exercises and configure the computer environment. Virtual teeth were designed to be integrated into the software (Dihaptic, Laval, France).

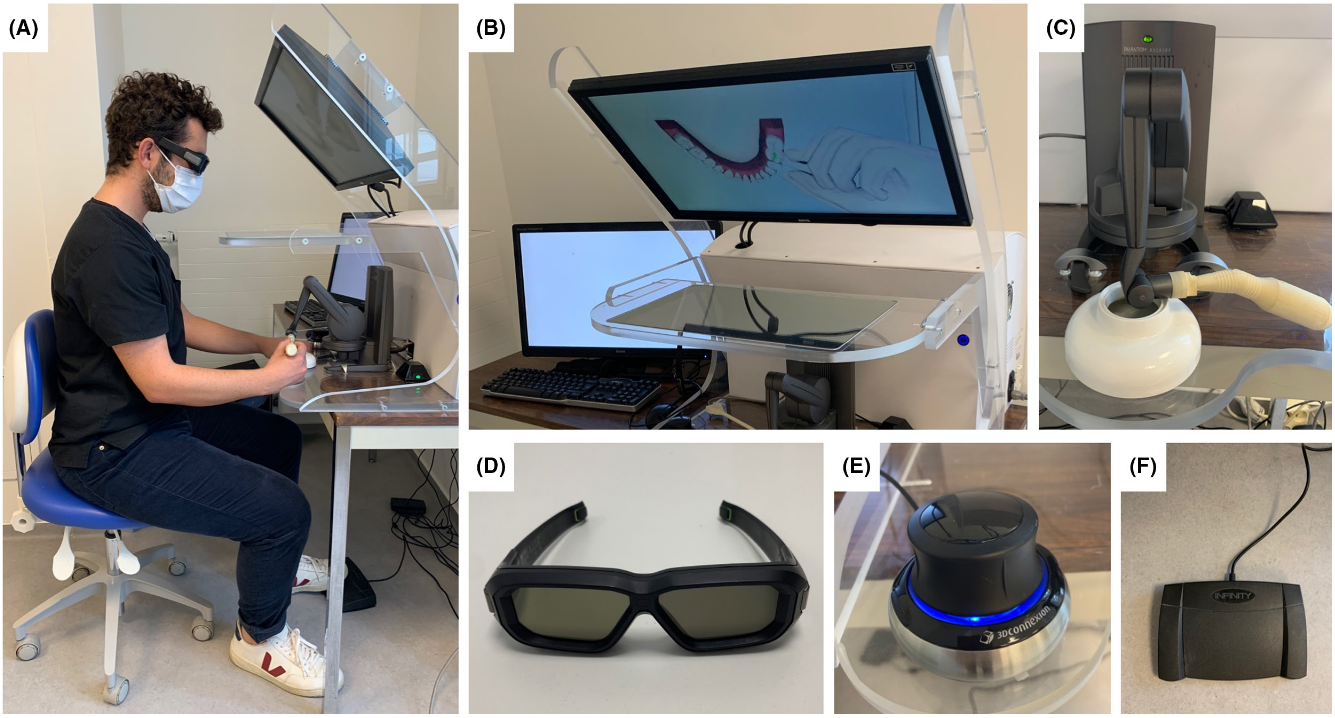

FIGURE 1 VirTeaSy© haptic dental simulator and its components. (A) Student working at the device, (B) computer connected to two screens (touch screen control system and high-resolution 3D display), (C) plastic handpiece connected to force feedback arm device, (D) 3D glasses, (E) 3D Mouse, (F) foot pedal to control handpiece

The exercise was divided into three steps: i/exercise presentation (pedagogical objectives, instructions, precautions to be taken and evaluation criteria), ii/simulation (exercise execution in the virtual environment) and iii/evaluation (objective assessment of the work).

2.2 | Participants

For this study, fifty-six participants were selected on a voluntary basis. To participate, volunteers had to be between 18 and 35 years old and had to have never used a dental haptic simulator. Five groups were formed: (1) participants with no theoretical knowledge or practical/clinical experience in restorative dentistry, called "non-dentists" (N = 12); (2) participants with theoretical knowledge and a beginner level of practice (one semester of practical work in restorative dentistry on Ivorine® teeth), called "1st-year undergraduate dental students" (Bordeaux University, France) (N = 10); (3) participants with theoretical knowledge and an intermediate level of practice (four semesters of practical work in restorative dentistry on Ivorine® and extracted teeth; one semester of clinical practice), called "3rd-year undergraduate dental students" (Bordeaux University, France) (N = 12); (4) participants with theoretical knowledge and an upper intermediate level of practice (five semesters of practical work in restorative dentistry on Ivorine® and extracted teeth; five semesters of clinical practice), called "final-year undergraduate students" (Bordeaux University, France) (N = 11); (5) participants with theoretical knowledge and an advanced level of practice (five semesters of practical work in restorative dentistry on Ivorine® and extracted teeth; five semesters of clinical practice; experience in private practice), called "recent graduates" (Bordeaux University, France) (N = 11). Repeating students were excluded from this study.

2.3 | Experimental procedures

The users were seated ergonomically on a stool facing the second screen, wore the 3D glasses, held the haptic stylus in their right hand (if right-handed), manipulated the 3D mouse with their left hand and put their foot close to the pedal.

Each participant was provided verbal instructions from a tutor and a demonstration on how to use the system before beginning the exercise. The proposed exercise was based on the preparation of an occlusal amalgam cavity (G.V. Black's Class I cavity) on a mandibular right first molar #46. The occlusal cavity preparation consisted of an outline form following a line located at half the distance between the groove and the edge of the corresponding cusp, with a depth equivalent to half the working part of the suggested bur (≈2.5 mm) and a mesio-distal width equivalent to three quarters of the width of the tooth (≈9 mm). The evaluation criteria mentioned on the interface also required a flat floor, rounded edges, verticality or slight (5°) convergence of the lingual and buccal walls and slightly divergent proximal walls (Figure 2). Once the user was familiar with the system, the exercise was started and

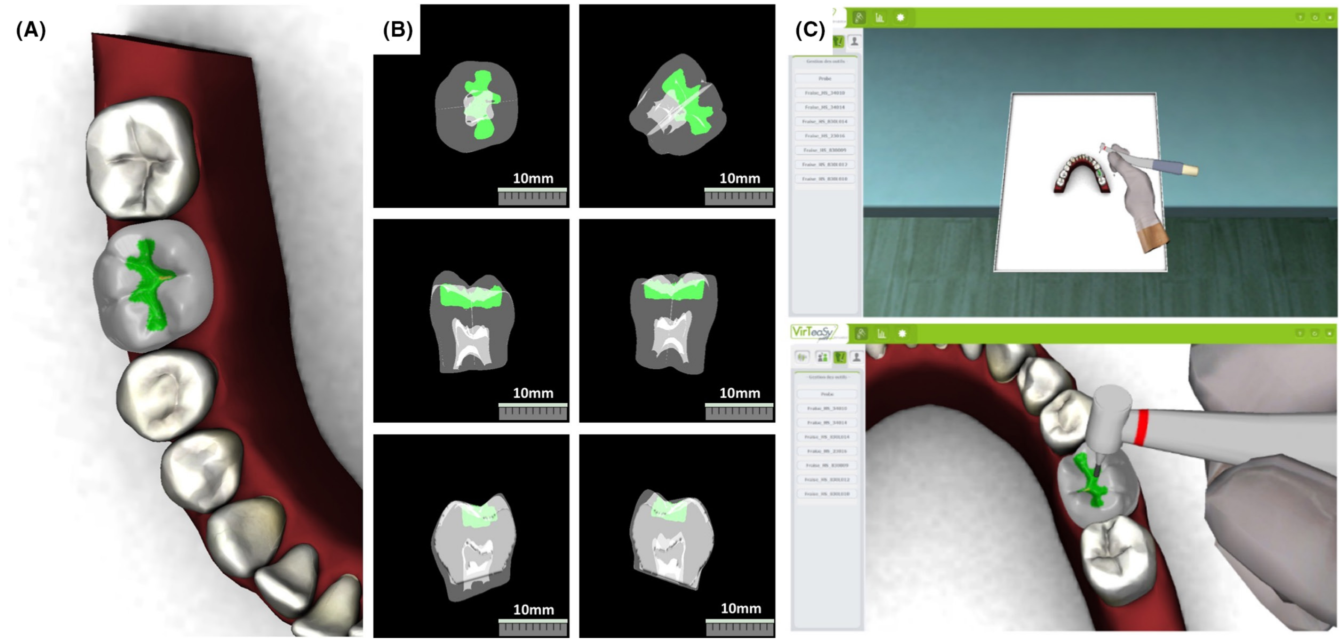

FIGURE 2 User interface of VirTeaSy© dental software V.0 for exercise entitled "occlusal amalgam cavity preparation on tooth 46". (A) Occlusal view of the target area (in green) on the hemiarch in 3D, (B) observation of the target area from different angles, (C) view of virtual mandibular arch before starting the exercise

must have been completed within 3 min. This 3-min time limit was determined according to a pilot study previously conducted (data not shown), so that time would not be a constraint for the completion of the exercise.

The aim of the exercise was to remove all the target tissue (colour green) without touching healthy tissue (white colour). After three minutes, or earlier if the participant wanted, the exercise was stopped, and the performance was evaluated by the software. The exercise was repeated three times successively.

2.4 | Outcomes of interest

2.4.1 | Objective indicators obtained from the simulator

After each exercise, the software calculated two variables: an inside volume (IV), corresponding to the volume removed by the participant (green target tissue) inside the target volume, and an outside volume (OV) or overextension, corresponding to the iatrogenic volume removed by the participant (white healthy tissue). Variables collected by the simulator were converted into percentages of inside and outside volume (Figure 3). A skill index was calculated using the formula 100 − IV + OV (%), with a perfect performance defined by a score of 0%. A progression rate was calculated for each group by comparing skill indexes between trial 1 and trial 3, with trial 1 being our benchmark, progression getting a positive percentage and regression a negative percentage.

2.4.2 | Subjective indicators obtained from the questionnaire

After completing the experiment, participants in groups 2 to 5 were asked to answer nine 5-point Likert scale questions (Table 1). A score of 5 corresponded to the highest level of agreement of the participant with the item and a score of 1 to the lowest. The scoring averages and standard deviation values were calculated for all the participants in each group. Subjects had also the opportunity to express themselves on the points mentioned in the questionnaire and on their general feelings and opinions about the simulation exercise through free writing comments.

2.5 | Statistical analysis

All statistical analyses were performed using GraphPad Prism 8.0 software (GraphPad Software, San Diego, CA, USA). Normality was assessed by Shapiro-Wilk tests. Statistical outliers were detected with Grubb's test, and significant outliers ($p < .05$) were removed from analyses. A two-way ANOVA statistical test was used to compare % inside volume, % outside volume and skill index variation between tests for each group. A one-way ANOVA statistical test was used to compare progression rates and also compare %IV and skill index for each group for the third attempt. A Tukey HSD post hoc test was conducted to compare each group. Questionnaire score averages were also studied. Differences were considered significant for a p value $p < .05$.

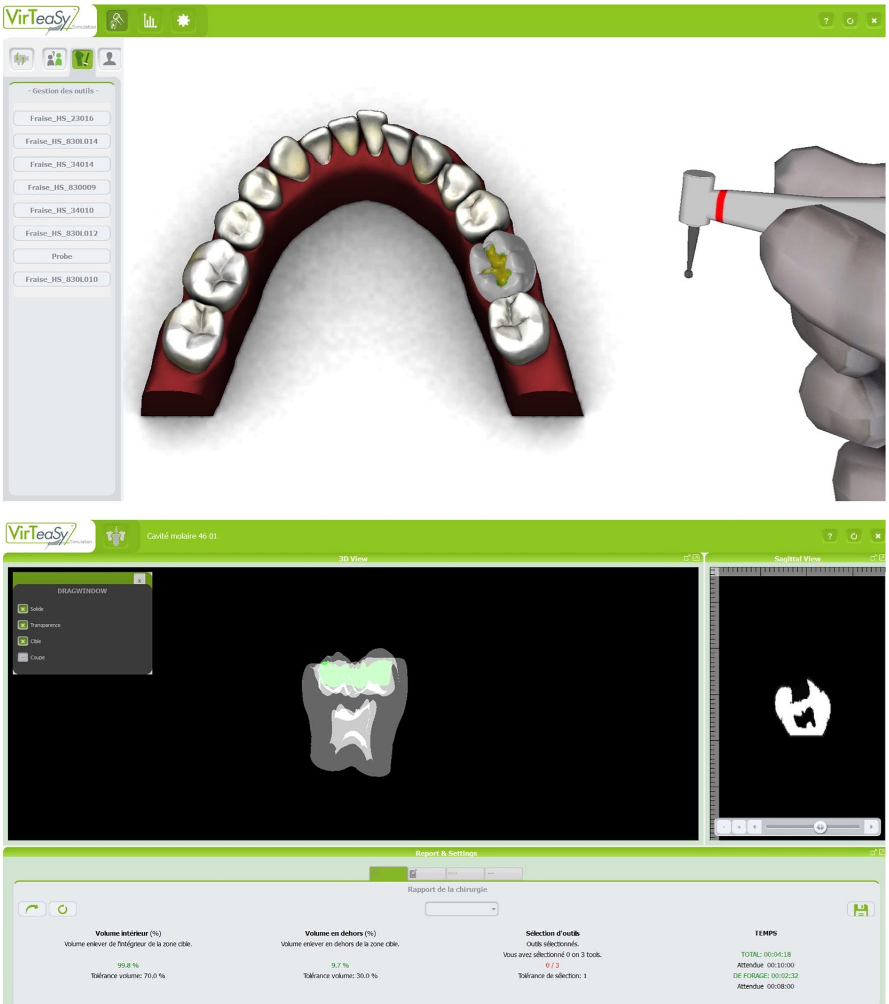

FIGURE 3 Example of an occlusal amalgam cavity prepared by a dental student on tooth 46 on VirTeaSy© haptic dental simulator and corresponding objective evaluation data (inside volume = 99.8%; outside volume = 9.7%; time = 2min32)

3 | RESULTS

For each group, the percentage of prepared inside volume (%IV) improved progressively between trial 1 (82.17 ± 12.1%) and trial 2 (86.18 ± 9.86%) and significantly between trial 2 and trial 3 (90.72 ± 7.57%) ($p < .001$) (Figure 4A). The results show a trend towards improvement based on repetition (trials 1, 2, 3), coupled with a decrease in inter-operator variability suggested by decreasing standard deviations. The percentage of overextension (%OV) remained stable despite the multiple attempts, with an overall average of 6.22% ± 2.68% for the first trial, 5.67% ± 2.33% for the second trial and 6.12% ± 2.14% for the third trial (Figure 4B).

Figure 4C shows the evolution in skill index for each group over repeated tests, representing the dexterity performance, with 0% being the target. A significant improvement was observed in the skill index between trial 1 (24.05 ± 10.65%) and trial 2 (19.55 ± 8.79%) ($p < .05$) and between trial 2 and trial 3 (15.47 ± 6.8%) ($p < .001$). Analysis of standard deviations confirms previous observations related to decreasing inter-operator variability over repetitions.

The progression rate, which is defined as the improvement (in %) in the skill index between trial 1 and trial 3 for each group, is represented in Figure 4D. We can note that all the groups progressed similarly, with an average progression rate of 27.76 ± 32.96%. Despite non-significant differences, the results suggest a lower progression rate (21.03%) for "1st year undergraduate dental students" compared with the other groups.

A focus was made on trial 3 in order to evaluate the performance of participants after repeated trials. The %IV and skill index for each group are shown in Figure 5. A significant difference was found between non-dentists (%IV: 94.02 ± 3.39%; SI: 13.24 ± 3.95%) and 1st-year undergraduate students (%IV: 84.42 ± 9.25%; SI: 20.85 ± 8.54%) and also between 1st-year undergraduate dental students and recent dental graduates (%IV: 93.76 ± 4.97%; SI: 12.4 ± 4.32%) ($p < .05$).

Regarding the 9-item Likert scale questionnaire, means and standard deviation values of the overall score for each group and questions are summarised in Table 2. The majority of participants declared that the simulator would not allow dexterity to be developed as effectively (2.16 ± 0.81) or quickly (2.02 ± 0.88) as the traditional learning method. Despite the ease of use (3.18 ± 1.08) and realism of the dental arch and instruments (3.84 ± 0.99), participants tended to consider the simulator as a learning asset (3.52 ± 1.09) rather than a substitute (1.66 ± 0.86) for traditional preclinical learning methods.

TABLE 1 Likert scale questionnaire distributed to participants to collect subjective indicators related to their first use of VirTeaSy© haptic dental simulator (level of agreement within shaded cells, from "1: strongly disagree" to "5: strongly agree")

Q.1 - The simulator's tactile sensations are similar to clinical reality	1	2	3	4	5
Q.2 - The dental arch and instruments in the simulator are realistic	1	2	3	4	5
Q.3 - The simulator is easy to use	1	2	3	4	5
Q.4 - I would feel more self-assured and my dexterity would be improved if I trained regularly on the simulator	1	2	3	4	5
Q.5 - The simulator allows manual dexterity to be acquired as quickly as traditional preclinical learning methods **(Ivorine®/extracted teeth)**	1	2	3	4	5
Q.6 - The simulator enables manual dexterity to be acquired as qualitatively as traditional preclinical learning methods **(Ivorine®/extracted teeth)**	1	2	3	4	5
Q.7 - The use of the simulator can be an asset to preclinical learning	1	2	3	4	5
Q.8 - The simulator could replace traditional preclinical learning methods (Ivorine®/extracted teeth)	1	2	3	4	5
Q.9 - I enjoyed this learning experience in simulated environment	1	2	3	4	5

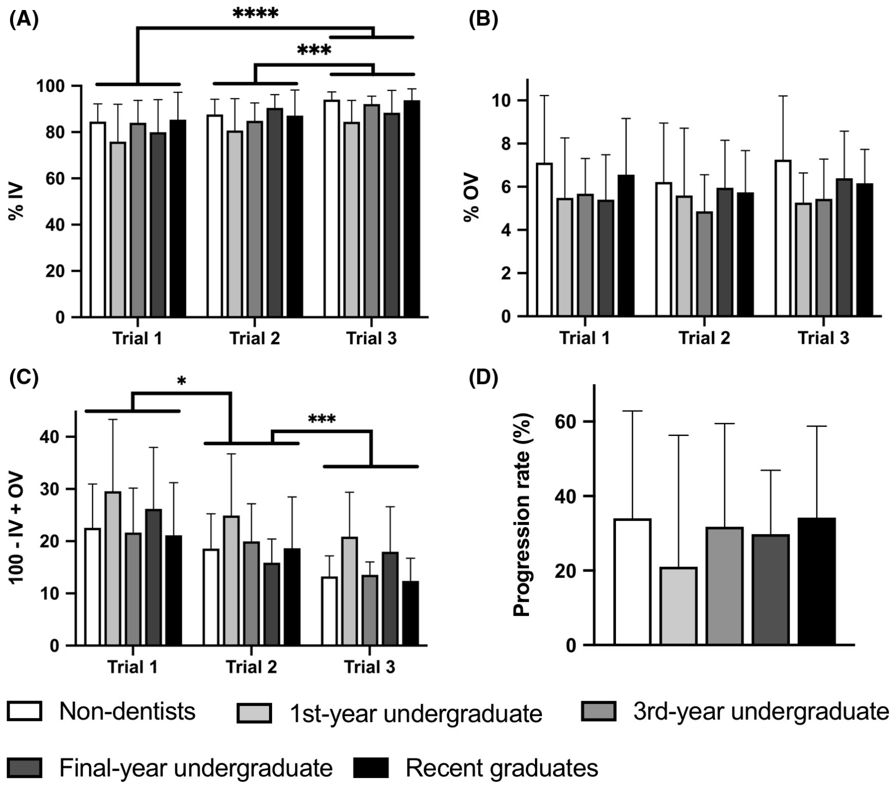

FIGURE 4 Performance data of participants measured using VirTeaSy© haptic dental simulator, for each group (non-dentists, 1st/3rd/final-year undergraduate dental students and recent dental graduates) at trial 1, trial 2 and trial 3: (A) percentage of inside volume (%IV) removed, (B) percentage of outside volume (%OV) removed, (C) skill index (100 − %IV + %OV), (D) progression rate of skill indexes between trials 1 and 3. The statistical significance of the difference was assessed by two-way ANOVA test; *$p < .05$; ***$p < .001$; ****$p < .0001$

All the participants enjoyed their learning experience in simulated environment, with an average score of 4.11 ± 0.87.

The "free writing comments" section allowed for additional feedback on how students felt about this first haptic simulation experience. To summarise, the most recurrent remarks were focused on: i/the fidelity of haptic feedback: some students reported to be impressed with the fidelity of the haptic feedback, whilst others declared that the simulator did not accurately reproduce the textures of the different dental tissues when cutting; ii/learning how to use the system: need for several trials before to use it efficiently; iii/ergonomics: less realism was deplored regarding finger rests, fulcrum and ideal wrist position compared to manipulations on dental manikin/Phantomhead, but on the other hand it was reported that simulator requires

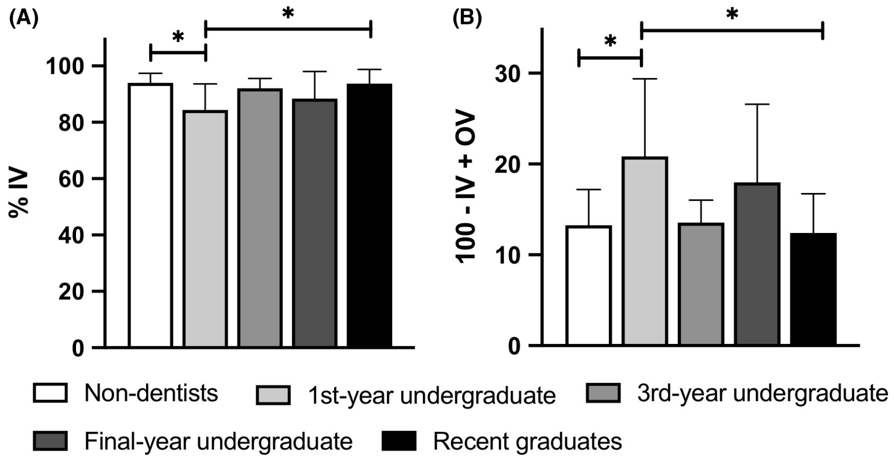

FIGURE 5 Comparison of performance data of participants measured using VirTeaSy© haptic dental simulator, for each group, at trial 3: (A) percentage of inside volume (%IV) removed, (B) skill Index (100 − %IV + %OV). The statistical significance of the difference was assessed by the Tukey HSD post hoc tests; *$p < .05$

TABLE 2 Scores obtained for the items of the Likert scale questionnaire, following completion of exercises on VirTeaSy© haptic dental simulator, by level and globally (sd: standard deviation)

	1st year undergraduate		3rd year undergraduate		Final year undergraduate		Recent undergraduate		ALL	
Items	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Q.1	2.5	0.6	2.9	0.7	2.4	0.8	2.6	1.1	2.7	0.8
Q.2	4.2	1.3	3.7	1.0	3.7	1.0	4.3	0.6	3.8	1.0
Q.3	3.2	1.1	3.3	1.1	2.7	0.9	3.6	1.2	3.2	1.1
Q.4	3.0	1.4	3.0	1.3	2.3	0.9	2.5	1.0	2.7	1.2
Q.5	2.0	0.8	1.9	0.7	2.2	0.9	2.3	1.1	2.0	0.9
Q.6	1.7	0.6	2.2	0.7	2.2	0.9	2.4	1.0	2.2	0.8
Q.7	3.5	1.2	3.8	0.7	3.2	1.3	3.5	1.2	3.5	1.1
Q.8	1.2	0.5	1.7	0.8	2.0	1.3	1.6	0.7	1.7	0.9
Q.9	4.0	0.6	4.5	0.8	3.6	0.8	4.1	1.0	4.1	0.9

working with an appropriate posture; iv/in comfort related to 3D; and v/the place of simulation in preclinical dental education: simulation could be a relevant complement to traditional learning but could not replace it.

4 | DISCUSSION

The transition to virtual reality has been initiated in response to the lack of realistic clinical exercises, teacher availability and time, natural teeth and objectivity in evaluations.[17] Virtual reality is seen as bringing benefits, such as increased theoretical knowledge in dentistry, correct working posture, self-assessment by students, faster acquisition of motor skills and positive perception of learning by students.[18–20] Moreover, since the breakthrough of coronavirus SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2) in the late 2019, the need for social distancing has made it necessary to rethink teaching methods and further develop the use of digital technologies.[21]

For many years, a large variety of fields have used simulators, especially high-risk professions such as aeronautics or military training.[22] In medicine, virtual reality and simulation are now widely developed for clinical skills training, as for example in laparoscopic surgery, vascular surgery, anaesthesiology, emergency medicine.[23–25] Simulation allows to acquire skills in a non-pressured environment, without compromising patient safety.[26]

A matrix of validity type for augmented reality applications to train medical professionals was proposed by Barsom et al.[27] Amongst existing research methods, construct validity is a commonly used criterion to evaluate simulators.[28] The study of construct validity is based on populations with different levels of skills and clinical experience in a specific field. As for example, previous studies aimed to assess motor performance using simulators and compare groups with broad differences in terms of experience (dental students, dentists and non-dentists)[13,29] or finer differences (dental students of different levels of study).[14] The present study aimed to evaluate the performance of different groups constituted according to a gradient of knowledge, practical experience and clinical experience.

The first trial should be considered as a pre-test to assess the basic skill level of each group. Consistently with the literature,[29,30] the "recent graduates" (advanced level of practice) performed better than the other groups in this first trial. Nevertheless, the differences were not significant and "non-dentists" showed an almost similar level of performance to the "recent graduates." Although the selection of more experienced experts might have allowed to better distinguish the initial level of dexterity between groups, the restriction to a young population was preferred in order not to induce an age bias that might affect the results.[31] Indeed, simulation technologies might be better mastered by new generations who are increasingly familiar with digital technology. This lack of significance of the results obtained after the first trial could also be explained by the large standard deviations. The haptic simulation being a new task for all participants, the inter-operator variability is maximal during the first use of the device and requires multiple repetitions to decrease. Re-evaluating the participants on the same simulator a few weeks later could have been interesting since the "novelty" effect could not have biased the results.

In this study, we observed that repeated tests had no influence on the rate of healthy prepared tissue, which remained stable at around 5%, whatever the operator skill level. On the other hand, the more trials the subjects performed, the more the rate of prepared carious tissue increased, which brought the skill index closer to the target between trial 1 and trial 3 for each group. These results are consistent with those obtained in the study by Vincent et al in 2019, revealing progressive improvement in student's preparation skill, characterised by a significant learning curve during the training phase.[32] This is also consistent with the comparative study of Eve et al.,[33] who found that both groups (novice and experienced residents) improved in precision from the first to the third exercise. The reduction in the variability of the performance, seen as a decrease in standard deviations, has also been reported in other studies.[34] This significant improvement with repeated exercises indicates an efficient simulation model. Learning curves of skills acquisition have been widely studied in virtual reality simulation training.[35] Learning curves graphically show the relationship between learning effort (repetitions and time) and learning outcomes. During the growth phase, the performance improves rapidly with each repetition.[36] Many authors demonstrated the impact of simulation and repetitions in boosting the learning curve in medical education.[37]

In our study, progression rates from trial 1 to trial 3 were not statistically different between groups, which could be explained by high standard deviations. The analysis of the results focused on the average progression of the different groups of learners in order to identify a general trend. Nevertheless, as the performance of each participant varies greatly, investigating learning curve of each individual could have been of interest. An increase in the number of attempts would be relevant for future work, in order to obtain exhaustive information for a complete learning curve: number of repetitions necessary to achieve competence, maximum learning achievable, existence of a latent phase.[36]

The lack of discrimination between groups could be also related to the level of the selected exercise. Performing a more complex exercise, such as extensive mesial-occlusal-distal cavity preparation, may have been more challenging and more appropriate to discriminate skill level of operators. This hypothesis is in agreement with Wang et al.[38] who suggested to increase the difficulty of exercise on the simulators to derive more meaningful results. In the same manner, Mirghani et al. were not able to capture differences between performances of experienced trainees with varying levels of expertise using Simodont®. For future work, they suggested to increase task demands: higher percentage of target removal, lower error rates, introduction of visual transformations (mirror) and restriction of time available to complete the exercise.[14]

Nevertheless, we observed a tendency for the "1st-year undergraduate dental students" to be more conservative (lower %IV for all 3 trials) which confirms the study by Eve et al.[33] on the VirTeaSy© simulator, in which first-year dental students were more conservative. The third trial showed a significant difference between "1st-year undergraduate dental students" and "recent dental graduates." These results are also in agreement with the study by Eve et al.[33] which showed the discriminating character of this haptic simulator between novice dental students and prosthodontics residents.

Surprisingly, the "non-dentists" obtained significantly better results than the "1st-year undergraduate dental students" in the third trial. We hypothesised that management of the software is easier when the user has no means of comparison with other training techniques (eg Ivorine® teeth). The lower performance of the "1st-year undergraduate dental students" could also have been influenced by the phenomenon of "movement specific reinvestment" in which conscious control of movements that are best controlled automatically disrupts performance.[39] In addition, the "1st-year undergraduate dental students" have already acquired knowledge, especially related to minimally invasive dentistry, which makes them aware of the principles of maximal tissue preservation and could lead them to take additional precautions when preparing cavities. This highlights one of the limitations of the simulator, where electronic grading does not seem appropriate for evaluation in a clinical setting. This study presented the electronic "volume" as the objective data, but the final shape of the cavity is not taken into consideration by the software. All dental tissues are not equivalent (dentin, pulp) and different deviations from the target (eg pulp proximity) will not have the same clinical impact. The scoring method is only a measure of the final outcome and does not consider the student's clinical approach and underlying surgical decisions. To date, virtual reality must be supervised since it does not provide appropriate feedback for novice students when used alone.[40,41]

Questionnaires have been frequently used to investigate the subjective experience of simulator users.[42] They are key tools to measure the acceptance of these new technologies in dental education.[43] In the present study, several drawbacks of the simulator were reported by the students through the Likert scale questionnaire and their free writing comments. They are consistent with those mentioned in the literature.[42] Fidelity of the force feedback is crucial in dental training, where different force feedback must be perceived for the different oral or dental tissues. Simulation of force feedback was reported to be not realistic enough, further optimisations are needed to improve it.[20] A stable finger rest is essential in operative dentistry to avoid accidental injury to the surrounding tissues.[11]

Simulation should allow to efficiently train on the use of finger rests. Moreover, the use of 3D glasses to achieve 3D display can result in discomfort such as vertigo and nausea and reduced resolution of the image.[33] Improvement of image display is needed to increase immersive experience. These observations are comparable to the results of studies carried out on the Simodont® simulator. It was reported that 80% of the professors regretted the similarity of texture between the different dental tissues, the absence of clinically relevant finger rests, the absence of wide selection of instruments and the difficulty of creating smooth surface preparations.[12] Tactile sensation is one of the main issues in dental simulation. Currently, typodont teeth with different cutting characteristics for enamel, dentin, pulp tissue and carious tissue are being developed and allow for a better level of realism of dental phantom head manikins. Nevertheless, reproduction of cutting characteristics is approximate and typodont teeth with caries and pulp space remain expensive. Virtual reality haptic simulator therefore seems to be the most promising tool to overcome this issue. Despite the limitations raised, the majority of students seem to have enjoyed this simulation-based learning experience. Students felt that the simulator should not replace traditional preclinical learning techniques but should be used as a complement to them. These data are consistent with other published works based on similar questionnaires.[44,45]

Although simulation technologies promise to overcome the limitations of conventional teaching methods, this paper allowed to point out that optimisations are needed in terms of realism, feedback and evaluation. Moreover, recommendations for use appear to be essential to ensure the effectiveness of these technologies in training students.

In order to optimise simulator usage, it is necessary to determine the number of simulator training hours which is sufficient to reach the required level. Urbankova et al.[46] concluded that the integration of 8 h of simulation, in addition to already existent preclinical training in restorative dentistry, would improve student performance. LeBlanc et al.[47] also showed that augmenting conventional training with 6–8 h of simulation could improve the performance of 2nd-year dental students. Virtual reality feedback has been demonstrated to be crucial for acquisition of dental skills.[48,49]

In this study, despite its limited relevance to clinical learning due to inappropriate assessment method, simulation seems to be an interesting tool to provide simple manual dexterity exercises for beginner students in order to develop basic psychomotor skills needed for restorative work. Then, student can develop manual dexterity prior to conventional practice, avoiding to waste resources by accidentally causing irreversible damage on plastic teeth.[50] Then, it would be interesting to include haptic simulation during the 1st year of dental studies, when notions of preparation and design concepts are introduced.

To summarise, the limitations of the haptic simulator discussed in this work are common to some of those mentioned for traditional methods. They are related to a non-faithful reproduction of tactile sensations, a lack of appropriate evaluation in a clinical setting and the need for teachers to be available for clinically relevant feedback regarding to the procedure performed and the ergonomics. Technological optimisations are still needed in order to fully meet pedagogical and clinical requirements of dental students' training and to be able to replace traditional methods with digital approaches.

5 | CONCLUSION

This study did not demonstrate an influence of prior knowledge, practical and clinical experience on dexterity performance during a clinical simulation exercise on the VirTeaSy© haptic simulator. The high inter-operator variability within each group suggests that more trials and larger cohorts of participants are needed to ensure reliable outcomes and conclude on the validity of such exercise. Nevertheless, the results allowed to discuss the current limitations of simulators, especially in terms of realism, feedback and evaluation. In particular, the development of new evaluation criteria seems to be a crucial step to improve clinical relevance of this tool.

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CONFLICT OF INTEREST

The authors do not have any financial, economic or professional interests that might have influenced the design, execution or presentation of the scholarly work.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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