Computer Methods and Programs in Biomedicine 221 (2022) 106831

Contents lists available at ScienceDirect

Computer Methods and Programs in Biomedicine

journal homepage: www.elsevier.com/locate/cmpb

Usability, acceptance, and educational usefulness study of a new haptic operative dentistry virtual reality simulator

Pedro Rodrigues[a,*], Artur Esteves[b], João Botelho[a], Vanessa Machado[a], Carlos Zagalo[a,d], Ezequiel Roberto Zorzal[c,e], José João Mendes[a], Daniel Simões Lopes[b,c]

[a] *Clinical Research Unit (CRU), Centro de Investigação Interdisciplinar Egas Moniz (CiiEM), Egas Moniz - Cooperativa de Ensino Superior, CRL, Almada, Portugal*
[b] *Instituto Superior Técnico, Universidade de Lisboa, Portugal*
[c] *INESC ID, Lisboa, Portugal*
[d] *IPO Lisboa, Instituto Português de Oncologia Francisco Gentil, Portugal*
[e] *ICT/UNIFESP, Instituto de Ciência e Tecnologia, Universidade Federal de São Paulo, Brazil*

ARTICLE INFO

Article history:
Received 29 July 2021
Revised 23 March 2022
Accepted 21 April 2022

Keywords:
Operative dentistry
Virtual reality
Tooth drilling
Haptic feedback
3D Sound
Simulator

ABSTRACT

Background: Dental preclinical training has been traditionally centered onverbal instructions and subsequent execution on phantom heads and plastic training models. However, these present present limitations. Virtual Reality (VR) and haptic simulators have been proposed with promising results and advantages and have showed usefullness in the preclinical training environment. We designed DENTIFY, a multimodal immersive simulator to assist Operative Dentistry learning, which exposes the user to different virtual clinical scenarios while operating a haptic pen to simulate dental drilling.

Objective: The main objective is to assess DENTIFY's usability, acceptance, and educational usefulness to dentists, in order to make the proper changes and, subsequently, to test DENTIFY with undergraduate preclinical dental students.

Methods: DENTIFY combines an immersive head mounted VR display, a haptic pen in which the pen itself has been replaced by a 3D printed model of a dental turbine and a controller with buttons to adjust and select the scenario of the simulation, along with 3D sounds of real dental drilling. The user's dominant hand operated the virtual turbine on the VR-created scenario, while the non-dominant hand is used to activate the simulator and case selection. The simulation sessions occurred in a controlled virtual environment. We evaluated DENTIFY's usability and acceptance over the course of 13 training sessions with dental professionals, after the users performed a drilling task in virtual dental tissues.

Results: The conducted user acceptance indicates that DENTIFY shows potencial enhancing learning in operative dentistry as it promotes self-evaluation and multimodal immersion on the dental drilling experience.

Conclusions: DENTIFY presented significant usability and acceptance from trained dentists. This tool showed to have teaching and learning (hence, pedagogical) potential in operative dentistry.

1. Introduction

The educational setting in dentistry traditionally involves two stages [1]: 1) theoretical schematic representation of the procedures to be performed; and, 2) their training on models, to mimic future application in supervised real clinical cases.

Initially, dental education was taught and trained in real tissues, such as removed teeth [2]. In 1894, phantom heads were firstly introduced and became the educational cornerstone in Dentistry [3]. Since then, they have permitted the recreation of theoretical clinical conditions after verbal and visual instructions on their execution. Nevertheless, these models lack realism, diversity as to pathologies and universal evaluation criteria thus contributing to subjective monitoring and grading [4]. The supervision of this type of educational approach is time-consuming and may be jeopardized by inadequate student/tutor ratio [5].

* Corresponding author.
E-mail addresses: prodrigues@egasmoniz.edu.pt (P. Rodrigues), daniel.lopes@inesc-id.pt (D.S. Lopes).

https://doi.org/10.1016/j.cmpb.2022.106831

As an alternative to these conventional training models, VR was introduced for dental training, providing superior tutoring aptitudes during students performance [6,7]. Virtual reality (VR) refers to technology that codes and compiles computer generated multisensory data to be perceived by users as alternative realities, allowing them to immersively interact with simulated tasks, events or scenarios frequently using head mounted displays. The growing use of simulation in healthcare, using VR technologies that mimic clinical reality, allows repetition and has been proven to add competence in health care providers, thus increasing performance in the clinical process and, therefore, increasing predictability and improving patient outcomes [8].

To increase the immersion and realism of the VR simulation, haptic technology has been proposed and used simultaneously in dental training [9]. Haptics is defined as the science of applying touch (tactile) sensation and control to interaction with computer applications [10]. A haptic training simulator is a computer based simulator enhanced with force (resistance to progression) and tactile feedback. Haptic experience contributed to advance the students' stage in the learning curve when later confronted with real scenarios [11].

Regarding the different dental specialties, several virtual models have been shown to increase learning skills in periodontal diagnosis and treatment [1], endodontic access cavities [12], oral surgery [13] and also for training regional blockage of the inferior alveolar nerve (proven to be adequate in several clinical parameters such as depth, anatomical location of the puncture, and resistance to progression) assisted by virtual tissue resistance [14].

Considering Operative Dentistry, haptic simulation may be decisive given the tactile complexity of the motor skills to be developed, namely resistance to the progression of cutting instruments offered by different elements (enamel, dentine, pulp, restorations and caries) with different degrees of mineralisation and density. Urbankova et al. [15] reported that the use of operative dentistry simulators at early stages of preclinical teaching improves student performance. Additionally, haptics and VR training resulted in greater learning efficiency, more hours of preclinical practice and allowed for more assessments per hour than students trained on traditional models in the University of Pennsylvania [16]. Also, fifth-year students from the Tokyo Medical and Dental University required less supervision by faculty members and showed greater skills [17].

We developed DENTIFY, a pedagogical multimodal immersive educational simulator, with the aim of recreating the cavity preparation phase inherent to operative dentistry, in a virtual environment. Contrary to other Operative Dentistry dental virtual reality simulators, DENTIFY includes the simulation of caries removal on more than one tooth (depending on the degree of difficulty established for the given exercise), and it already includes a multisensory stimulation by incorporating visual, tactile and auditory stimuli in the VR environment. It also allows for exercises to occur in two different modes: training mode and evaluation mode, although only the training mode was tested on dental professionals as a co-design strategy for future versions of DENTIFY. It is our objective to futher include full arch simulation exercises, soft tissue presence, bimanual handling and emergency scenarios.

Our goal is to verify if DENTIFY can positively assist teaching and learning experiences for cavity preparation tasks. In order to evaluate the educational usefulness, usability, and user acceptance of DENTIFY's interactive features, we conducted a user-study with professional dentists.

2. Materials and methods

2.1. Concept

DENTIFY is a tech probe aimed at assessing the user's perceived usability and educational potential by immersing a user in a virtual environment composed of visual, auditory and haptic stimuli. Combining a haptic pen, VR headsets, dental turbines drilling sounds, patient-specific teeth models and a laptop, its intention is to be a pedagogical tool with applicability in dental students' preclinical training environment.

Regarding the aforementioned preexisting simulators, we added 3D sound and an haptic device in which the pen itself has been replaced by a 3D printed model of a dental turbine. Furthermore, DENTIFY allows to simulate more than one cavity type in adjacent teeth (involving one or two dental surfaces). To ease the transition from the preclinical phase to the clinical university reality of operative dentistry, a virtual environment of the execution of a dental cavity was built.

2.2. Visual component

We resorted on the Oculus Quest 256GB that provided the visual immersive modality. Participants remained seated at a desk and used a haptic pen to perform cavity preparation tasks.

2.3. Apparatus and software

Our setup resorted on a laptop computer (Intel® Core™ i7.8750H CPU, 2.20GHz 2.21GHz Processor, 512GB RAM, 1TB HDD, NVIDIA GeForce RTX 2060) running Windows 10 x64 bits. DENTIFY was developed and coded with Unity 3D (version 2021.1.0) using the C# programming language. Integration with Virtual Reality was done using the XR Interaction Toolkit plugin. Regarding the integration process of the haptic pen with the simulator, we used the Openhaptics® Unity Plugin developed and maintained by 3D Systems (Fig. 1). The integration of the haptic device (3D Systems Touch Haptic Device) makes it possible for users to manipulate, touch and to deform virtual objects. Additionally, it also allows to configure the resistance offered as well as the vibration level. The integration process of the haptic pen with the simulator uses the 3D Systems Openhaptics® Unity Plugin, developed and maintained by 3D Systems. The touch haptic device allows the user to freely move the device in the x, y and z axes. Although there is a maximum limit on the range of movement, namely position/sensing input 6 degrees of freedom, this limit is sufficient to replicate the use of a turbine. It also allows a feedback force of up to 3.3N. Force feedback was provided by a PHANToM Omni (SensAble Technologies) that is considered an admittance-controlled device [18]. The collision between the tooth's mesh and the virtual drill was detected using a simple raycast technique (ray-triangular mesh intersection): the virtual drill emits a ray from its tip (raycast); once the ray intersects a triangle of the tooth mesh, and if the distance between the drill and the mesh is below a small threshold, then the mesh is instructed to deform at the point of intersection and the turbine's sound changes to represent the drilling of dental tissue. In order to try to make the simulation more immersive and closer to reality, the removable part of the pen was replaced by a 3D printed replica of a dental turbine (Fig. 2).

2.4. Auditory component

The audio added to the simulator was obtained from real sounds arising from the use of the dental turbine (high rotation

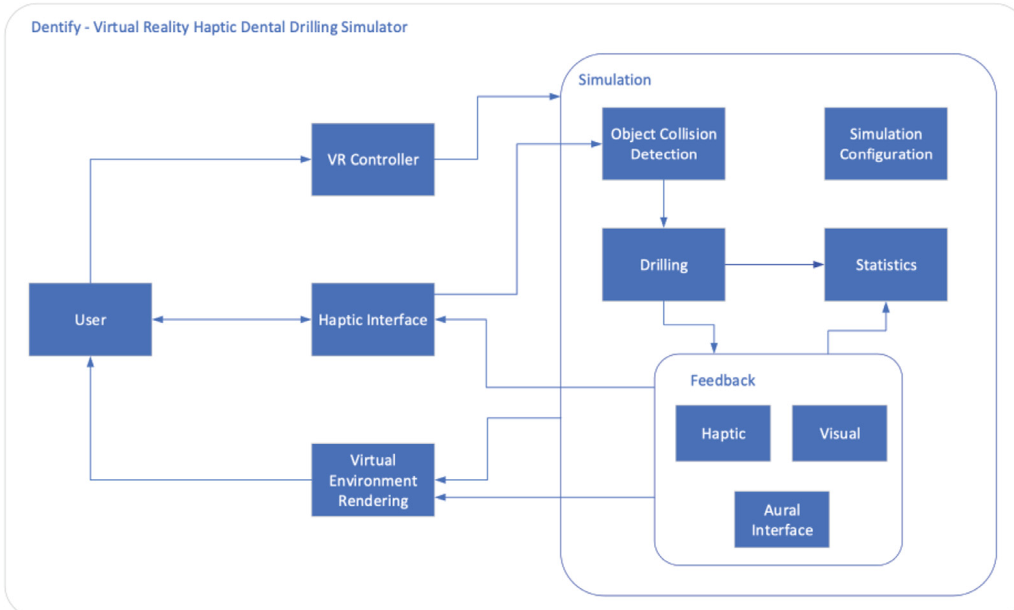

Fig. 1. System architecture.

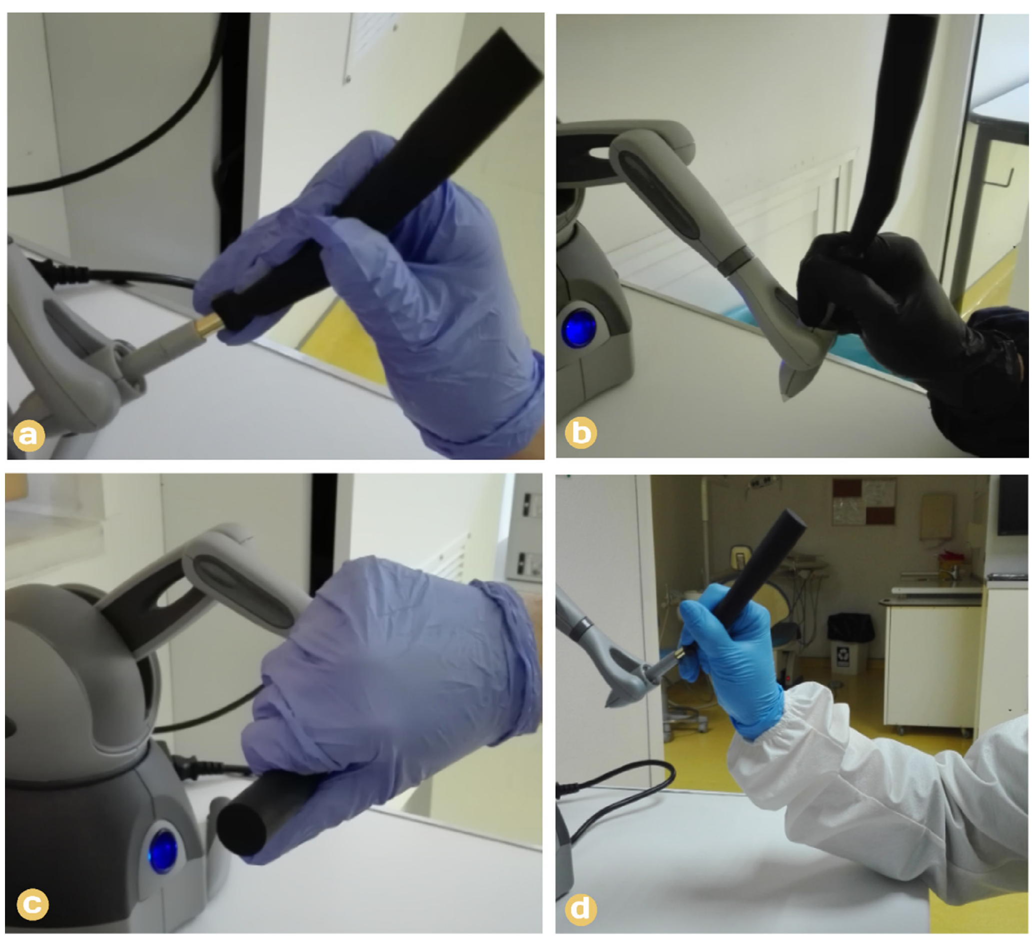

Fig. 2. Haptic pen handle. a) Haptic pen handle in the initial position. b) Haptic pen handle in adapted position. c) Haptic pen handle in unnatural position. d) Holding the haptic pen with arm support.

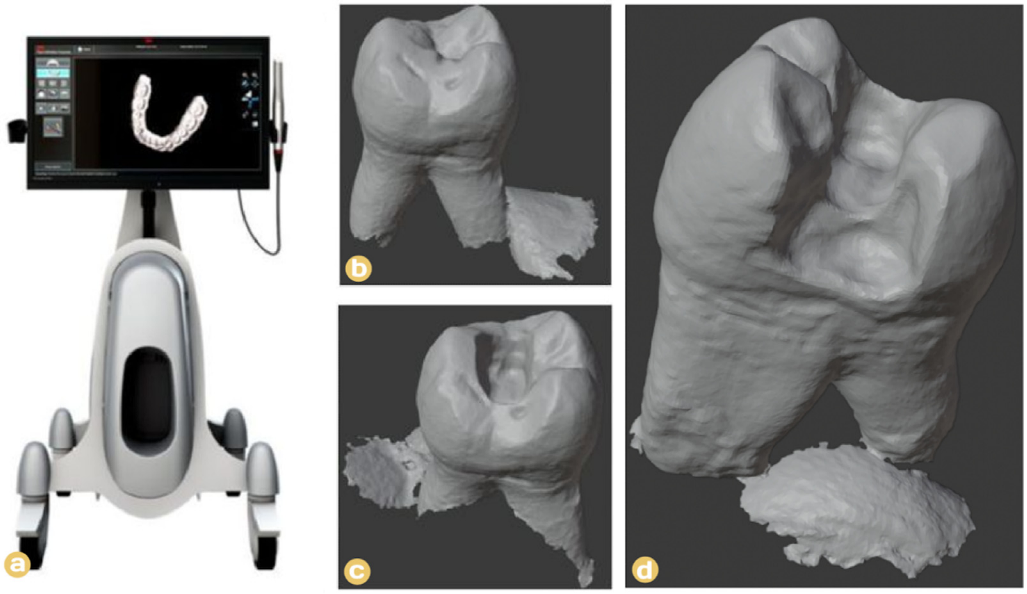

Fig. 3. 3D dental Scanner. a) 3M True Definition Dental Scanner. b) A 3D model of the healthy tooth. c) Tooth with a cavity on one dental surface. d) Tooth with a cavity on two dental surfaces.

instrument). A low-pass filter was applied to the sound of the turbine, both without contact and with contact whenever the deformation occurs in order to achieve a different sound that's closer to the real one during the drilling phase.

2.5. 3D Image data

A healthy molar tooth (freely donated to the Human Tooth Bank at Egas Moniz Dental Clinic) was scanned using an intra-oral scanner (3M True Definition, 3M Oral Care) (Fig. 3). The final virtual molar served as the basis for all exercises in the simulator. The same tooth was then prepared using a dental turbine and a spherical burr, obtaining a tooth with a cavity on the occlusal surface (Class I cavity). Then, the cavity was further drilled into an interproximal tooth surface (Class II cavity). Each of these cavity preparations was scanned. The scans generated STL files, which were then manipulated using a 3D modelling open source software (Blender, Amsterdam, Blender Foundation). The models had a very good level of detail and virtually no flaws in the virtual dental crown. The scans resulted in models with approximately 30,000 vertices. We relied on conventional surface rendering (Blinn-Phong shading of mesh triangles). No volume rendering was considered for rendering purposes.

Three anatomical structures were modeled this way: healthy tooth; tooth with a cavity on 1 tooth surface; and tooth with a cavity on 2 dental surfaces. To obtain the limits of both cavities, classes I and II, the model with the cavities was overlapped with the model of the tooth without deformations. After the limits of the respective cavities were properly extracted, it became possible to associate the class one or class two cavity limits to the original tooth..

2.6. Simulation environment

The simulation takes place in a virtual environment and is complemented with the haptic device, the virtual reality headsets, the corresponding controllers, and a laptop. It is possible to configure the simulation environment, ie, to choose the number of teeth in the simulation (1 or 2 teeth because the models created either only have the tooth to be deformed or have a tooth adjacent to the tooth to be deformed), and to select the type of cavity to prepare; namely, a class I (affecting 1 dental face) or class II cavity (involving 2 dental surfaces). The user can also indicate which hand is dominant. In this study, the user was able to choose only the dominant hand, since all other options were previously selected by the instructor.

In the task execution stage, a panel is displayed in the virtual environment containing the exercise description, where the aural interface will read the exercise description, which varies according to the cavity being prepared. Execution begins when the user clicks the OK button. A timer is displayed and, once it starts, the user will immediately see part of the turbine, the tooth to be deformed and a replica of the tooth to be deformed. To interact with the panel, the user can use the non-dominant hand to manipulate the controller (Fig. 4).

It is possible to return the tooth to its predefined position after starting the exercise. The user can choose between two types of drills with different diameters. Both drill models were created on the Blender software.

The next step of the simulation will be to prepare a cavity based on the description presented by the simulator. To perform the deformation, the user only needs to manipulate the haptic pen as if they were manipulating a dental turbine and bring the tip of the virtual drill close to the tooth surface to perform the drilling.

Once the user exercise is finished, the user should click Terminate and the haptic pen is deactivated (Figs. 5 and 6).

2.7. Participants

For this study, 13 unpaid participants were selected, of which 6 were female and 7 were male, with ages ranging from 24 to 38 (Median = 25, SD = 4,77) (Fig. 7). All participants were dentists. Their average experience, in years, is of approximately three and a half years. The minimum reported time working as a dentist was one month and the maximum was 14 years (Fig. 8). None of the participants reported having ever used a haptic pen.

2.8. Tasks and procedure

The study describes the simulator's evaluation. Each testing session involved the following steps: (I) completion of informed con-

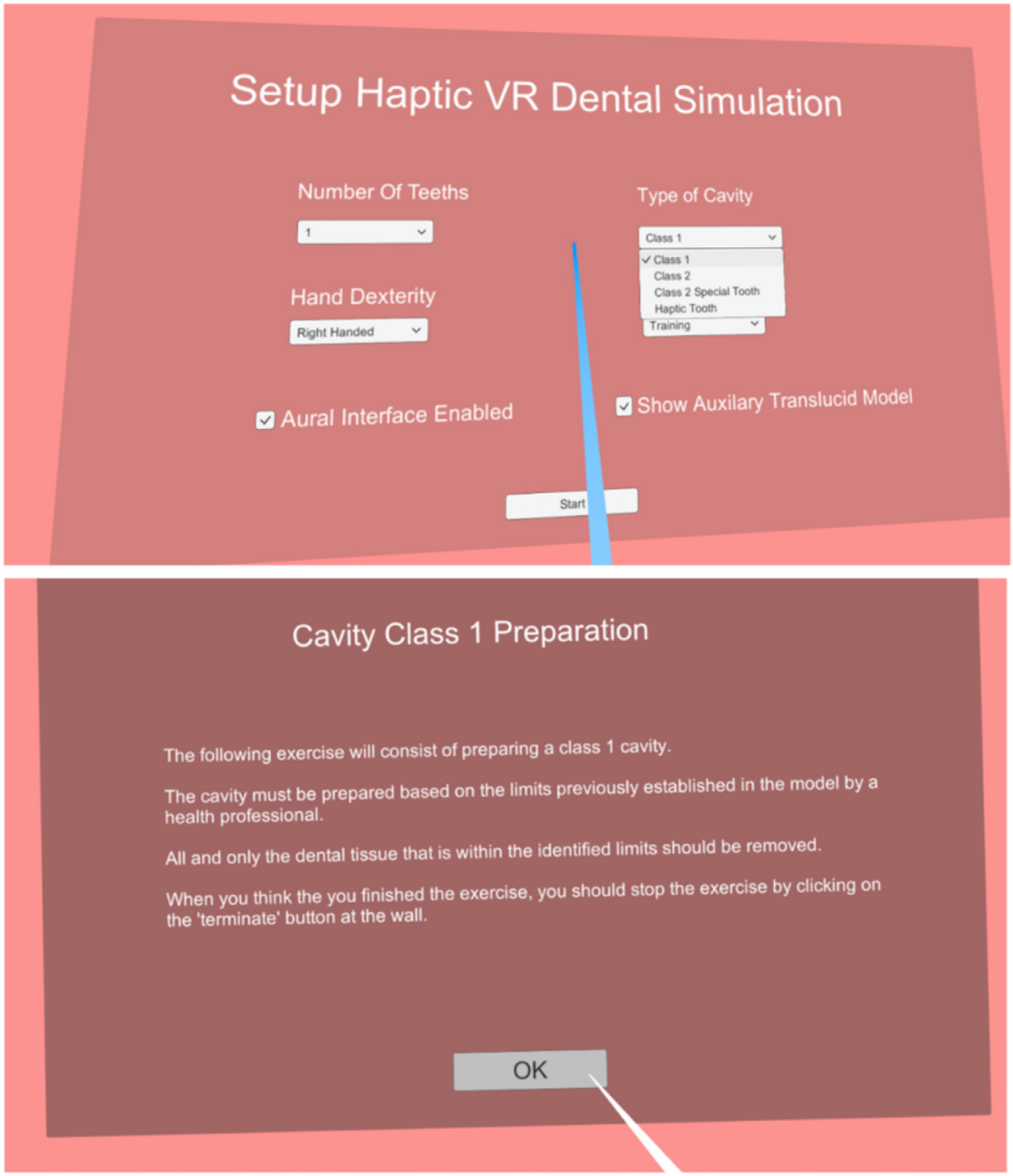

Fig. 4. Panels presented in the virtual environment for configuration and exercise description.

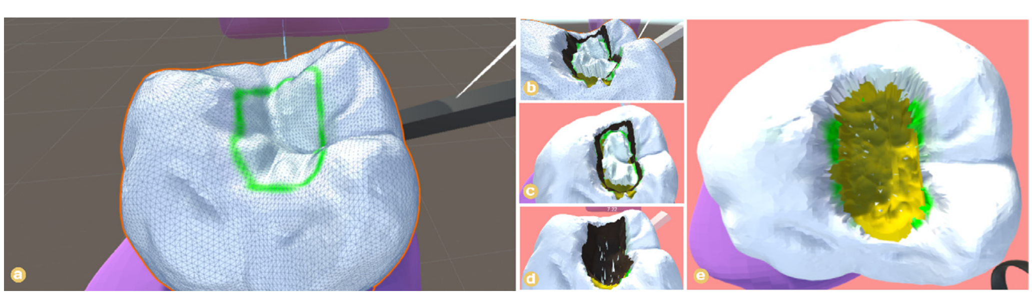

Fig. 5. Cavity Preparation. a) Initial Situation. b) Evolution of the Cavity Preparation. c) Occlusal view. d) Final Aspect of the cavity – cavity limits in brown. e) Occlusal view of Class I cavity preparation without the predefined cavity limits.

sent, (II) completion of demographic questionnaire, (III) introduction to the prototype, (IV) free experimentation, (V) execution of the tasks, (VI) completion of questionnaires associated with the experiment, and (VII) guided interview (Fig. 9).

The experiment-related questionnaires were: 1) Cyber Sickness Questionnaire (17); 2) SUS (System Usability Scale) Questionnaire and 3) NASA-TLX (NASA Task Load Index).

The NASA-TLX questionnaire aims to evaluate the workload felt by each participant during the drilling task. It includes six questions focused on the following: mental effort, physical effort, time effort, performance and frustration levels. It ultimately aims to assert user perception during the task completion experience. The SUS questionnaire measures the perceived usability of an interactive system; in our case, a dental simulator to perform virtual

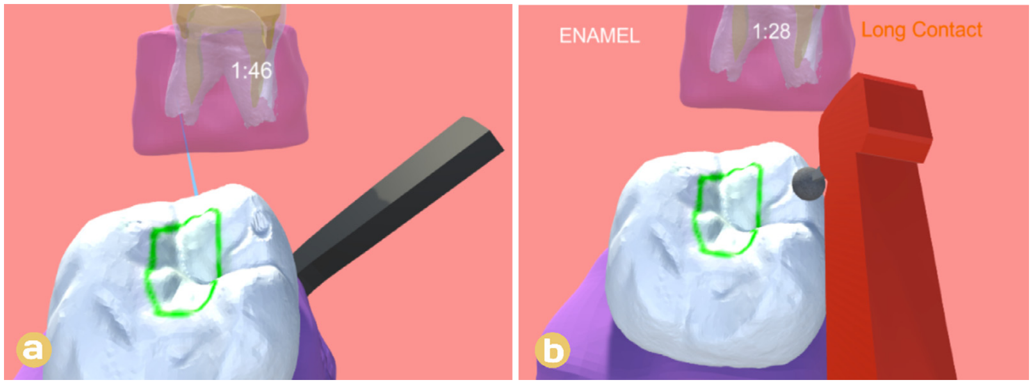

Fig. 6. Different status of the floating panels. a) Task timer on the floating panel. b) Full floating panel: center: timer; left: virtual tissues being prepared; right: prolonged contact warning.

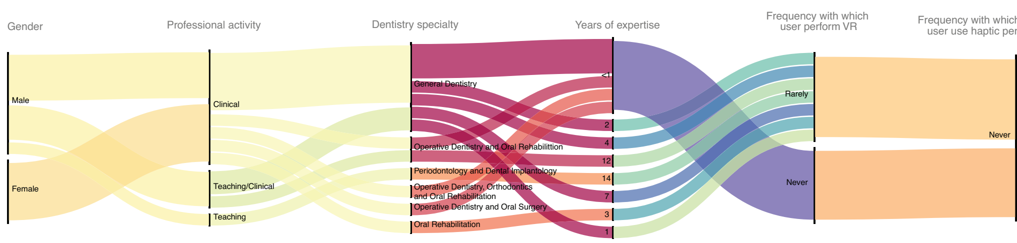

Fig. 7. Alluvial diagram summarizing the demographic data from profiles included in the evaluation.

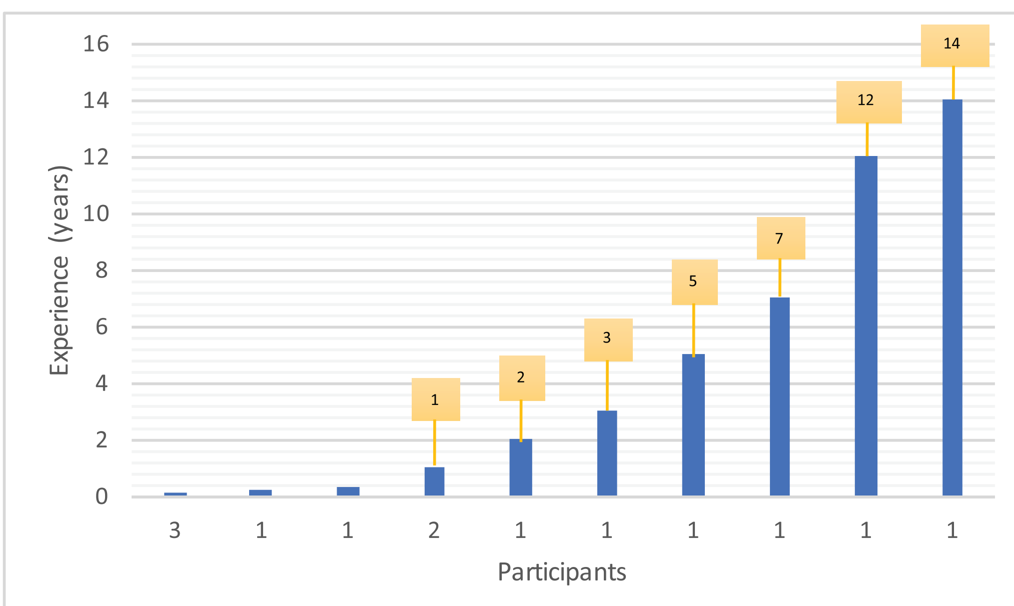

Fig. 8. Participants' professional experience.

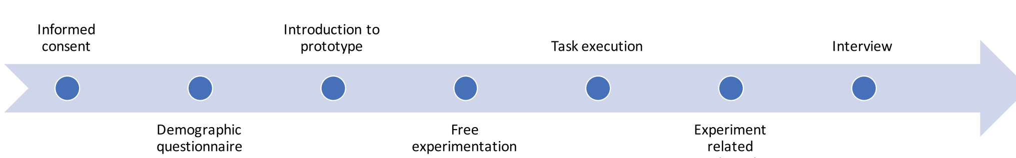

Fig. 9. Evaluation steps.

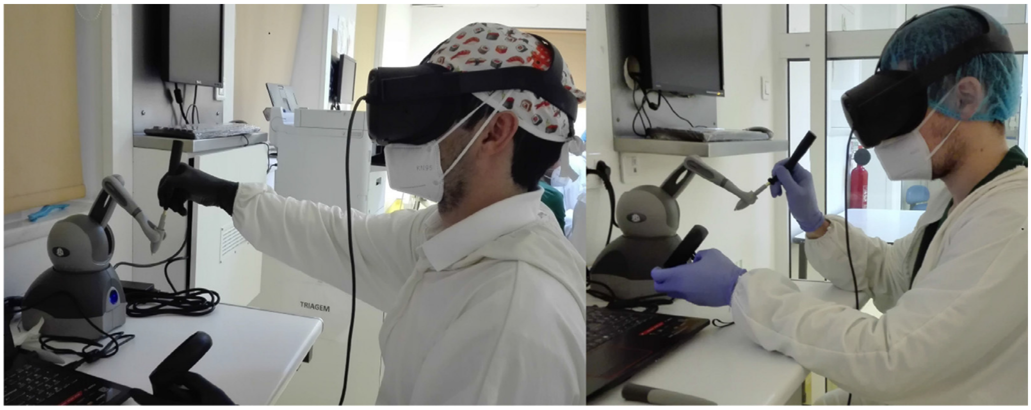

Fig. 10. Participants during an assessment evaluation session.

drilling tasks. Participant feedback was obtained through structured questionnaire or post-experiment interview-debriefing, regarding the limitations and benefits of the proposed interaction techniques.

The drilling task consisted of preparing a class 1 or class 2 cavity. Each user took an average of 1 h and the simulator assessment exercise took an average of 10–15 minutes. All the test sessions took place in a clinical environment at Egas Moniz Dental Clinic, namely under the supervision of C.i.i.E.M. (Centro de Investigação Interdisciplinar Egas Moniz, Monte da Caparica, Portugal) members.

2.9. Statistical analysis

The SUS scale score ranges from 1 to 100 and 68 points is considered the average score, according to a wide evaluation on several systems. The scores of the 10 items were transformed into a summary score ranging from 0 to 100, wherein the higher the value, the more user-friendly is proved to be. The scores are not percentages and should be considered only in terms of their percentile ranking.

Regarding NASA-TLX results, we considered the raw scores.

As for the cybersickness questionnaire results, they were obtained by calculating median and interquartile ranges responses. The gathered data were analysed using Microsoft Excel® statistical tools.

2.10. Hygiene and safety

To use the DENTIFY device, the user needs to make several physical contacts with the simulator, namely 3 points of contact. Additionally, the assessment tests needed to be performed during a pandemic, namely the COVID-19 pandemic, thus making it necessary to ensure all hygiene and biosafety conditions for the tests.

All testing sessions took place in a clinical environment at Egas Moniz Dental Clinic. Therefore, all participants were equipped with P.P.E. (Personal Protective Equipment), a KN-95 mask covered with a surgical mask, latex or nitrile gloves and a disposable or autoclavable cap (Fig. 10).

3. Results and discussion

3.1. Cybersickness

Regarding the Cybersickness questionnaire, participants reported only mild effects. The most frequently reported results were: slight headache in 7.69% (1 user), visual fatigue in 23.08% (3 users), difficulty maintaining focus in 15.38% (2 users) and blurred vision in 2 cases (15.38% of cases). These were attributed to fogging of the glasses due to air leakage in the nasal adaptation of the mask.

3.2. System usability scale

The highest reported score was 90 points and the lowest 62.50 points. Based on the responses, the system's average usability score was 77.50 points, with a standard deviation of 8.43 points (Table 1). The results are, therefore, 9.5 points above the average score of 68 defined by the scale.

3.3. NASA-TLX

The standard deviation was 14.7%, which suggests that there is some disagreement in the results, however not at an extreme level. From the graph, one can see that one participant had a rather high perception of workload, 77% of 100%. Compared to the minimum value of 20%, there is a considerable discrepancy between the lowest and the maximum reported values. There were, however, participants who were able to better adapt to the simulator and its limitations, displaying higher tolerance for experimental prototypes.

The time factor generated the highest discrepancy, with less experienced participants generally indicating that the exercise time corresponded to the time of a similar preparation on a real tooth, while more experienced participants indicated the opposite (Fig. 11). The physical fatigue presented was correlated with the absence of a resting point for one finger of the dominant hand, even though there was a support for the arm. However, all participants were able to prepare the proposed cavities. On average, users feel that it takes some effort to memorize control functionalities and ascertain the best position to perform the deformation, which can be correlated with non-existing previous experiences using haptic devices.

3.4. User experience

According to the feedback received, all participants indicated that they had a positive experience with the simulator. A slight learning curve was noted to be necessary since most participants reported an increasing ease of handling the simulator components as they approached the end of the task, suggesting a relatively short learning curve.

We considered the presented load index results to be relatively high because this study consisted mostly of experts who only used the system once and with no previous experiences using haptic devices. Also, we expect that the workload levels tend to decrease by increasing repetition.

Table 1
Descriptive statistics of SUS items: median, minimum value - Min, largest value - Max, interquartile range - IQR.

SUS item	Median	Min	Max	IQR
I think that I would like to use this system.	4.00	3.00	5.00	0.00
I found the system unnecessarily complex.	1.00	1.00	3.00	1.00
I thought the system was easy to use.	4.00	2.00	5.00	1.00
I think that I would need the support of a technical person to be able to use this system.	3.00	1.00	5.00	3.00
I found the various functions in the system were well integrated.	4.00	4.00	5.00	1.00
I thought there was too much inconsistency in this system.	1.00	1.00	4.00	2.00
I would imagine that most users would learn to use this system very quickly.	4.00	3.00	5.00	1.00
I found the system very cumbersome to use.	2.00	1.00	4.00	1.00
I felt very confident using the system.	4.00	3.00	5.00	0.00
I needed to learn a lot of things before I could get going with this system.	1.00	1.00	4.00	1.00
Total SUS score	**77.50**	**62.50**	**90.00**	**15.00**

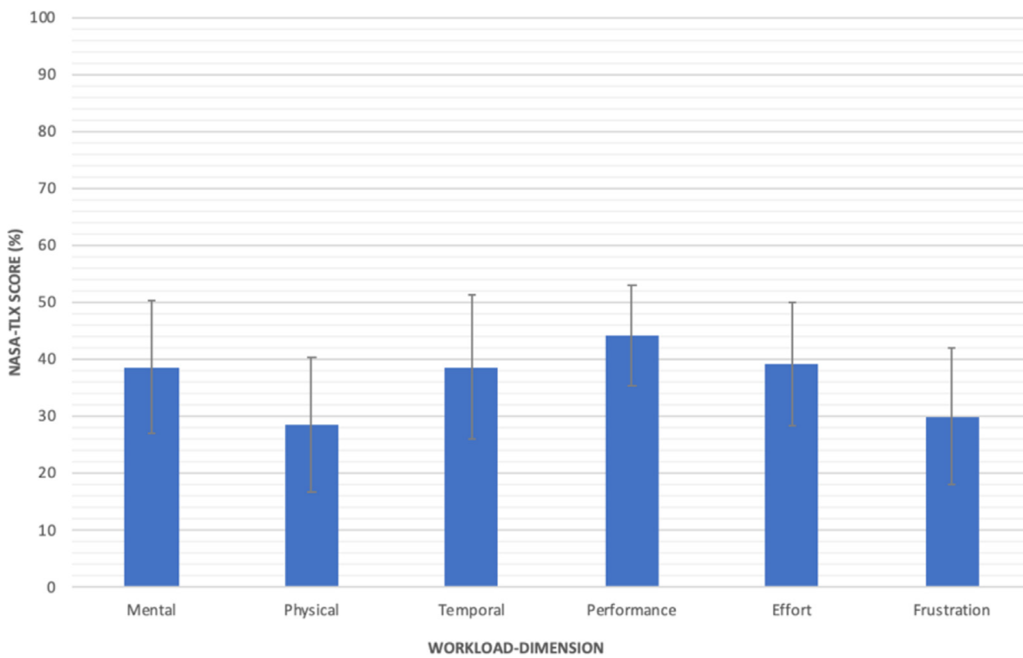

Fig. 11. NASA-TLX workload analysis results.

Table 2
Descriptive NASA-TLX workload dimensions: median, minimum value - Min, largest value - Max, interquartile range - IQR.

Workload dimension	Median	Min	Max	IQR
Mental	30.00	10.00	75.00	35.00
Physical	25.00	5.00	75.00	30.00
Temporal	40.00	5.00	80.00	37.50
Performance	40.00	20.00	65.00	37.50
Effort	45.00	10.00	70.00	35.00
Frustration	30.00	5.00	90.00	22.50

Although tactile sensitivity is subjective, all participants noted that they were able to feel the different resistance offered by the haptic pen on different virtual mineralised dental tissues and mentioned detecting differences between the progression resistance offered by the pen on virtual enamel and dentin. Overall, they reported that the drill's progression resistance in virtual enamel is approximate to that in real enamel, but considered the resistance offered to the virtual burr's progression in virtual dentin to be slightly excessive.

Users reported that there is still a noticeable learning curve when introducing students to the university clinic environment, and are of the opinion that familiarisation with a virtual clinical procedure scenario may help to mitigate difficulties inherent to this transition.

Participants mentioned that this exercise format is ideal for an initial phase of cavity preparation training, and that, at a later stage, the simulator should present an arch as opposed to only one or two teeth together, as well as include the presence of tongue, indirect vision and finger rest support. The initial phase of cavity preparation training for undergraduate teaching refers to the first learning stages that a preclinical dental student must undergo in operative dentistry, more specifically drilling using a dental turbine with an attached burr for cavity removal. In this context, traditional learning methods for preclinical dental students involve drilling on plastic teeth on phantom heads with theoretically described cavities. In our study, participants considered that the simulator adequately replicates the educational and pedagogical requisites for competence acquisition in this early phase of operative dentistry training. This first version of DENTIFY already incorporates metrics for automatic feedback on the trainee's performance which, undoubtedly, are powerful assessment tools on the students' performance (both self and tutor assessments). Such metrics include, for example, the total time spent performing the task (simulation time), drill elapsed time, average contact with simulated dental tissues in seconds, number of prolonged contacts, amongst others. The simulator also allows for users to save their data per user and per simulation, thus allowing to compile the user's graphical progressive evaluation. However, the present study aimed to evaluate user acceptance amongst trained dentists in a co-design phase, which allowed us to create a version 2.0 of

DENTIFY. We intend to test this newer version with dental undergraduate students and apply those metrics to evaluate personal performance and, consequently, further pedagogical value of the simulator.

All experts adhered well to the experiment, even mentioning that the use of virtual reality can help increase students' curiosity and interest, as well as serve as a pedagogical tool for exploration and acquisition of new skills. That said, the participants considered adopting and generalising the use of this type of technology as a complement to traditional training techniques.

3.5. Future work

This study's purpose was to introduce DENTIFY version 1.0 to experienced dental professionals to assess its pedagogical value and to obtain information regarding alterations it must undergo to better translate clinical day to day practice, thus reducing the distance between preclinical and clinical environments. In this context, DENTIFY's main limitations have been identified and further work must consider, for instance: adding more clinical simulated cases, bimanual manipulation including mirror and indirect vision, adding a finger resting point (for the dominant haptic device controlling hand), the creation of emergency scenarios and including both full dental arches. Although these limitations have been identified and are, currently, being worked on DENTIFY 2.0, version 1.0 presents some differentiated features, as already mentioned.

Besides the previously mentioned immersive multimodal simulation and multiple teeth training scenarios, DENTIFY's training mode and a simulation mode differ on the technical difficulty level of the presented task and also on the different adjustable settings between in each mode (which will be subject to future work). The study presented on this paper used only the training mode. Also, another main difference we can report is that the task exercises used to test version 1.0 were obtained from real human models, as described earlier in subsection 2.6. The authors believe that reducing the gap between simulation and clinical reality will ease the transition from preclinical undergraduate simulation into clinical reality. The use of real models is of our utmost priority. This way, we intend to collect real cases obtained at Egas Moniz Dental Clinic and, anonymously, convert them into simulation models so that undergraduate preclinical students can be exposed to a wide range database of real simulated clinical situations that dentists deal with on a daily basis. This will approach the pre-clinical student to clinical reality and, expectedly, increase treatment predictability and decrease human errors.

It is our objective to test DENTIFY V2.0 with undergraduate students and, hopefully, to incorporate these type of simulators in dental teaching, not only in Operative Dentistry but also in other areas of Dental Medicine. The authors consider that one of the main challenges for the developing dental simulators concerns their ability to translate real clinical scenarios into simulated ones. In other words, the realism of the simulation is a consequence of the realistic data added to the simulator. In this way, focus must be put on both visualization and touch feedback in order to improve realistic the inclusion of clinical cases to the training tasks and challenges of dental simulators.

One of the main limitations presented regarding the use of VR and, mostly, haptic technology is hardware and software costs. This must be considered when projecting the use of these technologies in dental schools, mainly in developing countries and schools with numerous students, for example. Further work must be put on simulators to prove their unequivocal benefit in terms of pedagogical advantage and, also, to make them more affordable since this can place some financial stress on dental schools. However, one must also consider the cost of creating rooms with numerous individual work posts equipped with compressed air, the hardware and logistics necessary to make these rooms a reality and, ultimately, the costs of the plastic models needed to perform classical dentistry teaching.

In this study, participants presented physical health and had no relevant issues that could affect the use of VR headsets. We agree that the presence of physical impairments could compromise their performance and, also, the results. This must be taken into consideration when the intention is to make these technologies generally accessible in dental schools. We emphasize that visual impairments are normally corrected by spectacles or contact lenses (it may be interesting to explore whether these corrective measures impact performance) and the probability of undiagnosed visual diseases is seldom. As such, we will consider this possible confounding variables in future tests.

4. Conclusion

The introduction of haptic technology and Virtual Reality (VR) have added new dimensions to education and the approach to daily professional challenges. Simulation in healthcare has been focused on both clinical and educational aspects. The fast growing pace of these technologies must be accompanied with clarity and objectiveness. Further debate is necessary to adress and clarify such studies, such as the guidelines proposed by Cheng et al. [8].

In Health education, the approach paradigm to both patient and disease has changed. It is unequivocally intended that a training process that is closer to reality will allow for fewer complications arising from the medical act, greater predictability and lower morbidity.

Pre and postgraduate education in Dentistry require an evolutionary break; a qualitative leap, in line with the real technological potential that we currently have. More predictable results are sought, exhibited by students with more training hours, and with the constancy of competence that comes from repetition. This is a real need and opportunity for Education, particularly applicable in the context of distance learning motivated by the pandemic. However, solutions closer to reality should be sought, based on feedback by professionals and teachers.

This study's results allow to conclude that DENTIFY was well accepted by this group of professional dentists who have also reported it to have usability, user acceptance and educational usfulness. Further studies are required to assess DENTIFY properties in Dental Education settings.

Credit author statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication before its appearance in the Computer Methods and Programs in Biomedicine.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The work reported in this article was partially supported by national funds through Fundação para a Ciência e a Tecnologia (FCT) with reference UIDB/50021/2020.

References

[1] S.A. Mallikarjun, S. Tiwari, S. Sathyanarayana, P.R. Devi, Haptics in periodontics, J. Indian Soc. Periodontol. 18 (1) (2014) 112.

[2] S. Perry, S. Bridges, M. Burrow, The role of simulation technology in dental education: a review, IADR Asia/Pacific Region (APR) Regional Meeting and Co-Annual Scientific Meeting of IADR Divisions, 2013.

[3] A. Plessas, Computerized virtual reality simulation in preclinical dentistry: can a computerized simulator replace the conventional phantom heads and human instruction? Simulation in Healthcare 12 (5) (2017) 332–338.

[4] P. Rhienmora, P. Haddawy, S. Suebnukarn, M.N. Dailey, Intelligent dental training simulator with objective skill assessment and feedback, Artif. Intell. Med. 52 (2) (2011) 115–121.

[5] E. Roy, M.M. Bakr, R. George, The need for virtual reality simulators in dental education: a review, Saudi. Dent. J. 29 (2) (2017) 41–47.

[6] M. Durham, B. Engel, T. Ferrill, J. Halford, T.P. Singh, M. Gladwell, Digitally augmented learning in implant dentistry, Oral Maxillofac. Surg. Clin. 31 (3) (2019) 387–398.

[7] E.R. Zorzal, S.F. Paulo, P. Rodrigues, J.J. Mendes, D.S. Lopes, An immersive educational tool for dental implant placement: a study on user acceptance, Int. J. Med. Inform. 146 (2021) 104342, doi:10.1016/j.ijmedinf.2020.104342.

[8] A. Cheng, D. Kessler, R. Mackinnon, T.P. Chang, V.M. Nadkarni, E.A. Hunt, J. Duval-Arnould, Y. Lin, D.A. Cook, M. Pusic, J. Hui, D. Moher, M. Egger, M. Auerbach, Reporting guidelines for health care simulation research, Simulation in Healthcare: The Journal of the Society for Simulation in Healthcare 11 (4) (2016) 238–248, doi:10.1097/sih.0000000000000150.

[9] M. Kaluschke, M.S. Yin, P. Haddawy, N. Srimaneekarn, P. Saikaew, G. Zachmann, A shared haptic virtual environment for dental surgical skill training, in: 2021 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), IEEE, 2021, doi:10.1109/vrw52623.2021.00069.

[10] J. Jerald, The VR book, Association for Computing Machinery (2015), doi:10.1145/2792790.

[11] C. Sewell, D. Morris, N.H. Blevins, S. Agrawal, S. Dutta, F. Barbagli, K. Salisbury, Validating metrics for a mastoidectomy simulator, in: MMVR, Citeseer, 2007, pp. 421–426.

[12] S. Suebnukarn, P. Haddawy, P. Rhienmora, K. Gajananan, Haptic virtual reality for skill acquisition in endodontics, J. Endod. 36 (1) (2010) 53–55.

[13] X. Chen, L. Xu, Y. Sun, C. Politis, A review of computer-aided oral and maxillofacial surgery: planning, simulation and navigation, Expert Rev. Med. Devices 13 (11) (2016) 1043–1051.

[14] C.G. Correa, M.A.D.A.M. Machado, E. Ranzini, R. Tori, F.D.L.S. Nunes, Virtual reality simulator for dental anesthesia training in the inferior alveolar nerve block, J. of Appl. Oral Sci. 25 (4) (2017) 357–366.

[15] A. Urbankova, Impact of computerized dental simulation training on preclinical operative dentistry examination scores, J. Dent. Edu. 74 (4) (2010) 402–409.

[16] J.A. Buchanan, Experience with virtual reality-based technology in teaching restorative dental procedures, J. Dent. Edu. 68 (12) (2004) 1258–1265.

[17] H. Kikuchi, M. Ikeda, K. Araki, Evaluation of a virtual reality simulation system for porcelain fused to metal crown preparation at tokyo medical and dental university, J. Dent. Edu. 77 (6) (2013) 782–792.

[18] D. Zhang, Q. Zhu, J. Xiong, L. Wang, Dynamic virtual fixture on the euclidean group for admittance-type manipulator in deforming environments, Biomed. Eng. Online 13 (1) (2014), doi:10.1186/1475-925x-13-51.