투고일 : 2020. 5. 19　　심사일 : 2020. 7. 8　　게재확정일 : 2020. 7. 24

1

Effects of auditory feedback and task difficulty on the cognitive load and virtual presence in a virtual reality dental simulation

[1]Department of Pediatric Dentistry, School of Dentistry, Chonnam National University
[2]Department of Education, College of Education, Chonnam National University

Byunggee Kim[1], Eunbyul Yang[2], Namki Choi[1], Seonmi Kim[1], Jeeheon Ryu[2]

ORCID ID
Byunggee Kim, https://orcid.org/0000-0003-3436-3750
Eunbyul Yang, https://orcid.org/0000-0003-0024-4964
Namki Choi, ID https://orcid.org/0000-0003-4830-8568
Seonmi Kim, ID https://orcid.org/0000-0001-5103-767X
Jeeheon Ryu, ID https://orcid.org/0000-0003-2891-283X

ABSTRACT

Effects of auditory feedback and task difficulty on the cognitive load and virtual presence in a virtual reality dental simulation

[1]Department of Pediatric Dentistry, School of Dentistry, Chonnam National University
[2]Department of Education, College of Education, Chonnam National University

Byunggee Kim[1], Eunbyul Yang[2], Namki Choi[1], Seonmi Kim[1], Jeeheon Ryu[2]

This research examined the difference in cognitive load and the virtual presence depending on auditory feedback and task difficulty in haptic-based dental simulation. In the field of dental education, practice-centered training using handpiece has been crucial because a practitioner's psychomotor experience has a significant impact on the mastery of treatment skills. For the novice, it is necessary to reduce errors in dental treatment to enhancing skill acquisition in the haptic practice. In the training process, the force-feedback is crucial to elaborate subtle movement to guide what to do and how it should be hard or soft. However, It is not easy to add force-feedback to generate kinetic experience training. As an alternative method, we examined that auditory feedback can help learners' skill training. In this study, we analyzed how the presence/absence of auditory feedback at the different levels of task difficulty impacts learners' psychological demand and virtual presence in the virtual reality simulation. For this study, 29 dental college students participated in a dental simulation. The participants were grouped into two conditions that are with and without auditory feedback. Additionally, two consecutive tooth preparation tasks with different levels of difficulty were used in the simulation. The auditory feedback condition gives alarms to a learner when he treats a non-targeted tooth with a virtual handpiece. The user's cognitive load and virtual presence were measured to examine the effects of auditory feedback. The results revealed that the main effect was found in cognitive loads. Also, a significant interaction effect was shown in the virtual presence. We discussed the effective design methods for the virtual reality-based dental simulation through the result of this study.

Key words : Cognitive load, Virtual presence, Virtual reality simulation, Dental education

Corresponding Author
Jeeheon Ryu
Department of Education, College of Education, Chonnam National University, 33 Yongbong-ro, Buk-gu, Gwangju, 61186, Korea
TEL : +82-62-530-2353 / FAX : +82-62-530-2340 / E-mail : jeeheon@jnu.ac.kr

ACKNOWLEDGEMENT　This work was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2018S1A5B8070203)

Introduction

Virtual reality (VR) provides hands-on-experience to learners by providing a haptic operation in a virtually enhanced learning environment. The VR simulation can provide the virtual world working just like in the real world so that the learners can improve the manipulative experience[1]. The VR training simulation gives opportunities for the learner with kinetic practice, which increases immersion and learning engagement in learning activities[2]. In the field of dental education, VR applications have been developed to take advantage of the immersive learning experience for the learners to give authentic experience. For instance, some applications (Simodont, VOXEL-MAN Dental, and Periosim) allow dental clinical treatments to practice in the VR learning environment[3]. The purpose of these applications is to help dental students acquire core dental treatment skills by practicing realistically. In a learning environment implemented with VR, learners acquire information in real-time through various sensory interactions. For the development of a dental VR simulation, the importance of providing haptic factor has been emphasized to increase realistic practice. Haptics is a factor increasing the virtual presence, which is a subjective psychological phenomenon perceived as if a given environment is real[4,5]. Two factors are necessary to create a haptic experience: the tactile sense giving textual through skin contact and the kinesthetic sense by muscle movement[6].

Utilizing the haptic interface in VR empowers the user to experience sensory elements other than audio-visual information when the user touches a virtual object in a virtual space[7]. The additional sensory elements allow the user to immerse more in-depth into the VR and perceive it as an authentic experience[8]. For the more realistic dental training, it is crucial to give force feedback, the physical sensation of resistive forces, to a VR device in controls of the virtual handpiece in a dental simulation. However, because it is not easy to implement force feedback to a VR simulation, we need to delineate an alternative method to stimulate the tactile sense during training. For this additive way, auditory feedback can amplify the haptic experience when a learner is using virtual tools if he is not correctly using a virtual tool on an undesirable target tooth. With the auditory information, a learner can have a realistic experience.

While we increase the immersive effect on learners with visual, auditory, and tactile stimuli, it is necessary to keep the learning information not too much provided to the learner. To increase the immersive perception, if too much information was given, the amount of information may be too much sufficient for learners to execute cognitive process[9]. Therefore, when designing a virtual learning environment, it is essential to set the cognitive load at an appropriate level, even if multiple types of information from tactile to auditory are given to the learning in the virtual learning environment. The cognitive load theory is a theoretical framework for designing the instructional media to effectively allocate the limited cognitive capacity of learners to perform tasks[10].

It focuses on reducing the unnecessary cognitive load and facilitating the essential mental effort for learning[11]. Mainly, when performing dental preparation in the VR simulation, auditory feedback can cause extraneous cognitive load by adding audio information in the VR simulation.

Further, the haptic experience can increase the cognitive load because it includes both audio and tactile stimuli. Therefore, the purpose of this study is to examine the differences in the virtual presence and cognitive load perceived by dental students while performing a simulated preparation with and without auditory feedback.

Materials and Methods

The study protocol was approved by the Institutional Review Board at Chonnam National University (IRB# 1040198-190819-HR-086-02).

1. Participants

The participants in this study were 29 students (17 men and 12 women) attending a school of dentistry at a flagship public university. All participants were recruited from the 3rd (15 participants, 51.7%) and 4th (14 participants, 48.3%) grades. The 3rd graders had completed practice classes using high-fidelity simulation. The 4th graders had additional clinical experiences with patients under supervision. The participants were randomly assigned to two conditions. The experimental group consisted of 15 students (3rd grade = 7 students, 4th grade = 8 students), and the control group consisted of 14 students (3rd grade = 8 students, 4th grade = 6 students). We used 2(task difficulty: high vs. low) × 2(auditory feedback: presence vs. absence) mixed design, with repeated measures on the first factor. Each participant experienced all two tasks.

2. Development of VR simulation

It was essential to build a dentiform to design a VR-based simulation to embedded in a virtual patient. To obtain a 3D graphic model, a standard dentiform with separate gums and teeth were scanned. The separated tooth could be used as the target tooth with a cavity. For the dentiform modeling, 3D MAX (Autodesk INC, California, US) with Optimize modifier the technique was used to smooth the surface(Fig. 1). The dentiform was embedded in a virtual child for virtual simulation. Unity 3D(Unity Technologies, San Francisco, US) was used to develop the simulation. Oculus Rift CV1 (Facebook Technologies, LLC. California, US) with controllers was used to operate a dental handpiece in the simulation(Fig. 2).

3. Experiment Procedure

Participants had a training session using the VR simulation with head mounted display (HMD) was provided for 10 min before the experiment. Auditory feedback was a buzzer to alarm a participant missing a target tooth. The feedback continued until

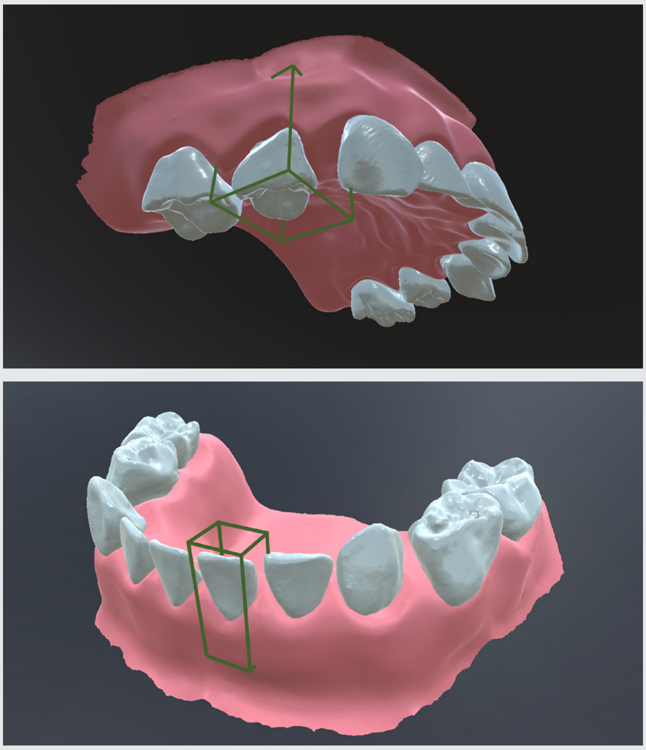

Fig. 1. Developed dentiform three-dimensional model.
Fig. 1a. Maxillary posterior teeth model.
Fig. 1b. Mandibular anterior teeth model.

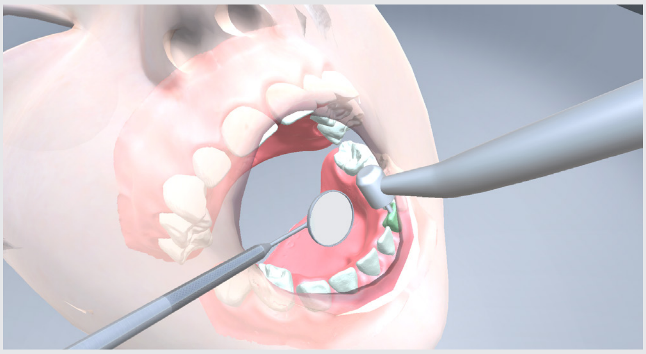

Fig. 2. VR tooth cavity preparation simulator: Participants' view.

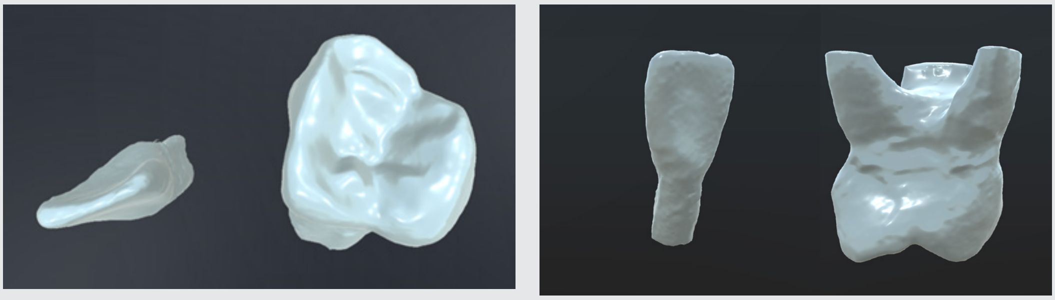

Fig. 3. Task difficulty: according to the surface size.
Fig. 3a. Buccal view of the teeth surface.
Fig. 3b. Occlusal view of the teeth surface.

he put a hand-piece on a target. The experimental group had this auditory feedback but not in the control group. For both groups, participants felt the haptic experience of vibration of the hand-piece.

In each group, two tasks of preparation were to be performed on the target tooth. The level of the task difficulty was categorized as high and low based on the size of the tooth surface. The high-difficulty task involved the preparation of the lower anterior tooth(#31). The low-difficulty task was a preparation of the upper posterior molar(#54)(Fig. 3). The size of the target tooth in the high-difficulty task was approximately four times greater than that in the low-difficulty task. The high-difficulty task was performed first. The experimental scene is shown in Fig. 4.

Fig. 4. Experimental Scene.

4. Evaluation of the developed VR tooth preparation simulator

Immediately after completing each task, participants were asked to fill out a questionnaire (Table 1). The questionnaire consisted of items to measure the cognitive load and virtual presence. We evaluated a self-rating scale considering the learners' subjective experience of the cognitive load and virtual presence.

Table 1. Survey items and mean scores for the VR simulation

section	Questionnaire
Cognitive load factors	
Task demand	I felt spent after the task.
	I felt the physical demands while I was using the simulator.
	I felt physically tired during the task.
	I felt exhausted when I was using the VR simulator.
Mental effort	I focused on the task to be performed.
	I performed hard to complete the given tasks.
	I concentrated on my mental effort when using the simulator.
	I did my best to understand the contents.
Perceived task difficulty	It was not easy to understand using the VR simulator
	The difficulty of the task was high.
	It was difficult for me to understand the concepts.
	It was hard to recognize the differences between concepts.
Self-evaluation	I think that I successfully understood the learning material.
	I am confident to properly apply what I performed.
	I am satisfied after solving the tasks.
	I think that I effectively performed the given tasks.
Virtual presence	
Spatial presence	I felt like I was actually looking at the subject.
	In the virtual environment, I had a sense of being there.
	I could easily recognize the atmosphere of the virtual practice environment.
	I felt like I could touch the object in the virtual environment.
	I felt the objects embodied in the virtual environment like a real thing.
Involvement	The presented screen seemed to capture all of my senses.
	The visual factors of the presented scene involved me.
	I seemed to be in the situation in the virtual environment.
	I was completely captivated by the virtual world.

section	Questionnaire
Realness	I felt immersed in the virtual practice.
	I felt the virtual object was real.
	The physical properties of space were perceived as real.
	I felt the virtual practical scenes were realistic.
	I felt the virtual object was realistic.
	I felt that the object of practice was natural.

In a cognitive load category, we assessed the cognitive load when using a VR simulator12). It contained 20 questions. There was a four-factor structure for the cognitive load ratings: task demand(TAD), mental effort(MEN), perceived task difficulty(DIF), and self-evaluation(SEV). TAD questions are a psycho-physical factor that evaluates learners' physical effort to perform the tasks. MEN covers a cognitive effort factor for cognitive processing. If a learner more effort towards learning outcomes, the mental efforts increases. DIF questions cover the perceived difficulty of using the VR tooth preparation simulator. The answer to these questions shows that participants had difficulty playing the simulator and reaching their goals. SEV questions cover their satisfaction with performance using a VR simulator. The Cronbach's alpha coefficient for the cognitive load was α=.97 for the TAD, α=.94 for the MEN, α=.95 for the DIF, α=.86 for the SEV.

In the section of virtual presence, the questionnaire containing 15 items related to the experience in the VR environment13). The virtual presence is sensory feelings that the individual's perception in VR environments. This questionnaire was based on the conception of presence and had three major sub-scales: spatial presence, involvement, and realness. Spatial presence items evaluate the sense of being physically surrounded while performing the tasks in the VR simulation. Involvement refers to users' immersion and attention in the performing tasks of the VR environment. Realness describes the subjective experiences of perceived realness in the VR simulation. The items were good to reliability coefficients for the virtual presence of a virtual simulator. Specifically, the Cronbach's alpha coefficient of the virtual presence was α=.95 for the spatial presence, α=.96 for the involvement, α=.96 for the realness. Each item was to be rated on a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). The procedure of the experiment composed of three sections: background investigation, treatment, and evaluation.

Results

We conducted a two-way repeated-measures multivariate analysis of variance (RM-MANOVA). A between-subjects factor is auditory feedback condition(presence vs. absence) that distinguishes between those groups, and a within-subjects factor is task difficulty with two levels(high vs. low). Table 2. provides descriptive statistics of all outcome

Table 2. Means and standard deviation of cognitive load and virtual presence

	High difficult task		Low difficult task	
	Auditory feedback	No auditory feedback	Auditory feedback	No auditory feedback
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*
Cognitive load				
Task demand	3.88 (1.49)	3.89 (1.75)	3.97 (1.59)	3.80 (1.56)
Mental effort	5.47 (1.09)	5.61 (1.09)	5.53 (0.95)	5.73 (1.19)
Perceived task difficulty	4.92 (1.46)	4.59 (1.38)	4.72 (1.45)	4.13 (1.40)
Self-evaluation	3.43 (1.16)	3.88 (0.99)	4.10 (1.48)	4.04 (1.22)
Virtual presence				
Spatial presence	3.39 (1.37)	3.70 (1.03)	3.73 (1.49)	3.80 (0.91)
Involvement	3.96 (1.51)	4.51 (1.24)	4.39 (1.24)	4.50 (1.39)
Realness	3.40 (1.39)	3.56 (1.01)	3.76 (1.43)	3.41 (0.85)

variables on each condition.

1. Cognitive load

The results of these MANOVA analyses on cognitive load are shown in Table 3. For the within-subject effects, there was a significant main effect of tasks on perceived task difficulty(DIF) with the Greenhouse-Geisser correction. DIF was evaluated at following conditions: $F_{(1,27)}$=5.11, p=.032, partial η^2=0.16. The mean DIF score was significantly higher with a high-difficulty task than a low-difficulty task. When performing a high-difficulty task (M=4.76, SD=1.41), participants perceived a signifi-

Table 3. Summary of MANOVA results on cognitive load

	TAD			MEN			DIF			SEV		
	df	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*
auditory feedback	1,27	0.02	.896	1,27	0.20	.661	1,27	0.82	.375	1,27	0.23	.639
task difficulty	1,27	0.00	.982	1,27	0.61	.442	1,27	5.11	.032*	1,27	3.38	.077
Auditory feedback x task difficulty	1,27	0.44	.511	1,27	0.06	.814	1,27	0.81	.376	1,27	1.26	.271

* p<.05

cantly higher task difficulty than when performing a low-difficulty task (*M*=4.43, *SD*=1.43)(Fig. 5). However, there were no interaction effects of the auditory feedback and task difficulty on DIF ($F_{(1,27)}$=0.81, *p*=.376 with the Greenhouse-Geisser correction). As for the main effect of the auditory feedback, there was no difference in DIF between the two group conditions ($F_{(1,27)}$=0.82, *p*=.375 with the Greenhouse-Geisser correction).

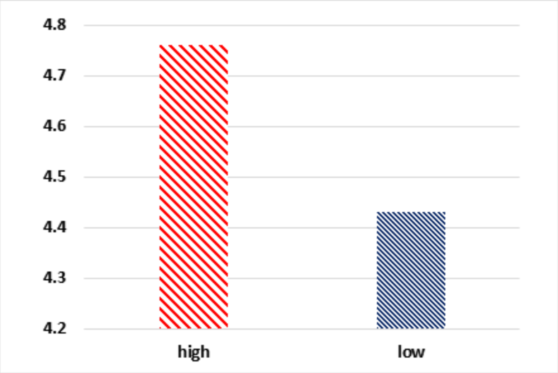

Fig. 5. Task difficult on Perceived task difficulty.

2. Virtual presence

For the within-subject effects, there was a significant interaction effect on the realness with the Greenhouse-Geisser correction ($F_{(1,27)}$=5.00, *p*=.034, partial η^2=0.16)(Fig. 6). However, results showed that

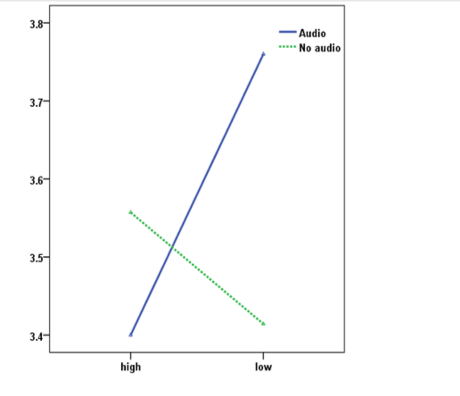

Fig. 6. Significant interactions on realness.

the main effect of neither the auditory feedback ($F_{(1,27)}$=0.05, p=.829 with Greenhouse-Gesieer correction) nor the task difficult main effect ($F_{(1,27)}$=0.93, p=.343 with Greenhouse-Gesieer correction). A summary of all main and interaction effects on virtual presence can be found in Table 4.

Table 4. Summary of MANOVA results on virtual presence

	Spatial presence			Involvement			Realness		
	df	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*
auditory feedback	1,27	0.19	.669	1,27	0.47	.498	1,27	0.05	.829
task difficulty	1,27	3.12	.089	1,27	2.59	.119	1,27	0.93	.343
Auditory feedback x task difficulty	1,27	0.95	.338	1,27	2.96	.097	1,27	5.00	.034*

* $p<.05$

Discussion

Dental education has continuously advanced innovative educational methods for a better transition from pre-clinical education to clinical-practice[3]. With these developments, the effective use of technology has become necessary with the current rapid expansion of training methods[14]. In the past few years, using artificial acrylic typodont teeth has been one of the most common hands-on-training methods to practice operative procedures in the simulation laboratory[15]. Training simulations have become an essential part of dental education to develop expertise[3]. It is not surprising that Ziv et al. (2003), in their educational study on simulation, claimed using the simulation to refine their clinical skills for almost two decades. The use of simulation is desirable to practice complicated skills within the safety of the patient during the training[16]. Furthermore, a dental student can repeatedly practice until achieving a target level of completion with the benefits of a safe method for patients.

Recently, dental educators start to using the virtual reality-based simulation to improve the transition from the pre-clinical student laboratory to the clinic[17]. For instance, because of the possible advantage of faster skill acquisition and the development of superior quality of preparation, the use of VR simulation significantly improved the satisfaction level[18]. However, in VR-based simulations, whether the simulation was effective in improving technical skills was evaluated while the influence of auditory feedback to enhance sophisticated operation without force-feedback in the VR simulation[15].

In this study, we examined how auditory feedback affected the cognitive load and virtual presence. The teeth's size and location determined the task difficulty: the posterior maxillary tooth was a low-difficulty task, while the mandibular anterior tooth was a high-difficulty task. The difficulty setting of the preparation was set in contrast than normal tooth preparation in oral cavity. This is because the study was not part of the actual sophisticated crown preparation, but analyzed the participants' responses to the auditory effects that occurs when the virtual handpiece bur contacts with adjacent teeth outside the surface of the target tooth. As a result, the mandibular anterior teeth with a small tooth surface size were set to be more difficult than the maxillary posterior teeth with large tooth surface area.

As a result, only the perceptual task difficulty(DIF) showed significant differences between the conditions in the cognitive load measurement. The task difficulty affected cognitive load. The perception level of dental students varied depending on how much they were in the immersive experiences of VR. In other words, the student's perceptual level depends on the presence or absence of auditory feedback and the task's difficulty. In the virtual presence area, realness had significant differences among the sub-scales. In the use of VR simulation, the haptic-based auditory feedback can be a crucial factor for increasing realism.

This study suggests the following: First, when the task is difficult in VR based on haptics, providing auditory feedback enhances user perception. However, when the task is easy, providing auditory feedback is not essential. Therefore, when designing a virtual dental simulation, whether or not audio should be provided at a level of difficulty to be aware of students' virtual presence in VR based on haptics should be considered. Second, the treatment condition and task-difficulty in this study showed a significant interaction effect on the realness of virtual presence. When the task was simple with auditory feedback, the participants perceived the simulation much realistic. It means that the high complexity of the task hindered to give enough realistic perception in VR condition regardless of auditory feedback. In other words, for dental students, the audible feedback did not add a robust virtual presence when it was challenging to manage.

Further studies using more levels of challenging tasks to measure the cognitive process of participants are required to have a better understanding of the effect of auditory feedback. The auditory feedback will have a significant effect on the cognitive load in the different levels of task difficulty. For example, a dental student can precede the preparation of tooth surfaces with a procedural knowledge-based task of diagnosing and treating cavities. The depth of cavity preparation and securing eyesight of the preparation using a dental mirror could provide more cognitive loads.

This study has some limitations. Although we examined the virtual presence and cognitive loads in the auditory feedback, it is not clear that force-feedback could affect in a VR environment. Also the device used in this study was Oculus Rift CV1. Oculus and auditory effects in pain reduction have been demonstrated[19)]. However, there are no dental educational studies on this devices related to the auditory feedback. The use of a universal HMD controller could have been difficult to accurately reflect auditory feedback when compared to a real dental handpiece, which is generally a more precise instrument. It seems that further research is needed using a simulator that enables physical contact feedback and more precise controller. Similar results, observed in the experimental and control groups suggest that it is necessary to include a control group with dentists to confirm the study results.

Conclusion

In conclusion, this study shows that the level of perception depends on how haptic experiences are working in VR. In a complex simulation-based on haptics, providing auditory feedback was more useful in an easier task for students' perception. However, the tasks in this study did not significantly affect cognitive loads. Therefore, further study about the cognitive loads is needed. The present study suggests that continued research on the educational potential of virtual devices will help apply dental VR simulation effectively.

참고문헌

1. Crespo R, García R, Quiroz S. Virtual reality application for simulation and off-line programming of the mitsubishi movemaster RV-M1 robot integrated with the oculus rift to improve students training. Procedia Comput Sci 2015;75: 107-112.
2. Schrader C, Bastiaens T. Relations between the tendency to invest in virtual presence, actual virtual presence, and learning outcomes in educational computer games. Int J Hum-Comput Int 2012;28(12):775-783.
3. Roy E, Bakr MM, George R. The need for virtual reality simulators in dental education: A review. Saudi J Dent Res 2017;29(2):41-47.
4. Sallnäs EL, Rassmus-Gröhn K, Sjöström C. Supporting presence in collaborative environments by haptic force feedback. Acm T Comput-Hum Int. 2000;7(4):461-476.
5. Witmer BG, Singer MJ. Measuring presence in virtual environments: A presence questionnaire. Presence. 1998;7(3):225-240.
6. Rovers, AF, van ESSEN HA. HIM: a framework for haptic instant messaging. CHI'04 Extended Abstracts on Human Factors in Computing Systems 2004; 1313-1316.
7. Stone RJ. Haptic feedback: A brief history from telepresence to virtual reality. International Workshop on Haptic Human-Computer Interaction 2000;1-16.
8. Park S. A developed of virtual reality contents of cultural heritage utilize the Haptic interface system - Focused on Keum-san-sa content-. Journal of Korea Design Forum 2010;26(0): 245-254.
9. Lindén A, Davies RC, Boschian K, Minör U, Olsson R, Sonesson B, Johansson G. Special considerations for navigation and interaction in virtual environments for people with brain injury. In The International Conference on Disability, Virtual Reality & Assoc. Tech 2000;287-296
10. Paas F, Renkl A, Sweller J. Cognitive load theory and instructional design: Recent developments. Educ Psychol 2003;38(1):1-4.
11. Van Merrienboer JJG, Schuurman JG, De Croock, MBM, Paas FGWC. Redirecting learners' attention during training: Effects on cognitive load, transfer test performance and training efficiency. Learn instr 2002;12(1):11-37.
12. Ryu J. Sensitivity of Cognitive Load Factors and Prediction for Learning Achievement upon the Levels of Task in Multimedia Learning. Journal of Korean Association for Educational Information and Media 2011;17(3):309-332.
13. Schubert T, Friedmann F, Regenbrecht H. The Experience of Presence: Factor Analytic Insights. Presence 2001;10(3):266-281.
14. Quinn F, Keogh P, McDonald A, Hussey D. A study comparing the effectiveness of conventional training and virtual reality simulation in the skills acquisition of junior dental students. Eur J Dent Educ 2003;7(4):164-169.
15. Murbay S, Neelakantan P, Chang JWW, Yeung S. Evaluation of the introduction of a dental virtual simulator on the performance of undergraduate dental students in the pre-clinical operative dentistry course. Eur J Dent Educ 2020;24(1):5-16.
16. Ziv A, Wolpe PR, Small SD, Glick S. Simulation-based medical education: an ethical imperative. Simul Healthc 2006;1(4):252-256.
17. Jasinevicius TR, Landers M, Nelson S, Urbankova A. An evaluation of two dental simulation systems: virtual reality versus contemporary non-computer-assisted. J Dent Educ 2004;68(11):1151-1162.
18. Buchanan JA. Use of simulation technology in dental education. J Dent Educ 2001;65(11):1225-1231.
19. Johnson, S, Coxon, M. Sound can enhance the analgesic effect of virtual reality. R Soc Open Sci 2016;3(3):150567.