Optimizing Medical Device Training: The Role of Multi-User VR and Expert Guidance

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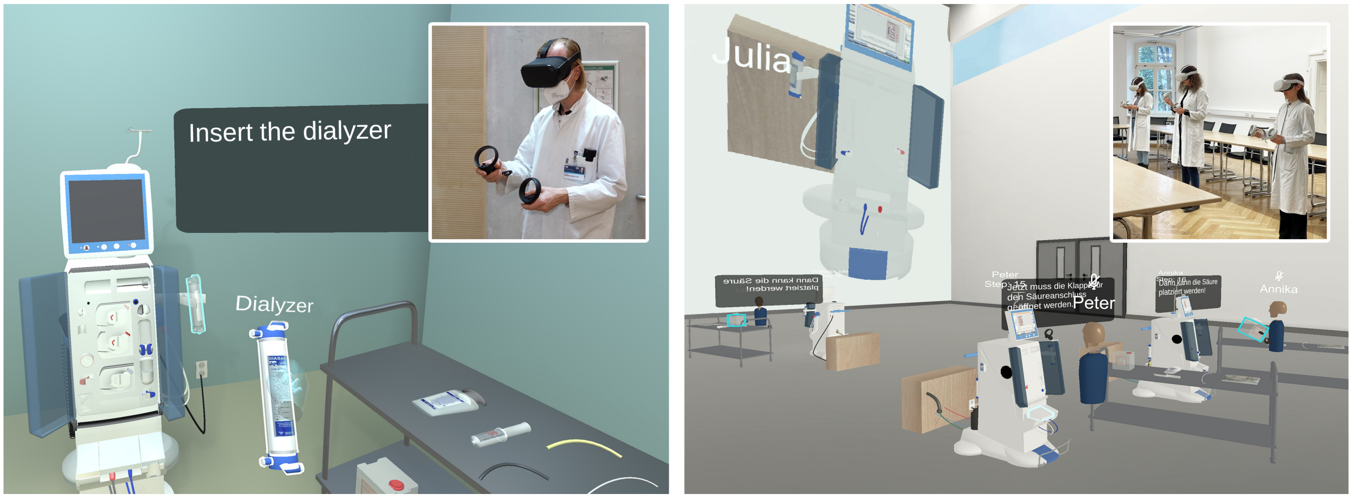

Figure 1: Medical device training on a dialysis machine in *Single-User VR* (left) and *Multi-User VR* (right).

Abstract

Before medical professionals are permitted to operate a medical device, they require appropriate training. The conventional training method, carried out on-site by an expert, has been shown to be deficient for years, posing a risk to healthcare professionals and patients. In contrast, single-user virtual reality (VR) training provides interactive priming of medical devices without the involvement of an expert but with increased training success. As multi-user VR training could offer the benefits of both methods, we investigate its potential for improving medical device training by designing, implementing, and comparing different training methods—1) conventional training under the guidance of an instructor for a group of people, 2) interactive VR training for single users, and 3) interactive VR training for multiple users with an instructor—we aim to address the existing problem of insufficient medical device training. Although the methods differ in terms of visual representation and interaction, the identical learning content in all methods allows for a valid comparison. Our findings demonstrate that Multi-User VR Training has the potential to be a useful, if not superior, alternative to conventional training.

CCS Concepts

• **Applied computing** → **Health informatics**; • **Human-centered computing** → *Virtual reality*; *Empirical studies in collaborative and social computing*.

Keywords

Multi-User, Computer-based Training, Virtual Reality, Telepresence, Medical Training, Dialysis, Assembly Task, Instruction Manual

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CSCW Companion '24, November 9–13, 2024, San José, Costa Rica.

ACM ISBN 979-8-4007-1114-5/24/11
https://doi.org/10.1145/3678884.3681883

ACM Reference Format:
Maximilian Rettinger, Julia Steinhaus, Annika Hackenberg, Lisa Lehr, Philip Neugebauer, Niklas Müller, Gerhard Rigoll, and Christoph Schmaderer. 2024. Optimizing Medical Device Training: The Role of Multi-User VR and Expert Guidance. In *Companion of the 2024 Computer-Supported Cooperative Work and Social Computing (CSCW Companion '24), November 9–13, 2024, San Jose, Costa Rica.* ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3678884.3681883

1 Introduction

Digital approaches to improve medical education have been a popular research topic in various medical fields for years [3–5, 14, 16, 17], but the area of medical device training is not as thoroughly explored. Healthcare institutions use various medical devices, necessitating staff training, typically provided on-site by a manufacturer's expert. However, this approach is generally insufficient and compromises patient safety [6, 7, 11]. Since this problem has been known for years [2, 28], no improvement is expected.

Due to financial constraints [24], training sessions are infrequent, resulting in large group sizes and complicated scheduling. The limited available space within healthcare establishments often confines training to smaller rooms [13]. Consequently, the crowdedness can negatively affect participants' performance, as other attendees or medical equipment can obstruct their visual field. These distractions reduce the effectiveness of the training [23]. In addition, trainees have limited opportunities to apply or hone their newly acquired skills, as the medical devices are mostly needed for the patients, and the staff shortages mean they have insufficient time [9]. Digital approaches, like virtual reality (VR), could mitigate these issues, offering benefits like reusability, multilingualism, and standardization [11, 15]. Previous contributions demonstrated that interactive *Single-User VR* training can improve the training outcome for medical device training compared to traditional training [22]. However, the lack of an expert to answer critical questions is a disadvantage since slight misunderstandings can have serious consequences. Multi-user VR training allows users to interactively prime the medical device and ask the instructor specific questions. As in conventional training, several users can be instructed simultaneously, but with the advantage of not being on-site. Despite these advantages, there is a lack of knowledge regarding the potential of multi-user VR training for improving medical device training. Therefore, we conducted a study ($n = 84$) to investigate the efficacy of *Multi-User VR* training compared to *Conventional* and *Single-User VR* training.

2 Related Work

Schild *et al.* [25] demonstrated that collaborative VR training can improve paramedic training. In their training scenario, two trainees worked together to treat a virtual patient in a life-threatening emergency situation. A trainer initiated and controlled the simulation. In a similar study conducted by Lerner *et al.* [12], two users had to handle a life-threatening situation of a child. The study results yield that the training is effective. Calandra *et al.* [1] presented the potential of collaborative VR training for firefighting scenarios. In another contribution, Rettinger *et al.* [19] present a scenario in which several medical professionals collaboratively investigate a complex disease in a virtual patient and discuss its treatment options, resulting in improved patient care from diagnosis to therapy.

Overall, related work highlights a lack of knowledge regarding the differences between VR training for single and multiple users and how its effectiveness differs from conventional training.

3 Method: Dialysis Training

Our work focuses on the priming procedure of a Fresenius Medical Care 5008s Cordiax hemodialysis machine used in kidney failure cases. The training content, defined by the manufacturer's manual and a nephrology expert, consists of 60 relevant training steps. These consist of 17 informative steps detailing certain features or theoretical aspects and 43 steps requiring user-machine interaction (see Table 1). These steps are identical for all three training methods. We implement the software for the two VR applications using Unity 3D (v. 2019.3.10f1) and create the required 3D models with the modeling tool Blender (v. 2.80). The hardware used is the Oculus Quest Head-Mounted Display and its controllers.

3.1 Conventional Training

The traditional device training involves a group of healthcare professionals getting trained simultaneously by a nephrology expert, performing and explaining all defined steps live on the medical device. Since our Conventional condition serves as the baseline, it occurs under the same conditions (*e.g.*, the training content and duration) as traditional device training. Due to pandemic hygiene regulations, this training method occurs in a lecture hall. This does not affect the evaluation since the space and seating arrangement provides a clear view of the training content.

3.2 Single-User VR Training

As depicted in Figure 1, this method allows users to immerse themselves in a virtual environment for interactively priming the medical device using the HMD Oculus Quest. For this, the software is implemented with Unity 3D, and the required 3D models are generated with Blender. Combined with the Oculus 6-degree-of-freedom controllers, interaction with the virtual environment can be carried out in various ways. Informative steps are confirmed by pressing a button. Virtual device switches are activated by colliding with the user's virtual hand. Device components that need to be placed on the virtual device are grabbed and transformed by pressing and holding a trigger and dropped by releasing the trigger. As it is a single-user application, instructions are provided via recorded voice instructions, which are also displayed as textual cues next to the dialysis machine. This approach aims to enhance training success and ensure comparability [20, 21]. Users are able to see only their virtual hands but not themselves as an avatar. As the dialysis machine is usually used in a patient's room, the virtual environment corresponds to it, thus increasing the user's immersion and mental performance [18].

3.3 Multi-User VR Training

This method extends the *Single-User VR* training, allowing multiple users to complete the dialysis training simultaneously and from any location in the same virtual room. As in *Conventional* training, an instructor demonstrates the priming procedure on a dialysis

Table 1: This table presents an extract of the steps performed by the users for priming the dialysis machine. These are consistent in all three training methods, but in *Conventional* training, they are carried out by the instructor, in *Single-User VR* training by the user, and in *Multi-User VR* training by the instructor and user.

ID	Interaction task	ID	Interaction task
1	Insert dialyzer	2	Insert citrasate canister
3	Connect canister with hose	4	Insert sporotal
5	Connect sporotal with tubing	6	Activate switch behind the machine
⋮	⋮	⋮	⋮
38	Turn and pull substitute port to attach substitute plug	39	Connect one end of the SafeLine to the substitute port
40	Close the substitute port	41	Attach red drain hose to lower part of the filter
42	Attach blue inlet hose to the upper part of the filter	43	Close the device doors

machine and answers users’ questions. However, the difference is that each participant has a dialysis machine placed in front of them, which they prime according to the instructor’s explanations. This means that the instructor carries out a step and explains it, followed by the participants performing this step on their machine before the instructor proceeds to the next step. As in the *Single-User VR* training, the participants see text cues for each step next to the device, but without voice records, as all users can communicate via voice chat. As illustrated in Figure 1, participants can see each other as an avatar, but as in the *Single-User VR* training, they can only see their own hands. Users can also see each other’s actions, device components, and progress. Above each user’s avatar, his name is displayed for mutual identification. This name is also visible above the user’s dialysis machine and the corresponding step number at which the user is currently in the priming process. This allows the instructor to see if a participant is having problems and to directly intervene. The instructor’s activities are also projected on a screen behind him, as in a lecture hall, to provide a better view of the training content. Photon Unity Network (PUN2) is used for user networking in the software.

4 Experiment

4.1 Preliminary Study

We performed a preliminary study (n = 10) to examine the functionality, usability, and challenges of the conditions *Single-User VR* and *Multi-User VR*. It revealed that users of the VR trainings complained about mild symptoms of cybersickness [10] while bending down. For this reason, we reduced the user’s bending motion by placing the interactable objects on the virtual table that were previously underneath it. Regarding the *Multi-User VR* training, we found that conducting the training simultaneously via telepresence in different rooms was difficult due to the limited number of free hospital rooms. For this reason, the participants completed the training together in one large room. The voice transmission in the application was accordingly deactivated to prevent any interference.

4.2 Study Design

A between-subjects design was conducted to evaluate participants’ training success with the training method as the only independent variable with three levels (*Conventional*, *Single-User VR*, and *Multi-User VR*). As dependent variables, we collected the participants’ training duration and their ratings of subjective questions. These were specific questions presented in Table 2 and the Raw NASA Task Load Index Questionnaire (RTLX) [8] for workload assessment. Furthermore, the effectiveness of the training was evaluated one week after the dialysis training using an online test, which participants received by e-mail. The online test questions listed in Table 3 consisted of single-choice questions with three possible answers and matching questions for assigning five items/labels in a figure.

4.3 Procedure

After explaining the study procedure, participants were asked to sign a consent form and provide their demographic information, followed by an explanation of the respective training method and its hardware. Subsequently, the *Single-User VR* and *Multi-User VR* training participants completed a tutorial scenario to familiarize themselves with the technology and its interaction. Dialysis training was then completed, followed by another questionnaire. Participants were informed that they would receive an online test by e-mail one week after the training and were expected to complete it honestly and without assistance. The study took about 45 minutes, with no time limit for each training method. Participants received a remuneration of $16.5 for their participation.

4.4 Participants

The participants (n = 84) were recruited through various methods, including mailing lists, social networks, direct outreach, and flyers distributed to different clinics. In order to obtain a comparable distribution across the three training methods, we divided the participants based on their demographic data, as shown in Table 4. Regarding technical experience, six participants in the *Single-User VR* group and eight in the *Multi-User VR* group already had previous experience with VR. Based on the use case, only participants, exclusively from the medical field (physicians, nurses, and medical students/doctoral fellows), were part of this study. Those with prior dialysis training were excluded.

5 Results

We evaluated the experiment’s results statistically, using one-way analysis of variance (ANOVA) and subsequent post-hoc Tukey’s HSD tests ($\alpha = 0.05$). Statistical assumptions were verified, and a

Table 2: After completing one of the three conditions, participants rated these questions. Q1 to Q3 on a 7-point Likert scale [1 = strongly disagree, 7 = strongly agree] and Q4 to Q5 on a 6-point Likert scale [1 = very good, 6 = not sufficient].

ID	Subjective evaluation question	Category
Q1	I think this training was clearly structured.	Structure
Q2	I think the training topic was interestingly prepared.	Motivation
Q3	I feel able to prime the dialysis machine without any problems.	Training success
Q4	Which grade would you give the quality of the content?	Content quality
Q5	Which grade would you give the training overall?	Overall assessment

Table 3: Online test questions for evaluating training success.

ID	Online test question	Type
1	How many switches/buttons are operated to turn on the device?	Single-choice
2	Which hose system is connected to the SafeLine?	Single-choice
3	Which blood pump is used for priming?	Single-choice
4	Which object is attached to the device first?	Single-choice
5	Where are the two tubes attached to the dialysis machine's side connected?	Single-choice
6	What is the step after which the priming of the device is complete?	Single-choice
7-11	Assign the correct items to the markers in the image.	Matching question
12-16	Assign the correct technical terms to the marker in the image.	Matching question

Table 4: Participants' distribution to the three conditions.

		Age		Gender		Medical Profession		
Method	n	M	SD	Male	Female	Doctor	Nurse	Student/PhD
Conventional	28	28.57	7.41	8	20	7	3	18
Single-User VR	28	33.89	11.02	11	17	8	11	9
Multi-User VR	28	25.68	4.00	11	17	4	2	22

Welch correction was applied if homogeneity was violated (Levene's test).

5.1 Training Duration

Welch's ANOVA results showed a significant difference in the average training duration (reported in minutes) participants needed to complete the training $F(2, 39.263) = 31.554$, $p < .001$, $\eta^2 = 0.334$. Pairwise comparisons indicated that the *Multi-User VR* training ($M = 12.07$, $SD = 2.56$) took significantly more time compared to the other two methods (all $p <= .003$). Also, the duration between the *Conventional* ($M = 8.39$, $SD = 0.58$) and the *Single-User VR* ($M = 10.10$, $SD = 2.68$) conditions ($p = .011$) differed.

5.2 Specific Questions

The descriptive scores of the questions Q1 to Q3, where high scores indicate a positive evaluation, are visualized in Figure 2. In contrast, lower scores on questions Q4 and Q5, visualized in Figure 3, indicate a positive rating.

Q1: "*I think this training was clearly structured.*" For the ratings of this question, Welch's ANOVA indicated significant differences between the groups $F(2, 50.930) = 18.942$, $p < .001$, $\eta^2 = 0.416$. Accordingly, the comparison between the conditions indicated that the structure of all groups was rated significantly (all $p <= .001$) better compared to the *Conventional* training ($M = 4.71, SD = 1.54$). In addition, the *Single-User VR* training ($M = 6.68$, $SD = 0.72$) received the highest scores followed by the *Multi-User VR* training ($M = 6.50$, $SD = 0.75$).

Q2: "*I think the training topic was interestingly prepared.*" Welch's ANOVA indicated a significant main effect for the preparation of the training $F(2, 48.578) = 19.760, p < .001, \eta^2 = 0.377$. The *Single-User VR* ($M = 6.54$, $SD = 0.69$) and *Multi-User VR* training ($M = 6.18$, $SD = 1.12$) were significantly (all $p < .001$) more appealing than the *Conventional* training ($M = 4.43, SD = 1.62$).

Q3: "*I feel able to prime the dialysis machine without any problems.*" For this question, we found that the three conditions significantly impacted the subjective ability of priming the machine $F(2, 81) = 4.045$, $p = .021$, $\eta^2 = 0.091$. The conditions *Single-User VR* ($M = 4.46$, $SD = 1.53$) and *Multi-User VR* ($M = 4.46$, $SD = 1.60$) received the best ratings and differed significantly (all $p = .042$) compared to the *Conventional* ($M = 3.46$, $SD = 1.43$) training.

Q4: "*Which grade would you give the quality of the content?*" In terms of content quality, no significant differences were observed between the methods $F(2, 81) = 1.956$, $p = .148$, $\eta^2 = 0.046$. On average, the *Single-User VR* ($M = 1.75, SD = 0.80$) and *Multi-User VR*

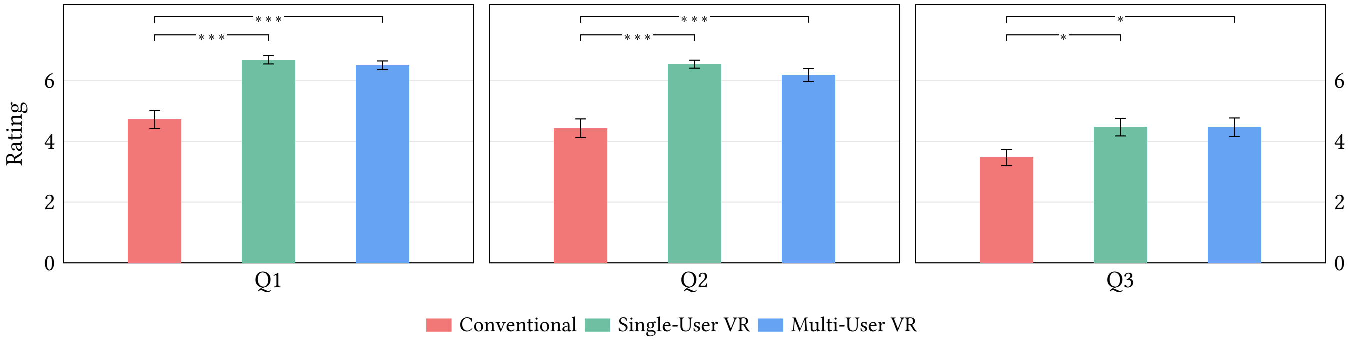

Figure 2: Mean values and standard error of the specific questions Q1 to Q3 using a 7-point Likert scale [1 = strongly disagree, 7 = strongly agree].

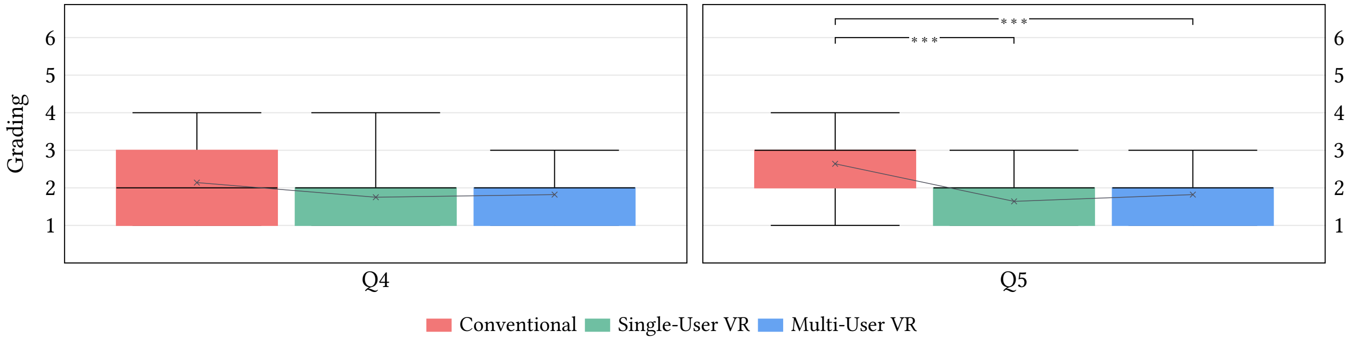

Figure 3: Results of the specific questions Q4 and Q5 using a 6-point Likert scale [1 = very good, 6 = not sufficient]. The connected crosses indicate the mean values.

($M = 1.82$, $SD = 0.61$) conditions received the best rating compared to the *Conventional* ($M = 2.14$, $SD = 0.93$) training.

Q5: "*Which grade would you give the training overall?*" The one-way ANOVA indicated a significant difference in the overall assessment of the training methods $F(2, 81) = 14.347$, $p < .001$, $\eta^2 = 0.262$. Overall, the *Single-User VR* ($M = 1.64$, $SD = 0.56$) and *Multi-User VR* training ($M = 1.82$, $SD = 0.72$) received the best ratings and indicated a significant (all $p < .001$) difference compared to the *Conventional* ($M = 2.64$, $SD = 0.91$) training.

5.3 Workload

The ratings of perceived cognitive load are presented in Figure 4 and are statistically analyzed in the following way.

MD: "*Mental demand*" Welch's ANOVA showed significant differences for mental demand $F(2, 52.970) = 5.500$, $p = .007$, $\eta^2 = 0.103$. The *Single-User VR* ($M = 30.54$, $SD = 18.73$) method performed significantly (all $p <= .032$) better than the *Conventional* ($M = 46.07$, $SD = 21.83$) and *Multi-User VR* ($M = 46.96$, $SD = 26.68$) training.

PD: "*Physical demand*" For the perceived physical demand, the statistical analysis showed an effect $F(2, 81) = 4.256$, $p = .017$, $\eta^2 = 0.095$. The physical demand of the participants in the *Conventional* ($M = 11.96$, $SD = 8.09$) condition was significantly ($p = .025$) lower than in the *Single-User VR* ($M = 23.39$, $SD = 16.84$) condition. Pairwise comparison showed no effect in the *Multi-User VR* ($M = 22.14$, $SD = 20.66$) group.

TD: "*Temporal demand*" Regarding temporal demand, Welch's ANOVA showed differences between the conditions $F(2, 53.220) = 6.356$, $p = .003$, $\eta^2 = 0.145$. Tukey's post-hoc test indicated a significant ($p = .001$) difference between the *Conventional* ($M = 41.96$, $SD = 25.22$) and the *Single-User VR* ($M = 20.89$, $SD = 18.51$) methods. Ratings for the *Multi-User VR* ($M = 30.18$, $SD = 19.74$) group were between the two methods.

P: "*Performance*" A main effect for participant perceived performance was shown by the ANOVA $F(2, 81) = 21.251$, $p < .001$, $\eta^2 = 0.344$. It indicated that the *Conventional* ($M = 48.39$, $SD = 19.72$) training performed significantly (all $p < .001$) lower compared with the *Single-User VR* ($M = 26.96$, $SD = 20.83$) and *Multi-User VR* ($M = 16.79$, $SD = 14.35$) conditions.

E: "*Effort*" Statistical comparison using Welch ANOVA showed that the effort differed between the methods $F(2, 52.635) = 4.808$, $p = .012$, $\eta^2 = 0.112$. Participants of the *Conventional* ($M = 36.96$, $SD = 23.31$) condition required the highest effort, followed by the *Multi-User VR* ($M = 25.54$, $SD = 19.83$) and the *Single-User VR* ($M = 20.36$, $SD = 15.81$) conditions. Results differed significantly ($p = .007$) between *Conventional* and *Single-User VR*.

F: "*Frustration*" In terms of frustration, the ANOVA showed a difference between the groups $F(2, 81) = 7.647$, $p < .001$, $\eta^2 = 0.159$.

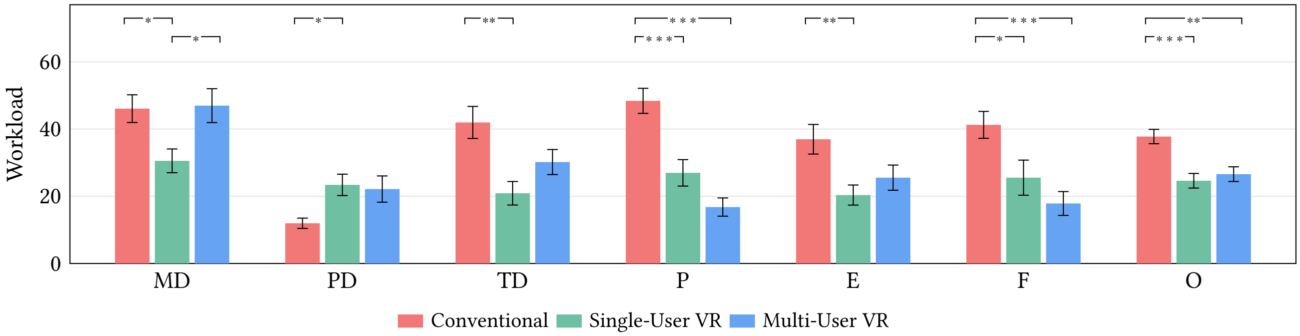

Figure 4: Mean scores of the NASA-RTLX assessments ranging from 0 [very low] to 100 [very high]. The scales are (MD) Mental demand, (PD) Physical demand, (TD) Temporal demand, (P) Performance, (E) Effort, (F) Frustration, and (O) Overall. Error bars depict the standard error.

The *Single-User VR* ($M = 25.54$, $SD = 27.63$) and *Multi-User VR* ($M = 17.86$, $SD = 18.73$) groups were significantly (all $p <= .031$) less frustrated than the *Conventional* ($M = 41.25$, $SD = 21.15$) group.

O: "*Overall*" In addition, the statistical analysis of the overall workload scores showed a clear difference between the three conditions $F(2, 81) = 10.715$, $p < .001$, $\eta^2 = 0.209$. The workload was significantly (all $p <= .001$) higher for the *Conventional* ($M = 37.77$, $SD = 11.31$) method compared to the *Single-User VR* ($M = 24.61$, $SD = 11.51$) and *Multi-User VR* ($M = 26.58$, $SD = 11.59$) methods.

5.4 Online Test

The online test to assess the training success was completed by 80 of the original 84 participants. The Welch's ANOVA showed no main effect between the average correct answers of the groups $F(2, 49.398) = 1.595$, $p = .213$, $\eta^2 = 0.039$. Regarding the descriptive findings, participants of the *Single-User VR* ($M = 8.11$, $SD = 3.07$, $n = 28$) group answered most questions correctly, followed by the *Multi-User VR* ($M = 7.79$, $SD = 1.95$, $n = 28$) and *Conventional* ($M = 6.92$, $SD = 2.24$, $n = 24$) groups.

6 Discussion

The results show that the *Multi-User VR* training duration is the longest. This is due to the fact that the training does not immediately continue after one participant completes a specific step. Instead, progress is collectively determined, requiring all participants to complete each step before the instructor continues with the next step, ensuring a concurrent learning pace. In addition, participants in the multi-user scenario engaged more with the instructor by asking more questions than in the group condition. These questions were not related to the priming but to its associated effects, such as the respective reactions in the device, which is consistent with the results of Q2 indicating that VR training users have a higher motivation. Therefore, we hypothesize that the communication barrier in VR is lower than in a physical environment, which should be investigated in future work.

Regarding Q2, participants rated the VR conditions structure significantly higher. However, it is essential to note that all training methods provided the same training content in the same order, supported by the equally rated content quality (Q4). For this reason, we attribute this effect to the training speed controlled by the participants' interactions in the VR methods.

The RTLX scale results indicate a lower workload in the VR conditions, except for the physical demand, which is due to its interactivity. Furthermore, the VR conditions only differ in the RTLX scale mental demand, which is explainable by the additional training information and the other participants, increasing the extrinsic load [23, 26].

The VR conditions achieved significantly higher ratings for perceived training success (Q3), mirroring the overall ratings (Q5) and the overall workload of the RTLX. Nonetheless, the findings of the online test, in which the VR conditions yielded the highest scores, indicated no statistical effect. However, these results show that virtual methods are no less effective than conventional training and demonstrate that virtual training methods can supplement or replace conventional training in terms of subjective assessment.

Considering the findings and the possibility that *Multi-User VR* training combines the advantages of both methods (*Conventional* and *Single-User VR*), we recommend paying more attention to this method, especially for priming medical devices or similar assembly tasks.

7 Conclusion

For years, a wealth of experts have advocated for integrating improved training methods, as the long-standing issue of medical device training is a significant challenge to patient safety [27, 29]. Therefore, this contribution introduced two innovative approaches to dialysis machine training and conducted a between-subjects study ($n = 84$) to evaluate their effectiveness. The methods compared included *Conventional*, *Single-User VR*, and *Multi-User VR* training.

The findings clarify the ability of the *Multi-User VR* training method to complement or even replace traditional approaches to increase patient safety. Finally, medical professionals can participate more successfully in a training session conducted by an expert, regardless of location and without negative influencing factors (*e.g.*, restricted field of view or noise), while interactively priming the medical device.

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