Evaluating Wearable Tactile Feedback Patterns During a Virtual Reality Fighting Game

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Abstract

A two-study approach was used to explore the effects of tactile feedback patterns on virtual reality gaming experiences of participants, including presence, flow, usability, emotion, technology adoption, and tactile sensation. In our main study, participants were instructed to play a virtual reality fighting game. Five experimental conditions with different tactile feedback patterns (no-tactile, random, fixed, discrete, and realistic tactile feedback) were examined. The results of our study indicated that: (1) tactile feedback patterns have no significant effect on flow and emotion, and (2) the no-tactile feedback condition was rated significantly lower by the participants than other tactile feedback conditions in terms of presence, usability, technology adoption, and tactile sensation. A follow-up study was then conducted to understand the different effects of realistic feedback in active versus passive fighting games. The results of our follow-up study indicated that participants rated tactile sensation and usability higher when under the passive gaming condition. We discuss our findings along with the study limitations and future research directions.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality; Hardware—Communication hardware, interfaces and storage—Tactile and hand-based interfaces—Haptic devices

1 Introduction

Tactile feedback technology allows the user to experience realistic feedback while interacting in virtual environments, and it has become an important factor in enhancing realism in immersive environments [6, 24, 37]. With such technology, it is possible to apply feedback to the hands [9, 32], main body [23], and even feet [39]. Tactile feedback is widely applied in different areas, such as mobile interaction [5], augmented reality [3], surgery [21], and computer animation [23]. One major area of tactile feedback application is virtual reality (VR) gaming since VR controllers house tactile actuators.

In the 1990s, tactile feedback was implemented in game controllers[1] and arcade game machines [41]. Many game consoles, such as the PlayStation 4, Nintendo Wii, and Xbox One, already feature native controller tactile feedback in many of the major titles. With the development of tactile suits and vests, real-time tactile feedback brings VR games into a new era. Research using VR games has started to study the effect of tactile feedback on user's presence in immersive environments [25], rehabilitation [14], and training [28]. Although it has been shown that tactile feedback improves the gaming experience of participants [12, 25] and the overall user experience [23, 26], the way in which different tactile feedback patterns could influence the gaming experiences of users is still unexplored. Due to the rise in VR games and greater support for tactile feedback, it has become essential to understand the effect of tactile feedback patterns on players' gaming experience.

To further explore how users experience tactile feedback, we followed a two-study approach. In our main study, a virtual reality fighting game (active experience) was developed, and our participants were asked to fight an enemy while wearing the bHaptics tactile feedback vest in the presence of either no-tactile, random, fixed, discrete, or realistic tactile feedback. In the follow-up study, a passive game was developed, and participants' experiences were evaluated against the active fighting game that was used in the main study. In the follow-up study only the realistic tactile feedback pattern was applied in both games. Considering the fact that VR games highly improve user's immersion [4, 27], understanding the effect of different tactile feedback patterns will provide important insight to researchers and game developers. Thus, the conducted studies attempt to answer the following two research questions:

- **RQ1:** Do different tactile feedback patterns affect players' gaming experience in VR?
- **RQ2:** Do realistic tactile feedback patterns affect players' gaming experience differently in an active versus passive virtual reality game?

The paper is organized as follows. Section 2 presents work related to our study. Section 3 provides details on the main study, and Section 4 provides details on the follow-up study. Our results are discussed in Section 5, and limitations and future directions are presented in Section 6.

2 Related Work

Tactile feedback is the physical feedback of a device produced from a set of actuators. Tactile feedback devices can be used to induce somatosensory sensations in users, and it has proven to effectively provide realism for the user. Cho et al. [6] developed a pen writing tactile feedback system to provide users with the feeling of writing on a physical surface when conducting handwriting tasks on touch surfaces. Kuchenbecker et al. [24] used tactile feedback to help users identify materials in a virtual environment. In a crowd simulation, Koilias et al. [22] found that, with tactile feedback, participant's movement behavior was affected and became sensitive to surrounding virtual characters. Turchat et al. [37] developed a walking simulator with haptic feedback for subjects sitting on a chair to enhance their physical navigation in virtual environments.

Georgiou et al. [12] developed a mid-air haptic rhythm game in VR. Their haptics engine successfully produced complex tactile feedback and displayed acoustic pressure in real time with less latency. In a VR game cutscenes study, Khamis et al. [20] applied electro muscle stimulation in their cutscenes, named ElectroCutscenes. They found that applying ElectroCutscenes significantly improved user sense presence and realism over controller feedback and no-tactile feedback. Finally, Gutierrez et al. [14] applied tactile feedback in serious games for upper limb rehabilitation with results showing

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[1] https://news.microsoft.com/1998/02/03/microsoft-and-immersion-continue-joint-efforts-to-advance-future-development-of-force-feedback-technology/

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that their VR rehabilitation platform can be used to retrieve motor control information.

Many VR games can also be played with tactile feedback with the support of tactile vests. For example, The Thrill of the Fight[2] supports tactile feedback when boxing an opponent; Death Horizon[3] allows for receiving tactile feedback when fighting the living dead; Apex Construct[4] gives players realistic feedback when taking damage hits by sci-fi attacks; and Realms of Eternity[5] provides feedback when players are mastering Kendo. In all these games, the tactile feedback is perfectly accurate, increasing experiences of horror, adventure, and fights.[6]

Studies on tactile feedback patterns find their positive effects on the user and their gaming experience. Israr et al. [17] designed a haptic feedback chair for gamers. The haptic engine extracts information from the game and gives feedback to the user using a preset tactile feedback pattern to provide an enjoyable gaming experience. Kettner et al. [19] compared vibrotactile feedback and pressure-based feedback and found that vibrotactile feedback increased users' stress levels to a greater degree. Yatani and Truong [42] developed different tactile feedback patterns for mobile touch-screen devices and found that participants could distinguish different patterns and that featuring various interaction patterns supports more realistic interactions with mobile devices.

This paper utilizes knowledge from previous studies and game examples and extends upon them by investigating the effects of various tactile feedback patterns on participants' gaming experience. We conducted two studies to determine how tactile feedback patterns contribute to participants' VR gaming experience as well as to understand how the participants perceived tactile feedback with the different game types.

3 Main Study

The below section presents our methodology and the results obtained from the main study.

3.1 Participants

We recruited 34 participants from our department via email and posters. There were 10 females (age $M = 22.37$, $SD = 2.01$) and 24 males (age $M = 23.71$, $SD = 2.49$). Of the sample, 21 of the participants did not use VR before. All participants completed the entire experiment and responded to all questions. All participants volunteered for this study.

3.2 The VR Game

We developed a VR fighting game in which the participants needed to fight an enemy in order to finish the game. Both the player character and the enemy character were assigned a mannequin model featuring different textures. The enemy had an attached animator controller with three types of fighting movement: a quick punch, a heavy punch, and a wide kick. The game started with a tutorial level (see Figure 1) followed by the actual level (see Figure 2). Before the fight started, participants had a chance to practice the action and familiarize themselves with the game. In order to attack the enemy, participants only needed to wave their controllers to perform a "sword slash" action to attack the enemy. Each slash resulted in a certain amount of damage. The enemy was destroyed after five slashes. Players were able to view a health bar displayed on top of the enemy. When the enemy's health reached zero the player would win. Irrespective of the tactile feedback patterns, the enemy had the same fighting mechanisms attached to them for all examined tactile feedback conditions.

Figure 1: The tutorial level in which the participants had a chance to practice the actions and familiarize themselves with a the game.

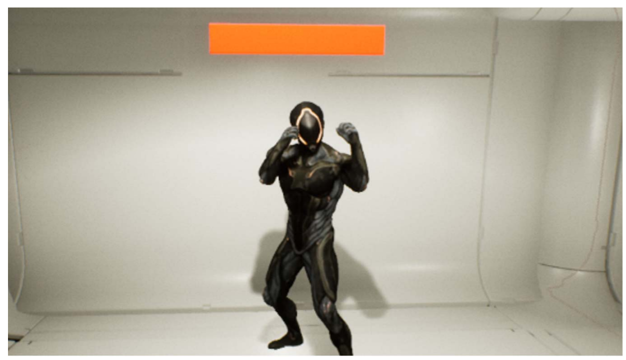

Figure 2: Stills from the enemy fighting game level.

The game was developed in Unreal Engine 4. Along with the game, we used Oculus Quest and the bHaptics tactile vest, which is a vibrotactile wearable display with 40 Eccentric Rotating Mass Vibration Motor (ERM) actuators. The enemy mechanics were designed using Unreal Blueprint with a custom event. In between a specified interval, the enemy would randomly pick one of the attack functions and execute it. When the enemy would hit the player, the actuators on the vest would be activated and provide tactile feedback to the participants. Each actuator was programmed to vibrate for only one second long, and the feedback intensity of the tactile vest setting was set to .50. This value was referred to other studies, which was approved to be effective [7, 8, 40]. Depending on the tactile feedback patterns, certain actuators would vibrate. The tactile vest was connected to the computer via Bluetooth. Figure 3 shows a participant during the gameplay wearing all the equipment.

3.3 Experimental Conditions

We created five different tactile feedback pattern conditions, similar to previously conducted studies [7, 11] concerning tactile feedback patterns:

- **No Tactile Feedback:** Participants do not feel any tactile feedback from the enemy's attacks.
- **Random Tactile Feedback:** The system randomly chooses how many actuators should be generated. Then, the tactile vest generates vibrations based on this random selection. The range for this selection is in between 1-20 actuators.

[2] https://www.oculus.com/experiences/quest/3008315795852749/
[3] https://www.oculus.com/experiences/quest/2115015981923610/
[4] https://www.oculus.com/experiences/quest/2096570290365140/
[5] https://sidequestvr.com/app/881/realms-of-eternity-wt
[6] https://medium.com/super-jump/are-haptic-suits-the-future-of-vr-c7b52d573935

Figure 3: A participant wearing the bHaptics tactile vest and head-mounted display during gameplay.

- **Fixed Tactile Feedback:** We define ten actuators in the front side of the tactile vest to be generated each time a collision occurs. For every single collision, only the selected actuators are activated and generate vibration regardless of the actual hitting location.
- **Discrete Tactile Feedback:** All actuators of the vest are generated once a collision occurs. Participants feel the vibration from all actuators upon taking a hit.
- **Realistic Tactile Feedback:** Only the actuators that correspond to the colliders will be generated. In order to achieve this, we map the location of all actuators to the collision box of the player character. When the character is hit, based on the location of the collision, actuators mapped at that location will respond and vibrate. Therefore, the participants will experience a more realistic feeling of getting attacked.

3.4 Measurements

The data was collected using the Tcha-Tokey et al. [36] questionnaire on user experience in immersive environments. The questions were altered to fit the scope of this project. The questionnaire contained six variables: presence (Q1-Q3), flow (Q4-Q6), usability (Q7-Q9), emotion (Q10-Q12), technology adoption (Q3-Q15), and tactile sensation (Q16-Q18). Each variable contained three questions to be answered on a seven-point scale. The questionnaire is shown in Table 1.

3.5 Study Procedure

In the beginning, participants read and signed a consent form, which was approved by the Institutional Review Board (IRB) of our university. Once they agreed to participate, they filled out a demographics questionnaire. Following this, we guided them in wearing the tactile vest and setting up and adjusting the VR headset. Participants needed to stand during the experiment. As soon as the setup was finished, the research team walked them through the tutorial level and made sure all participants were familiarized with the basic controls. Then, the participants were asked to fight the enemy while experiencing one of the five conditions.

In between each condition, the game was paused, and participants were instructed to take off their headset and respond to the main questionnaire. The tactile patterns were randomized using Latin squares to avoid biases across the conditions. After the participants finished all five conditions and answered the questionnaire for each one, the research team helped them take off the tactile vest. Then, the participants were thanked and excused. In total, the participants did not spend more than 45 minutes in our lab for the study.

3.6 Results

All results obtained from the study are summarized in this section. The normality assumption of the self-reported ratings were evaluated with Shapiro-Wilk tests at the 5% level and graphically using Q-Q plots of the residuals. All items in each variable were tested for reliability (Cronbach's alpha: $\alpha > .73$ for all variables), and, due to sufficient correlation, we used a cumulative score of all items in each scale as the final result, and treated each variable as continuous scale—as is typical. One-way analysis of variance (ANOVA) was used to analyze the obtained data, with the tactile feedback patterns as the independent variables and gaming experience (in terms of emotion, flow, presence, tactile sensation, technology adoption, and usability) as the dependent variable. Individual differences were assessed using a post hoc Bonferroni correction if the ANOVA was significant.

No significant differences were found in terms of **flow** [$\Lambda = .800$, $F(4,30) = 1.876$, $p = .14$, $\eta_p^2 = .020$] and **emotion** [$\Lambda = .914$, $F(4,30) = .708$, $p = .59$, $\eta_p^2 = .086$]. However, we found a significant effect of tactile feedback pattern on **presence** [$\Lambda = .630$, $F(4,30) = 4.401$, $p = .006$, $\eta_p^2 = .370$]. Post hoc comparison showed that the no-tactile feedback pattern ($M = 3.53$, $SD = 1.43$) was rated lower than the random tactile feedback pattern ($M = 4.58$, $SD = 1.34$), fixed tactile feedback pattern ($M = 4.59$, $SD = 1.27$), discrete tactile feedback pattern ($M = 4.83$, $SD = 1.20$), and realistic tactile feedback pattern ($M = 5.01$, $SD = 1.24$).

We also found a significant effect of tactile feedback patterns on **tactile sensation** [$\Lambda = .363$, $F(4,30) = 13.142$, $p = .000$, $\eta_p^2 = .637$]. Post hoc comparison showed that the no-tactile feedback pattern ($M = 2.882$, $SD = 1.21$) was rated lower than the random tactile feedback pattern ($M = 5.04$, $SD = 1.50$), fixed tactile feedback pattern ($M = 5.06$, $SD = 1.34$), discrete tactile feedback pattern ($M = 5.16$, $SD = 1.29$), and realistic tactile feedback pattern ($M = 5.22$, $SD = 1.27$).

In terms of **technology adoption**, we found a significant effect of the tactile feedback pattern [$\Lambda = .363$, $F(4,30) = 13.142$, $p = .000$, $\eta_p^2 = .637$]. Post hoc comparison showed that the no-tactile feedback pattern ($M = 2.38$, $SD = 1.31$) was rated lower than the random tactile feedback pattern ($M = 5.04$, $SD = 1.51$), fixed tactile feedback pattern ($M = 5.06$, $SD = 1.34$), discrete tactile feedback pattern ($M = 5.16$, $SD = 1.29$), and realistic tactile feedback pattern ($M = 5.22$, $SD = 1.27$)

Finally, we found a significant effect of tactile feedback on **usability** [$\Lambda = .712$, $F(4,30) = 3.038$, $p = .032$, $\eta_p^2 = .288$]. Post hoc comparison showed that the no-tactile feedback pattern ($M = 4.32$, $SD = 1.91$) was rated lower than the random tactile feedback pattern ($M = 5.55$, $SD = 1.27$), fixed tactile feedback pattern ($M = 5.50$, $SD = 1.21$), discrete tactile feedback pattern ($M = 5.55$, $SD = 1.15$), and realistic tactile feedback pattern ($M = 5.56$, $SD = 1.27$).

3.7 Discussion

Our results indicated that tactile feedback has a significant effect on presence. Participants rated the four patterns of tactile feedback higher than the no tactile feedback pattern, which is in line with previously published work [30, 33]. However, our study confirmed such findings by implementing tactile feedback in the VR game. Participants were able to feel themselves "getting hit" by the enemy through the actuators. We observed their realistic reactions, such as dodging and yelling, during the fight, which indicated that our participants felt that they were part of the VR gaming environment.

In terms of tactile sensation, participants rated conditions with tactile feedback higher than conditions without tactile feedback.

Table 1: The questionnaire that was used in our user study.

No.	*Questions*	*Rating*
Q1	Rate your sense of being in the virtual environment.	1=being in the real environment, 7=being in the virtual environment
Q2	To what extent were times during the experience when the virtual reality became the "reality" for you, and you almost forgot about the "real world" in which the whole experience was really taking place?	1=not at all, 7=totally
Q3	During the time of the experience, which was strongest on the whole, your sense of being in virtual environment, or of being in the real world?	1=being in the real world, 7=being in the virtual environment
Q4	Time seemed to flow differently than usual.	1=not at all, 7=totally
Q5	I felt I was experiencing an exciting moment.	1=not at all, 7=totally
Q6	I was not worried about what other people would think of me.	1=not at all, 7=totally
Q7	I thought the tactile vest was easy to use.	1=not at all, 7=totally
Q8	I thought there was too much inconsistency in the virtual environment.	1=not at all, 7=totally
Q9	I found the tactile vest very cumbersome to use.	1=not at all, 7=totally
Q10	I got tense in the virtual environment.	1=not at all, 7=totally
Q11	When my actions were going well, it gave me a rush.	1=not at all, 7=totally
Q12	I enjoyed being in this virtual environment.	1=not at all, 7=totally
Q13	I would like to use the tactile vest.	1=not at all, 7=totally
Q14	Using the tactile vest is a good idea.	1=not at all, 7=totally
Q15	The tactile vest would make the game more interesting.	1=not at all, 7=totally
Q16	It seemed as if I felt the tactile feedback in the location where I saw the virtual body being attacked.	1=not at all, 7=totally
Q17	It seemed as if the touch I felt was caused by the enemy touching my virtual body.	1=not at all, 7=totally
Q18	It seemed as if the enemy was physically attacking me.	1=not at all, 7=totally

From our findings, it is clear that having a feedback pattern will generate a stronger tactile sensation to users, which is also supported by Longo et al. [25] that asserts that having tactile feedback helps people to better understand their virtual body. Prior to our study, the location of the body of the self-avatar was adjusted to match the physical body of the participants in size. Hence, with the help of tactile feedback, our participants were able to sense the attack, indicating that, with the precise mapping and synchronization of the tactile feedback and hitting location, it was possible to increase participants' tactile sensations.

Participants rated higher the technology adoption variable in all tactile feedback conditions compared to the no tactile feedback condition. Most participants rated the use of the tactile vest highly, with many commenting verbally to the research team that it was "interesting," "easy," and "cool" to use during the experiment. Initially, participants were surprised on how the tactile vest worked. Throughout the experiment process, they started to receive the tactile feedback and completely understand the mechanics of the vest. Moreover, in line with previously conducted studies concerning tactile feedback [34, 38], the functionality of the tactile aided the participants' adoption of the vest, and some participants mentioned that they would like to use the tactile vest again in the future.

According to our findings, participants rated usability higher under with-feedback conditions. Many other studies have also proven the effect of tactile feedback on improving usability [10, 15, 31]. Aligning with these previous studies, we also found that enabling tactile feedback improved the usability of the tactile vest in the VR games. From the questionnaire and responses, participants reported that the tactile vest was easy to wear and use. Moreover, they reported that the vest was simple to setup on the computer platform via wireless (Bluetooth) connection. All these convenient features led to the high rating of usability in with-tactile feedback conditions.

In terms of flow and emotion, we did not find any significant effects. Archambault et al. [2] mentioned that flow relies on entertaining principles in the virtual world instead of the reactivity of audio and video signals. Moreover, Jin [18] was not able to confirm that tactile stimulation can be a positive predictor of flow. In our case, the game content was simple, and the process was rather short; thus, participants did not have sufficient time to generate a strong sense of flow. In addition, the tactile feedback only happened with the enemy attacks; no other events were designed using tactile feedback. Therefore, it can be said that tactile feedback in this game was just interaction mechanism and therefore did not generate any effect. We suggest that the lack of game mechanics also caused the tactile feedback to not affect the participants' flow.

We noticed that the different tactile feedback patterns did not have a significant difference on participants self-reported emotion across our experimental conditions. In our game, we used vibrotactile actuators to simulate the feeling of getting hit. Considering that mechanical force feedback has been found to induce a stronger effect on participants' emotion than vibrotactile actuators [1] as well as that no mechanical forces were applied to generate vibration in our study, we suggest that this could have possibly led to unrealistic force simulation and therefore, the tactile feedback was not able to induce emotional responses in the participants.

4 Follow-up Study

After our data analysis for the first main study, we realized that a follow-up study comparing the effect of tactile feedback in an active versus passive fighting game would help us further interpret the findings of the main study. Thus, in this section, we present our methodology and results for the second (follow-up) study.

4.1 Participants

We recruited 12 participants from our department via email and posters. There were four females (age $M = 25.75$, $SD = 2.03$) and eight males (age $M = 23.25$, $SD = 1.67$). All participants had prior VR experience. No compensation was given for participation.

4.2 Game Application

We created an additional game in which the participant was hit by the enemy during a fighting passive experience. The application was developed in the Unreal 4 game engine, and the enemy character was controlled through an Unreal Blueprint similar to that in the main study. Participants were still free to move and look around in the VR environment, but they could not attack the enemy. The participant was also placed in the same environment as the one in the main study. The enemy would attack the participants 12 times (three sets of animation) and then the game ended.

4.3 Experimental Conditions and Measurements

Only one feedback pattern explored in this follow-up study: the realistic feedback pattern. The purpose was to compare the difference between an active and passive gaming experience. "Active" refers to the game application that was used in the main study, which allowed the user to fight against the enemy, while "passive" refers to the same game but without the participant being allowed to fight against the enemy. The questionnaire used in the main study (see Table 1) was also used to evaluate the gaming experience of our participants between the active and passive game.

4.4 Procedure

The study was conducted in the same lab as the main study. We first asked the participant to read and sign the consent form that was approved by the IRB if they agree to participate. As soon as they signed the form, the participants were asked to fill out the demographics questionnaire. Then, they received help with the VR setup. We instructed the participants to play both the active and passive games in a random order using Latin squares. In both games, only the realistic feedback pattern was assigned. At the end of each gaming condition, the participants were asked to fill out the questionnaire. Then, the participants took off the headset, and the research team helped them with the tactile vest. After they finished the questionnaire, the participants were thanked and excused. The total duration of the follow up study did not exceed 20 minutes.

4.5 Results

We compared the two studies' results using a paired samples t-test between the active and passive gaming experience in the presence of realistic tactile feedback. A significant difference in terms of **tactile sensation** ($t(11) = -2.384$, $p = .036$) was found, showing that the active game ($M = 3.97$, $SD = 1.27$) was rated lower by the participants than the passive game ($M = 5.39$, $SD = 1.29$). We also found significant differences in terms of **usability** ($t(11) = -4.582$, $p = .001$). Similarly, we found that the active game ($M = 3.56$, $SD = .69$) was rated lower than the passive game ($M = 5.47$, $SD = 1.24$).

No significant difference was found in terms of **presence** ($t(11) = .369$, $p = .719$) between the active ($M = 5.30$, $SD = 1.17$) and passive ($M = 5.13$, $SD = 1.10$) games. Moreover, no significant result was found in terms of **technology adoption** ($t(11) = -1.692$, $p = .119$) between the active ($M = 4.97$, $SD = 1.66$) and passive ($M = 6.05$, $SD = .90$) games. Similarly, no significant difference was found in terms of **emotion** ($t(11) = -.979$, $p = .349$) between the active ($M = 4.50$, $SD = 1.35$) and passive ($M = 5.11$, $SD = 1.18$) games. Finally, no significant different was found in terms of **flow** ($t(11) = -.185$, $p = .856$) between the active ($M = 4.77$, $SD = 1.63$) and passive ($M = 4.67$, $SD = 1.57$) games.

4.6 Discussion

Our results indicated that tactile sensation and usability were rated higher in the passive condition than active condition. A possible reason for enhancing tactile sensation was that the punches from the enemy were done quickly and the collision size was relatively large. Moreover, other actions were not available to participants and they were focused on feeling the hit from the enemy. Hence, when compared to the active game, during the passive game participants had a greater opportunity to experience passive tactile feedback. In line with previously conducted studies [13, 29, 35], it can be concluded that passive tactile feedback has a significant effect on tactile sensation. Based on the above, participants preferred tactile feedback due to a less distracting sensation.

In terms of usability, the participants in the follow-up study had a better understanding of the tactile vest since we asked them to focus on feeling the hits from the enemy. Our result on participant's usability ratings align with previously conducted studies [11, 16, 40], which indicated that using tactile feedback devices in passive conditions helps in improving the usability of the tactile vest.

5 Overall Discussion

We have found several significant results in both studies and are able to answer the two research questions posited in the introduction section. In response to our **RQ1**, tactile feedback patterns significantly effected participants' gaming experience in terms of presence, tactile sensation, technology adoption, and usability. As a result, participants rated the no-tactile feedback pattern significantly lower than all the other patterns. As discussed above, having tactile feedback enhances presence and body tactile sensation in immersive environments. The finding for presence agreed with the results from the main study that losing touch feedback will break the sense of presence [30], while vibrotactile feedback enhances presence [33]. The findings on tactile sensation confirm the assertion that the implementation of tactile feedback facilitates virtual body size and location mapping [25]. Tactile feedback also improves the user's adoption of the tactile vest, which is due to its setup simplicity. Previous studies [34, 38] have found that enabling and implementing new technology improves adoption. In our case, enabling tactile feedback also improved the participants' willingness to adopt the tactile vest. Finally, studies in the fields of robotics [10], surgery [31], and mobile technology [15] have commonly proven that tactile feedback increases usability, which is something also found in our VR study.

We were also able to answer **RQ2** through the follow-up study. Our results show that there is a significant difference in terms of tactile sensation and usability. Specifically, the participants rated lower the tactile sensation and usability during the active gameplay compared to the passive experience. Studies in different areas [13,29, 35] have pointed out that passive tactile feedback provides a stronger sense of "touch." In our study, passive tactile feedback also provided a stronger sense of being punched by the enemy, which extends upon these previous findings. Additionally, prior studies on tactile feedback [11, 16, 40] found that passive tactile feedback enhanced the user experience and task performance. Participants in our study also verbally commented that the passive tactile feedback generated a more realistic experience in the virtual environment, which is a finding that also extends our knowledge on tactile interaction.

6 Limitation and Future Work

This paper reported two studies conducted to investigate how tactile feedback patterns and different games (active vs. passive) could affect the gaming experience of participants. Beside the interesting findings we reported in the previous sections, we would like to report two limitations. First, the player character was animated through a simple animator controller that only included fighting actions. We suggest that including additional movements, such as walking, crouching, and running, would have enhanced the gaming experience of the participants. Second, we only used the tactile vest to provide tactile feedback to our participants. We think that providing full-body tactile feedback can be essential for gameplay.

In our future studies, we plan to continue working toward understanding how tactile feedback patterns can possibly affect the gaming experience of participants through creating highly immersive and engaging virtual reality games. Specifically, in our future work, we would like to explore the effects of render style on tactile sensation when using realistic, stylized, and low poly 3D models. In our experiment, the tactile feedback was designed to be rather short (one second) to create the sense of getting hit. Increasing the duration of tactile feedback can have a possible significant effect on the game experience. Thus, in our future studies, we would also like to investigate the effects of tactile feedback duration on gaming experiences. Last but not least, the study results should be applied and considered to other body parts than the torso in the development process. Tactile feedback patterns tend to be the same for all body parts and in VR games tactile feedback can happen anywhere. Therefore, it is important to take different body parts into consideration. All of the above will help us create games that are not only considered more realistic but also as enhancing users' gaming experience.

In the end, these results could potentially turn into guidelines in developing augmented reality (AR) and mixed reality (MR) games and applications. Because tactile feedback can also happen in AR and MR environments and there is a chance of enhancing the user experience under these conditions, applying our study results into future AR and MR studies can be valuable for understanding even more the effects of tactile feedback patterns.

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