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Toward understanding embodied human-virtual character interaction through virtual and tactile hugging

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Abstract

This between-group study investigated participants' experiences of tactile feedback patterns when asked to hug a virtual character. Five experimental conditions were developed, one with no tactile feedback and four with tactile feedback. The participants were placed in a virtual city and informed they would be meeting a virtual friend, who they were instructed to hug once the character came close to them. During the virtual hug, one of the five experimental conditions was examined. Immediately after the hug, participants were asked to complete a questionnaire to capture their experiences. The results obtained from this study indicated that: (1) even if the tactile feedback is not considered to be highly accurate in terms of timing, duration, and position, as long as it is perceived as less persistent, it provides a more positive experience; (2) the perceived realism of the virtual hug is strongly correlated with the perceived realism of the tactile feedback; and (3) the female participants had a more intense interaction with the virtual character (friend) compared with the male participants. Limitations and future study directions are discussed.

KEYWORDS

tactile feedback, tactile sensation, virtual character interaction, virtual hugging, virtual reality

1 | INTRODUCTION

In real-world interaction scenarios between humans, it is common to observe people interacting with each other through physical contact, which is among the most important ways of establishing and maintaining social interaction.[1] Physical contact with another person is considered a common gesture of affection,[2] and a person's willingness to touch or be touched by another person implies an element of trust.[3] In addition to human communication obtained through such interaction, a variety of information can be elicited by other types of signals,[4] such as emotional expressions.[5] According to prior studies, touching and hugging are considered one of the most emotionally loaded types of physical contact between humans, since they elicit warmth, love, and affiliation.[2,4,5]

Although virtual reality interaction relies heavily on vision and hearing,[2] to simulate a more realistic interaction, physical embodiment must also be considered. Thus, various haptic and tactile interfaces (e.g., vest and suits) have been developed to provide pseudo-physical embodiment. These interfaces help to make the interaction in virtual environments more realistic,[6,7] and thus make the close contact interaction (e.g., touching and hugging) with virtual characters become more convincing.

Previous virtual reality studies have shown[8,9] that tactile devices positively affect the experiences of humans when the provided feedback relates to the task.[10] However, it is not yet known how people perceive and react to different tactile

FIGURE 1 A participant hugging a virtual character while wearing the required equipment (head-mounted display and tactile vest) and the first-person view that is projected onto the head-mounted display (left), a third person view of the virtual environment and hugging (middle), and close-up view of the virtual hugging (right)

feedback patterns while hugging a virtual character. Thus, this study explores the effects of different tactile feedback patterns (no tactile, random tactile, fixed tactile, discrete tactile, and collision-based tactile) when participants are placed in a virtual city and instructed to perform a social interaction task—to hug a virtual character. Understanding the experiences of people while hugging a virtual character in the presence of tactile feedback could help virtual reality developers create immersive experiences in which people in the presence of tactile feedback can socialize and interact with virtual characters more effectively. Figure 1 depicts a participant hugging a virtual character while wearing the necessary equipment.

Considering the importance of tactile feedback during hugging with a virtual character, we attempt to answer the following research questions:

- *RQ1:* How do the different tactile feedback patterns affect the virtual hugging?
- *RQ2:* How do participants perceive the different tactile feedback patterns?
- *RQ3:* How do the different tactile feedback patterns affect the interactions with the virtual character?
- *RQ4:* Do the tactile feedback patterns affect the participants' self-perception (presence and embodiment) in the virtual environment?
- *RQ5:* How do the different tactile feedback patterns affect the male and female participants across the experimental conditions?

The remainder of this article is organized as follows. Section 2 presents related studies, and Section 3gives the methodology and implementation details. The results are presented in Section 4 and discussed in Section 5. Section 6 describes the limitations of our study, and Section 7 addresses the conclusions and potential for future research.

2 | RELATED WORK

Tactile and haptic feedback has been a topic of research in the scientific community from two perspectives. Some researchers have focused on the development of new tactile devices[11,12] in the field of robotics, particularly the use of telemanipulation[13] or remote touch.[14] Other researchers have focused on human factors and have attempted to understand how people perceive the provided feedback in various interaction paradigms based on custom-made or commercial tactile devices.[15]

Considering that vibrotactile devices are easily accessible and relatively easy to manufacture, several research groups have focused on the development of tactile devices.[16,17] The development of vibrotactile feedback has been explored to convey spatial[18] or contextual[19] information, and several tactile devices[20] and platforms[21] have proved to be quite useful in virtual reality interaction. The survey/review papers from Pacchierotti et al.,[22] Perret and Vander Poorten,[23] Benali-Khoudja et al.,[24] and Lécuyer[25] have summarized most of the trends in research concerning tactile feedback.

This study uses vibrotactile feedback devices to induce the hugging sensation in the participants. Vibrotactile feedback devices have been extensively used in various virtual reality studies.[19,26] Tactile feedback, which is achieved by involving more senses through providing additional stimuli,[10] is responsible for enhancing the interaction realism in a virtual environment.[12,27,28] Tactile feedback has also been used to improve users' performance in virtual environments.[10] However, such findings mainly apply when the provided stimuli correlate with the performed activity.[10] Other studies have explored the effects of tactile feedback patterns of humans' perceptions in virtual environments.[29,30] These studies have found that the haptic feedback patterns can be used to induce information to humans[31] and that when the tactile feedback pattern expresses the interaction in the virtual environment appropriately, such tactile feedback enhances the realism of tactile interaction,[27] especially when compared with illogical or inaccurate tactile feedback.[29] Moreover, in terms of self-perception in the virtual environment, it has been stated that haptic feedback enhances both the sense of presence[32] and embodiment,[33] but it also impacts the emotional state of the participants.[34]

Although a few studies have already been conducted that involve hugging robots,[35,36] which are a form of tactile hugs, to the best of our knowledge, this study is the first to investigate immersive tactile hugs with virtual characters. "The Hug" interface was introduced by DiSalvo et al.[8] to allow remotely connected people to communicate. The shape of this interface (a koala pillow puppet) mimics that of a child wrapping its arms and legs around an adult, and the temperature of the koala pillow puppet rises once users have been hugging it for a while. The pillow lights up/glows and plays a melody to notify a user they are being sent a hug and vibrates in a pattern to match before warming up. The Hug Shirt[1] is another interface that allows remote hugging by sending a hug-like sensation over distances. In this interface, users wear a shirt with embedded actuators and sensors. However, these interfaces have various disadvantages. First, as they are incapable of reproducing the natural hug sensation, the provided experience cannot be considered emotionally loaded.[9] Second, these interfaces do not provide visual feedback to their users. Therefore, the simulated hugs do not match real-life hugs that include visual and physical feedback.

The HaptiHug[4] interface attempts to overcome this issue by integrating tactile hugs into virtual hugs performed in Second Life[2](an online virtual social network). The implemented social pseudo-haptic feedback of HaptiHug increased the hugging immersion and the hugging sensation. However, even though this interface is able to create some sensations in the participants, it is not yet known how the participants perceive and react to different tactile feedback conditions during a virtual reality hug in which they are responsible for performing the hugging action by controlling their body in an immersive virtual reality setup, rather than controlling the hug through a keyboard.

We used a commercially available tactile vest in our experimental study to create the hugging sensation for our participants. These vests have been used in various studies investigating interactions with virtual characters,[29,37] training,[38] medicine,[39] rehabilitation,[40] and serious games.[41] However, it is not yet known whether these vests could induce the hugging sensation. Therefore, this study explores how the participants' experiences are affected while hugging a virtual character in the presence of tactile feedback. Based on the functionalities of the tactile vest, we considered multiple tactile feedback conditions and explored several concepts related to the participants' experiences during a virtual hug with a virtual character. Because the provided tactile feedback is related to the virtual reality experience, we investigate the patterns of the tactile feedback while hugging a virtual character to understand and further improve the realism of the interaction. During our literature research, we found several papers[4,8,9] referring to how the hugging sensation is transmitted through tactile feedback. However, we were unable to find related work that investigates the impact of tactile feedback patterns while the user is instructed to hug a virtual character. Thus, we consider our main contribution to be the investigation of how immersive hugging in the presence of different tactile feedback patterns is experienced by our participants.

3 | MATERIALS AND METHODS

This section presents the methodology and details of this study.

3.1 | Participants

The participants were recruited in multiple ways: e-mails were sent to undergraduate and graduate students, posters were placed on various notice boards on campus, and in-class announcements were also made. Seventy-five students participated voluntarily, and no compensation was given for participating. All volunteers were asked to review and sign a consent form that was approved by the Institutional Review Board of Purdue University. The study group consisted of 25 female students ($M = 23.33$, $SD = 2.24$) and 50 male students ($M = 22.62$, $SD = 2.40$). The majority of our participants (79%) reported having prior virtual reality experience. The participants were divided into five groups randomly while ensuring that each group consisted of the same number of male and female participants (10 males and five females per group).

[1]https://cutecircuit.com/the-hug-shirt/
[2]https://secondlife.com/

FIGURE 2 The virtual city in which the participants were immersed while waiting for their virtual friend at the meeting location

FIGURE 3 The participant's point of view of the virtual environment (left and middle) and the virtual friend that approaches the participant (right)

3.2 | Virtual reality scenario and application

We developed a virtual reality scenario in which the virtual hug would occur. Figure 2 shows the virtual environment and the developed scenario. In our scenario, the user was immersed in a virtual city and placed on a pavement outside a bistro. Because the interaction with the virtual characters was designed to be performed in an outdoor virtual environment, afternoon sunlight was added to light the scene. Audio effects were used to enhance the realism of being on a sidewalk outside the bistro. Virtual pedestrians were scripted to walk on the sidewalk. In this scenario, the participant is waiting for his friend, as they had arranged to meet.

After waiting for a few minutes, a virtual friend approaches the self-avatar of the participant and says, "Hey, I'm sorry I'm late." Then, the virtual friend extends his arms to invite the participant to hug the character (see Figure 3). We implemented this action to ensure that the participants recognized the virtual friend they were supposed to hug. The hugging action of the participants was used to indicate that the participant understood the situation and to indicate to the virtual friend that they were not irritated by the short delay. During the hug, one of the five experimental conditions (see Section 3.3) was generated depending on the group to which each participant was assigned.

For the virtual city, the Amazon Lumberyard Bistro[3] three-dimensional model provided under the Creative Commons CC-BY 4.0 license was used. The virtual characters were designed in Adobe Fuse, rigged in Mixamo, and animated with motion sequences that were downloaded from the Unity Asset Store. The Unity Mecanim animation engine was used to animate all virtual characters. A neutral idle motion was assigned to the virtual friend during the hug. To enhance the realism of the virtual character, we also added facial animations (lip and eye motion) using the SALSA LipSync suite found in the Unity Asset Store.

The application used for this study was developed in the Unity game engine (version 2019.1.4). A Dell Alienware Aurora R7 desktop computer (Intel Core i7 CPU, 32 GB Memory, NVIDIA GeForce RTX 2080) was used to run the application, an HTC Vive Pro head-mounted display was used to project the virtual reality content, a Kinect for Xbox One tracking device was used to retarget the motion of participants to the self-avatar to allow the participant to hug the virtual character using their own body, and a bHaptics[4] tactile vest, which consists of 40 actuators attached all over the vest, was used to deliver the hugging sensation to the participants through the developed tactile feedback patterns.

3.3 | Conditions

We developed five experimental conditions, one without and four with tactile feedback, to determine how different tactile feedback patterns affect the experiences of the participants while hugging a virtual character. Each participant

[3] https://developer.nvidia.com/orca/amazon-lumberyard-bistro
[4] https://bhaptics.com

experienced only one condition (according to our between-group design). For this study, the following experimental conditions were examined:

- *No tactile feedback (NT):* This is our baseline condition, in which the participants received NT feedback. However, the participants assigned to this group were instructed to wear a tactile vest. With this condition, we aim to understand how most of the people would experience a virtual hug from their home virtual reality setup, since most virtual reality users most likely do not have access to a tactile vest.
- *Random tactile feedback (RT):* In this condition, the participants were exposed to a randomly activated tactile feedback pattern. A preprocessing stage took place to randomly assign to each actuator (tactor) a random timestep $t = [0, 4]$ (t is in seconds) that would be activated. Moreover, each actuator was set to remain active and provide tactile feedback to the participants for 1 s. This randomization process was run only once, and the output configurations for the RT feedback pattern were stored. Thus, it was possible for all participants to experience the same RT feedback condition. $t = 0$ is defined as the time step of the contact between the character that represents the participant (self-avatar) and the opposite character (friend) to be hugged. This condition was used to explore how an inaccurate tactile feedback pattern that is randomly activated could affect the participants' responses.
- *Fixed tactile feedback (FT):* This fixed (continuous) tactile feedback pattern set the actuators to remain active throughout the duration of the hug. Specifically, all actuators were activated once a collision (contact) between the two bodies occurred and deactivated when there was no further collision between them. This condition was used to investigate whether persistent tactile feedback could affect the participants' responses.
- *Discrete tactile feedback (DT):* In this condition, the participants experienced DT feedback. Specifically, once a collision between the two bodies was detected, all actuators of the tactile vest were activated for 1 s. This condition was used to investigate how a less persistent tactile feedback pattern could affect the participants' responses.
- *Collision-based tactile feedback (CT):* The participants sense the tactile feedback once a collision (contact) between the upper-body part of the self-avatar and the opposite character (virtual friend) occurred. Note that since there are 40 actuators attached to the vest, 40 colliders were placed on the body of the self-avatar in the positions of the actuators. Each collider was then responsible for activating its corresponding actuator. Thus, during the collision, the actuator of the tactile vest assigned to the collided body part was activated. This condition was used to understand how a more accurate tactile feedback pattern could affect the participants' responses.

3.4 | Questionnaire

For this study, we collected subjective ratings (questionnaire responses) to investigate the effects of the tactile feedback patterns on participants' experiences in the virtual environment. The questionnaire, which included 18 items, combined parts of multiple questionnaires: interaction realism,[42] emotional reactivity,[43] emotional contagion,[44] body ownership,[45] and presence.[46] The authors were responsible for developing and adding the question regarding the body sensation of the virtual character to the questionnaire. The questions were altered to fit the scope of our experimental study. The participants were asked to answer this questionnaire in a computer-based environment right after the virtual hug was completed. A designated area was also provided for participants to leave comments or concerns about the study. Table 1 shows the questionnaire. Note that we did not ask questions regarding tactile feedback (Q5–Q8) to those who were assigned to the NT condition. This is a common practice in experimental studies since people get confused by answering questions that do not relate to the provided stimulus.

3.5 | Procedure

The experimental study was conducted in the virtual reality lab of our department. Since it was stated in the advertisement flier, the participants were aware before coming to the study they would have to hug an avatar. After informing the participants about the project, the equipment, and the task they were asked to perform while immersed in the virtual environment (to perform the hugging action once the friend character approached them and extended his arms), the experimenter asked the participants to sign the consent form if they agreed to participate to our study and then complete the demographic questionnaire. Then, the experimenter asked the participants to wear the necessary equipment (tactile vest and head-mounted display) and to stand in a particular location in the lab space in front of the Kinect for Xbox

TABLE 1 The questionnaire that was developed and used for this study

#	Question	Anchors of the scale
Realism of the virtual hug (virtual hugging)		
Q1	I felt that the virtual hug was a real one.	1 = not real at all, 7 = totally real
Q2	I felt that I was hugging a real person	1 = not at all, 7 = totally
Emotional reactivity to the virtual hug (virtual hugging)		
Q3	I felt calm during the virtual hug.	1 = not calm at all, 7 = totally calm
Q4	I felt comfortable during the virtual hug.	1 = not comfortable at all, 7 = totally comfortable
Realism of the tactile feedback (tactile feedback)		
Q5	How realistic was the tactile feedback?	1 = not realistic at all, 7 = totally realistic
Q6	How accurate was the tactile feedback?	1 = not accurate at all, 7 = totally accurate
Emotional reactivity to the tactile feedback (tactile feedback)		
Q7	Was the tactile feedback pleasant?	1 = not pleasant at all, 7 = totally pleasant
Q8	Was the tactile feedback comfortable?	1 = not comfortable at all, 7 = totally comfortable
Emotional reactivity to the virtual character (virtual character)		
Q9	I felt comfortable hugging the virtual character.	1 = not comfortable at all, 7 = totally comfortable
Q10	I felt ease hugging the virtual character.	1 = not ease at all, 7 = totally ease
Emotional contagion to the virtual character (virtual character)		
Q11	I was influenced by the virtual character.	1 = not at all, 7 = totally
Q12	The virtual character affected my mood.	1 = not at all, 7 = totally
Body sensation of the virtual character (virtual character)		
Q13	I felt that the virtual body I hugged was a real body.	1 = not at all, 7 = totally
Q14	I felt that the virtual body I hugged belonged to a real person.	1 = not at all, 7 = totally
Body ownership (self-perception)		
Q15	How strong was the feeling that the body you saw was your own?	1 = not strong at all, 7 = totally strong
Q16	How much did you feel that you were looking at your own body?	1 = not at all, 7 = totally
Presence (self-perception)		
Q17	Please rate your sense of being in the virtual environment.	1 = not at all, 7 = totally
Q18	To what extent were there times during the experience when the virtual environment felt realistic to you?	1 = feeling completely in the real world, 7 = feeling completely in the virtual environment

One tracking device. The experimenter assigned a male or female self-avatar to the participant based on the demographic information provided by each participant (see Figure 4). The self-avatars (male and female) assigned to the participant as well as the virtual friend were the same for all participants. We decided not to change the skin tone, clothes, and size of the self-avatar and virtual friend because we considered these to be critical to standardizing the experimental conditions. Moreover, the gender of the virtual friend was kept to be male for all participants for all conditions for the same reason.

The participants were told that as they waited for their virtual friend, they were allowed to observe the virtual environment and move their hands and feet to get a sense of their body, but they were not allowed to walk around the virtual environment except for a small step, if necessary, when approaching their virtual friend. Before commencing the experiment, the experimenter asked the participants whether they felt comfortable wearing the equipment and if they were ready to begin. Once the participants indicated that they were ready, the virtual reality scene started. The virtual reality condition to which each participant would be exposed was not mentioned. The participants were informed that the experimenter would let them know once the virtual reality scenario was completed.

While the virtual reality application was running, the participants saw numerous virtual characters walking on the sidewalk. However, only one character was scripted to approach the user in the virtual environment. The participants

FIGURE 4 The male and female self-avatars that the participants embodied

were told that the hug interaction would be performed only once and were asked to hug the virtual character for at least 5 s. All participants wore the tactile vest, but none were aware of the tactile condition that was to be generated. In addition, the participants were told that there was no imposed time limit for the duration of hugging the virtual character and that it was up to them to decide how much more than the 5 s they would hug the virtual character.

Once the virtual hug was completed, the experimenter stopped the virtual reality application and helped the participant remove the headset and the tactile vest. Subsequently, the participant was asked to complete the questionnaire. Many participants had questions about the study, which we answered only once they had finished the questionnaire segment. The total duration of the virtual reality experience did not exceed 5 min per participant. The last minute of this period was the period during which the virtual character approached the participant and the participant hugged the character. In total, each participant spent a maximum of 30 min in the lab in which the experiment was conducted. None of the participants left before finishing the experiment.

4 | RESULTS

We compared the self-reported ratings across the examined conditions to explore the participants' experiences of the tactile hugging. A one-way analysis of variance (ANOVA) was used to analyze the obtained data, using the experimental conditions as independent variables and the self-reported ratings as dependent variables. In addition, two-way ANOVAs (Condition×Gender) were used to examine gender differences. Finally, all examined variables were screened for correlations using the Pearson product-moment correlation coefficient.

The normality assumption of the self-reported ratings was evaluated graphically using Q-Q plots of the residuals. The Q-Q plots indicated that the obtained data fulfilled the normality criteria. Statistically significant results were assessed using Bonferroni post hoc pairwise differences. A p-value $<.05$ was considered statistically significant. Table 2 provides the descriptive statistics for the self-reported ratings.

4.1 | Virtual hug

Statistically significant results in the *realism of the virtual hug* were found $[F(4, 70) = 2.931, p < .05]$. Pairwise comparisons show that the mean rating of the FT condition was significantly lower than for the CT condition ($p < .05$). The results also revealed statistically significant differences in the *emotional reactivity to the virtual hug*$[F(4, 70) = 3.476, p < .05]$. Pairwise comparisons show that the mean rating of the FT condition was significantly lower than those of the NT condition ($p < .05$) and the CT condition ($p < .05$).

4.2 | Tactile feedback

Statistically significant results were revealed in the *realism of the tactile feedback*$[F(3, 56) = 6.929, p < .001]$. Pairwise comparisons show that the mean rating of the FT condition was significantly lower than those of the RT condition ($p < .05$), the DT condition ($p < .01$), and the CT condition ($p < .001$). Regarding the *emotional reactivity to the tactile feedback*, we found statistically significant differences across the four conditions $[F(3, 56) = 15.240, p < .001]$. Specifically, the mean rating of the FT condition was found to be significantly lower than those of the RT condition ($p < .05$), the DT condition ($p < .001$), and the CT condition ($p < .001$). In addition, the mean rating of the RT condition was significantly lower than that of the CT condition ($p < .01$).

TABLE 2 Descriptive statistics (Mean [*M*], standard deviation [*SD*], minimum [*Min*], and maximum [*Max*] value) across the experimental conditions for each self-reported rating and patterns of differences

Condition	*M*	*SD*	*Min*	*Max*	Pattern of differences
Realism of the virtual hug					
NT	3.76	1.08	2.00	6.00	FT<CT
RT	3.93	.94	2.50	5.50	
FT	2.97	1.02	1.00	4.50	
DT	4.13	1.43	2.00	6.50	
CT	4.26	1.22	2.00	6.00	
Emotional reactivity to the virtual hug					
NT	4.53	1.59	2.00	7.00	FT<(NT=CT)
RT	3.80	1.46	1.00	6.00	
FT	2.96	.71	2.00	4.00	
DT	3.46	1.52	1.50	6.00	
CT	4.40	1.27	2.50	6.50	
Realism of the tactile feedback					
RT	3.76	.90	2.00	5.00	FT<(RT=DT=CT)
FT	2.57	1.11	1.00	4.50	
DT	4.07	1.43	1.50	6.50	
CT	4.43	1.23	2.50	6.50	
Emotional reactivity to the tactile feedback					
RT	3.53	1.24	1.50	5.00	FT<(RT, DT, CT)
FT	2.07	.86	1.00	3.50	RT<CT
DT	4.13	1.43	2.00	6.50	
CT	5.03	1.32	3.50	7.00	
Emotional reactivity to the virtual character					
NT	3.90	1.36	1.00	6.00	NT=RT=FT=DT=CT
RT	4.13	1.44	1.50	6.00	
FT	5.16	1.21	3.00	7.00	
DT	4.30	1.36	1.50	6.00	
CT	3.80	1.38	1.50	6.50	
Emotional contagion to the virtual character					
NT	3.13	1.36	1.00	5.00	NT=RT=FT=DT=CT
RT	3.56	1.08	1.50	5.00	
FT	3.23	1.67	1.00	6.50	
DT	3.63	1.40	1.50	6.00	
CT	3.16	1.12	1.50	5.00	
Body sensation of the virtual character					
NT	2.50	1.14	1.00	4.50	NT=RT=FT=DT=CT
RT	3.33	1.37	1.50	5.50	
FT	3.03	1.58	1.00	6.50	
DT	3.07	1.13	1.50	5.00	
CT	3.23	1.16	1.50	5.50	

(Continues)

TABLE 2 (Continued)

Condition	*M*	*SD*	*Min*	*Max*	Pattern of differences
Body ownership					
NT	2.33	1.02	1.00	4.00	NT<CT
RT	3.53	1.42	1.50	5.50	
FT	2.93	1.38	1.00	6.50	
DT	3.37	1.26	1.50	5.50	
CT	3.73	1.01	2.00	5.50	
Presence					
NT	3.03	1.45	1.00	6.00	NT=RT=FT=DT=CT
RT	3.30	1.19	1.00	5.00	
FT	3.83	1.63	1.00	7.00	
DT	3.73	1.39	1.50	6.50	
CT	3.80	1.62	1.00	7.00	

Abbreviations: CT, collision-based tactile; DT, discrete tactile; FT, fixed tactile; NT, no tactile; RT, random tactile.

4.3 | Virtual character interaction

The results did not show statistically significant differences regarding the *emotional reactivity to the virtual character* [$F(4, 70) = 2.404$, $p = .058$]. Moreover, no statistically significant differences were found for the emotional contagion to the virtual character [$F(4, 70) = .455$, $p = .768$] or the *body sensation of the virtual character* [$F(4, 70) = .933$, $p = .450$].

4.4 | Self-perception

Statistically significant results regarding *body ownership* were found [$F(4, 70) = 3.060$, $p < .05$]. Pairwise comparisons show that the mean rating of the NT condition was significantly lower than that of the CT condition ($p < .05$). However, no significant results were found regarding *presence*[$F(4, 70) = .877$, $p = .482$] across the five experimental conditions.

4.5 | Gender differences

We investigated the gender effect on the experimental conditions (Gender×Condition) for all the different concepts examined in this article. There was neither a statistically significant interaction effect [$F(4, 65) = .911$, $p = .463$] nor a statistically significant main effect on Gender [$F(1, 65) = .804$, $p = .373$] when exploring the *realism of the virtual hug*. For the *emotional reactivity to the virtual hug*, there was neither a statistically significant interaction effect [$F(4, 65) = 1.179$, $p = .281$] nor a statistically significant main effect on Gender [$F(1, 65) = 1.373$, $p = .245$]. Similarly, no statistically significant interaction effect [$F(3, 52) = .833$, $p = .482$] or main effect for Gender [$F(1, 52) = 2.882$, $p = .096$] was found on the *realism of the tactile feedback*. No statistically significant interaction effect [$F(3, 52) = .183$, $p = .907$] or main effect for Gender [$F(1, 52) = .058$, $p = .811$] was found on the *emotional reactivity to the tactile feedback*. Finally the *emotional reactivity to the virtual character* did not reveal a statistically significant interaction effect [$F(4, 65) = .149$, $p = .963$], and no main effect for Gender [$F(1, 65) = 3.930$, $p = .052$] was found between males and females.

In terms of *emotional contagion to the virtual character*, we were unable to find a statistically significant interaction effect [$F(4, 65) = 1.695$, $p = .162$]; however, a statistically significant main effect was obtained for Gender [$F(1, 65) = 4.584$, $p < .05$]. Post hoc comparison using Bonferroni corrected estimates showed that the emotional contagion of females was higher ($M = 4.12$, $SD = .35$) than that of male participants ($M = 3.26$, $SD = .19$).

The *body sensation of the virtual character* did not reveal a statistically significant interaction effect [$F(4, 65) = 2.176$, $p = .081$]; however, it did reveal a statistically significant main effect for Gender [$F(1, 65) = 4.347$, $p < .05$]. Post hoc

TABLE 3 Summary of bivariate Pearson product-moment correlation coefficient for all examined subjective ratings

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Realism of the virtual hug								
(2) Emotional reactivity to the virtual hug	.208							
(3) Realism of the tactile feedback	.735[a]	.260[b]						
(4) Emotional reactivity to the tactile feedback	.703[a]	.284[b]	.798[a]					
(5) Emotional reactivity to the virtual character	−.092	−.067	−.039	−.116				
(6) Emotional contagion to the virtual character	.043	.029	.280[b]	.035	.287[b]			
(7) Body sensation of the virtual character	.008	.147	.201	.119	.176	.473[a]		
(8) Body ownership	.037	.106	−.045	.108	−.310[a]	−.236[b]	−.112	
(9) Presence	.031	−.238[b]	.133	−.025	.051	.083	−.129	.168

[a]Correlation is significant at the .01 level (two-tailed).
[b]Correlation is significant at the .05 level (two-tailed).

comparison using Bonferroni corrected estimates showed that the body sensation of the virtual character was higher for female participants ($M = 3.84$, $SD = .32$) than for male participants ($M = 3.07$, $SD = .18$).

In terms of *body ownership*, we found neither an interaction effect [$F(4, 65) = 1.178$, $p = .329$] nor a main effect for Gender [$F(1, 65) = 1.186$, $p = .668$]. Similar results were found when examining participants' *presence*. Specifically, we found no interaction effect [$F(4, 65) = 1.193$, $p = .322$] and no main effect for Gender [$F(1, 65) = 1.317$, $p = .255$].

4.6 | Correlations

We conducted a correlation analysis to understand the correlations between the examined variables. Table 3 summarizes the bivariate Pearson correlation coefficients for all examined variables.

We found a strong positive correlation between the *realism of the tactile feedback* and the *realism of the virtual hug* [$r = .735$, $n = 60$, $p < .001$] and a weak positive correlation between the *realism of the tactile feedback* and the *emotional reactivity to the virtual hug* [$r = .735$, $n = 60$, $p < .05$]. A strong positive correlation was found between the *emotional reactivity to the tactile feedback* and the *realism of the virtual hug* [$r = .703$, $n = 60$, $p < .001$], a weak positive correlation was found between the *emotional reactivity to the tactile feedback* and the *emotional reactivity to the virtual hug* [$r = .284$, $n = 60$, $p < .05$], and a strong positive correlation was found between the *emotional reactivity* to the tactile feedback and the *realism of the tactile feedback* [$r = .789$, $n = 60$, $p < .001$].

Weak positive correlations were found between the *emotional contagion* to the virtual character and the *realism of the tactile feedback* [$r = .280$, $n = 75$, $p < .05$], and between *emotional contagion to the virtual character* and the *emotional reactivity to the virtual character*[$r = .287$, $n = 75$, $p < .05$]. A moderate positive correlation was found between the *body sensation of the virtual character* and the *realism of the tactile feedback* [$r = .473$, $n = 75$, $p < .001$]. A moderate negative correlation was found between *body ownership* and *emotional reactivity to the virtual character*[$r = -.310$, $n = 75$, $p < .01$], and a weak negative correlation was observed between *body ownership* and the *emotional contagion* to the virtual character [$r = -.236$, $n = 75$, $p < .05$]. Finally, a weak negative correlation was found between *presence* and *emotional reactivity to the virtual hug* [$r = -.238$, $n = 75$, $p < .05$].

5 | DISCUSSION

We examined whether the participants' experiences while hugging a virtual character exhibited changes across the experimental conditions (*RQ1*). The results indicated that the FT feedback negatively affected the realism of the virtual hug and the emotional reactivity to the virtual hug. However, when the tactile feedback was generated only on the body parts that collided with the virtual character's body, the virtual hug seemed more realistic and had less impact on the emotional reactions of the participants. These results suggest that persistent tactile feedback patterns distracted our participants, and this distraction impacted the way they experienced the virtual hug.

Differences were found when examining the tactile feedback across the experimental conditions (*RQ2*). The participants in the FT feedback condition rated their experiences lower, indicating that a persistent tactile feedback negatively affected this participant group. The results from the correlation analyses suggest that the realism and accuracy of the tactile feedback have an impact on the emotional reactivity of the participants. As the tactile feedback becomes more realistic and less persistent, the participants become more receptive, since less persistent tactile feedback is considered more comfortable,[47] and this comfort can impact the emotional states of participants in a positive way.[5,34] The participants' sensitivity to tactile feedback indicates that, even if the tactile feedback is not considered to be highly accurate in terms of timing, duration, and position, as long as it is perceived as less persistent, it affects participants' reactions in a positive way.

Our results indicated that the tactile feedback patterns did not influence the interaction with the virtual character (*RQ3*). No sufficient evidence was found across the tactile feedback conditions, indicating that the participants were able to distinguish the visual and haptic modality of the experiment, regardless of the experimental condition to which the participants were exposed. The results of the correlation analyses indicate that the participants were able to distinguish that the tactile feedback affected their emotional state[47] and not their direct interaction with the virtual characters. The participants were aware that the interaction with the virtual character was not real,[48] and this affected the way they perceived the interaction between the tactile feedback and the virtual character. This means that our participants were able to distinguish between real-world interaction and sensation, especially hugs, perhaps either because they are considered to be emotionally loaded activities[2,9,20] or due to the fact that presence ratings were generally low, which, in turn, did not make the experience emotionally loaded enough for them to react realistically. Finally, another interpretation could be that the hug was an initiated activity by the experimenter rather than that being initiated by the participant or the other virtual character, which could render it less believable in this context.

In terms of self-perception in the virtual environment (*RQ4*), the results indicate that the missing tactile feedback made our participants think that the interaction was not real. The likely cause of this perception is that because hugging is an interaction that is performed almost daily, people possess significant prior knowledge of it and know exactly how it feels to hug a real person.[49,50] Therefore, the participants likely had certain expectations regarding their sensory perception of the physical interaction despite being aware they were interacting with a virtual character. Enhancement of a body ownership illusion is achieved when the tactile feedback is deemed realistic and accurate; otherwise, the participants tended to ignore it and focused more on the visual information and the task they were instructed to perform.[37] Thus, even though pseudo-physical embodiment could affect some somatic sensations to the participants (e.g., the sense of touch), it is difficult to accurately replicate a more engaging and emotionally loaded real-world experience, such as hugging. Finally, we should also consider the inability of the Kinect sensor to capture participants' movement accurately. Motion artifacts on self-motion could lead to a reduction of the illusion of body ownership.[51] It is for these reasons we think our participants reported low levels of body ownership.

In contrast to prior findings that have shown that the sense of presence[32] increases when providing tactile feedback, our study found that the participants' presence did not vary significantly across the participant groups, most likely because the participants were exposed to the exact same virtual environment. In this study, even though the participants were able to control their body and interact with the virtual character by hugging him, they experienced lower levels of presence across all conditions and had minimal actions to perform in the virtual environment. According to previously conducted research, it is important for the participant to be active if we want to elicit the feeling of presence.[45] Moreover, presence is difficult to report via existing questionnaires[52] since it relates to action and interaction rather than the environment. Therefore, the minimal interaction in the virtual environment affected the sense of presence of the participants.

This study also revealed significant gender differences (*RQ5*) in virtual character interaction variables. Females showed more negative experiences when interacting with the virtual character (friend) compared with male participants. However, this result should not be considered surprising because it is known that both biological and sociocultural factors could induce gender differences to artificial entities with anthropomorphic appearance.[53] Moreover, past studies related to physical/virtual touch and human-human touch interactions have reported the important effects of gender in a touch context.[54,55] For example, males often have negative impressions of another male's touch, and females typically hug more often than males.[56] It is thus likely that these were the reasons that impacted potential gender differences in most of the examined variables.

An overall observation of the results showed no differences between the no-tactile feedback condition and most of the tactile feedback conditions. We attribute this finding to the fact that our participants were impatient when they were expecting something to happen when wearing the tactile vest. Impatience increased the emotional responses of our participants,[57] and this feeling impacted their responses throughout the questionnaire and prevented us from identifying the expected differences in the examined conditions. We think that participants' impatience also made them rate the NT condition pretty high compared with other tactile conditions. The inclusion of a condition in which no vest was worn seems critical to further understand the participants' responses.

Anecdotally, we would like to mention that all the participants were willing to hug the virtual friend and that most mentioned that such an interaction with a virtual character was perceived as unusual to them. Several participants also mentioned that the missing feeling of warmness induced with the temperature of the body during hugging made the hugging part of the virtual reality experience less realistic. In retrospect, it can be said that the participants were responsive to the tactile feedback and that its persistency and accuracy were responsible for affecting their experiences in the virtual environment when hugging the virtual character. Based on the results, we can conclude that the realism of the virtual hug correlates strongly with the realism of the tactile feedback and that the participants were able to distinguish the different modalities (visual, haptic, and kinesthetic) contributing to the virtual reality experience to avoid confusion, especially when attention is drawn to particular sensory characteristics.

6 | LIMITATIONS

This study has some limitations. The first limitation is the small sample size of female participants, which limits the generalizability of the results. The inclusion of additional female participants is critical for future studies concerning hugging with virtual characters. Second, we did not capture data related to the duration of the hugging for each participant. Such data is considered valuable when exploring the interaction with the virtual character. Third, each participant experienced only one hug. By allowing the participants to experience the tactile feedback only once, we were able to examine a more accurate reaction, since there was no carryover effect. However, experiencing the feedback only once provided us with an immediate reaction and not an overall reaction that a virtual reality user would have when experiencing the interaction multiple times. Fourth, although the participants were unaware of the tactile condition to which they were exposed, the fact that all of them were wearing the tactile vest prompted the participants to expect something to happen or to feel something on their bodies. We could not overcome this limitation because of the nature of the experimental study and the device used for generating the tactile feedback. Fifth, although current technology can be used to impact some of the participants' experiences, it can be inferred that tactile vests are not yet able to express real-life experiences by providing a pseudo-tactile experience to virtual reality users. Emotionally loaded interactions, such as hugging, require completely differently types of tactile vests and suits. Finally, the average ratings for most of the subjective measures were below 4, where 7 is the best score. Perhaps the virtual reality scenario bore our participants. They were standing for 4 min observing the virtual environment before the virtual friend approached them, and they mostly had a passive interaction in the virtual environment. As such, the participants provided low ratings either due to the passive experience or due to the prior virtual reality experiences they had (e.g., compared with either a virtual reality gaming application or other more engaging virtual reality scenarios).

7 | CONCLUSIONS AND FUTURE WORK

Considering that hugging is an emotionally loaded action that humans are familiar with and perform on a daily basis,[2,4,5] this article examined the participants' experiences when this interaction was performed with a virtual character in a virtual city scenario with and without the presence of tactile feedback. Several concepts were investigated and notable results were obtained. Our findings revealed that the way participants experienced the virtual reality hugging is highly related to the persistence of the tactile feedback. We found that more accurate tactile feedback enhances the realism of the hug interaction, while persistent tactile feedback negatively impacted the participants' experiences in the virtual environment. Moreover, our results confirmed that female participants are more sensitive when interacting with a virtual character.

The current study is a step toward understanding participants' perceptions and reactions while hugging a virtual character in a virtual environment in the presence of tactile feedback. Future research should examine the details of such an interaction, such as gender (male and female virtual friends), age (child, adult, older adult), and appearance of the virtual character (e.g., regular human, cartoon, zombies, or robots). Moreover, interesting insights about the participants' experiences and sensations when hugging a virtual character could also be obtained by capturing and analyzing physiological and eye-tracking data. This research direction requires further exploration.

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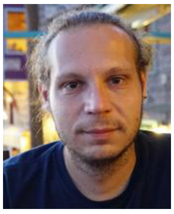

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