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Fostering empathy in social Virtual Reality through physiologically based affective haptic feedback

Jeanne Hecquard Justine Saint-Aubert Ferran Argelaguet Claudio Pacchierotti Anatole Lécuyer Marc Macé
Inria Rennes Inria Rennes Inria Rennes CNRS/IRISA Inria Rennes CNRS/IRISA

Abstract—We study the promotion of positive social interactions in VR by fostering empathy with other users present in the virtual scene. For this purpose, we propose using affective haptic feedback to reinforce the connection with another user through the direct perception of their physiological state. We developed a virtual meeting scenario where a human user attends a presentation with several virtual agents. Throughout the meeting, the presenting virtual agent faces various difficulties that alter her stress level. The human user directly feels her stress via two physiologically based affective haptic interfaces: a compression belt and a vibrator, simulating the breathing and the heart rate of the presenter, respectively. We conducted a user study that compared the use of such a “sympathetic” haptic rendering vs an “indifferent” one that does not communicate the presenter’s stress status, remaining constant and relaxed at all times. Results are rather contrasted and user-dependent, but they show that sympathetic haptic feedback is globally preferred and can enhance empathy and perceived connection to the presenter. The results promote the use of affective haptics in social VR applications, in which fostering positive relationships plays an important role.

Index Terms—Virtual Reality, Affective Haptics, Empathy, User Experience.

I. INTRODUCTION

THE democratization of immersive Virtual Reality (VR) technologies has led to a significant increase in their application in many everyday activities, including gaming, teaching, training, remote working, as well as to interact with friends, family, and colleagues. As a result, virtual social events and platforms multiplied. However, such virtual social environments are affected by the same issues as other online discussion platforms, including cyberbullying and sexual harassment. The causes of cyberbullying are complex, rooted in ignorance but also in reduced empathy, which is strengthened by the anonymity and lack of accountability provided by online platforms [1]. Therefore, preventing harassment and cyberbullying has become crucial to create safe virtual environments (VE) for all users.

In this respect, this paper proposes the use of haptic interfaces for conveying emotions during VR immersive experiences, as a way to address hateful behaviours by fostering empathy between users represented by virtual avatars. Haptic feedback has already been proven central for delivering emotions and increasing the sense of presence in a broad

range of VR scenarios [2]–[6]. For instance, Ju et al. [6] successfully used vibrotactile feedback to express different subjective feelings such as joy, sadness, or anger. We analyze the impact of affective haptics in immersive VR with respect to the feeling of empathy, but also to embodiment, presence, and anxiety. We conducted a VR user study where 38 participants attended a meeting involving a presentation made by a virtual agent. A wearable haptic system, composed of a vibrotactile actuator and a compression belt, was used to provide the participants with a dynamic physiologically based feedback of the emotional status and stress level of the presenter throughout the presentation. We expect such dynamic affective haptic feedback to increase the emotional connection with the presenter and, in turn, the level of empathy towards her.

II. RELATED WORKS

A. Fostering empathy in VR

Positive technology is defined as “the use of technology for improving the quality of our personal experience through its structuring, augmentation and/or replacement” [7]. In this respect, Kim et al. [8] showed that, while victims often experience harsher attacks in immersive VE, (cyber)bullies are also more receptive to positive emotions in these settings. For these reasons, it is important to foster empathy in VR as a way to make users more aware of others’ feelings and emotions, as also done in [9]–[11] by embodying certain perpetrators in the body of their victims (also known as the *Proteus effect* [12]). Hasler et al. [9] showed that this technique of embodiment in VR powerfully enhances mimicry behaviours, which are associated with interpersonal sensitivity and empathy; Peck et al. [10] proved that a short period of embodiment of Caucasian people in black virtual bodies can make their racial bias against black people diminish; Schoeller et al. [13] combined immersive VR and biofeedback to put users into the shoes of a distressed individual so as to train their sense of compassion. Herrera et al. [14] presented the “Becoming Homeless” experience, where users could live in VR the experience of being evicted and then becoming homeless, proving a significant increase in empathy toward homeless people in the participants.

B. Measuring empathy in VR

Empathy is usually measured using self-reporting questionnaires, as well as observing the participants and collecting behavioural and physical measurements. In this respect, one of

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the most commonly used empathy measure is the Interpersonal Reactivity Index (IRI), which is composed of 28 questions targeting four areas [15]:

- *Perspective Taking*, assessing the tendency to spontaneously adopt the psychological point of view of others;
- *Fantasy*, assessing the tendency to transpose into the feelings and actions of fictitious characters in fiction;
- *Empathic Concern*, assessing feelings of sympathy and concern for unfortunate others;
- *Personal Distress*, assessing feelings of personal anxiety and unease in tense interpersonal settings.

Herrera et al. [14] also used self-report questionnaires to measure user levels of distress and empathy toward another avatar. Nonetheless, self-report questionnaire are often difficult to analyze and interpret, as they have been often proven less honest and effective than “objective” (e.g., behavioural and physical) measures [16]. Examples of objective metrics can be the user’s heart rate, gaze, electrodermal activity, or even some relevant post-experimental actions [14], [17]–[19].

C. Affective haptics

Since haptic devices focus on the sense of touch, they are often combined with VR in order to magnify the users’ sense of presence [20], [21]. Affective haptics aims at influencing or communicating the emotional state of human users through the sense of touch [3], [22]. Most affective haptic systems have been designed to simulate the delivery of hugs or caresses during remote or virtual interactions [23]–[25]. A representative example is the HaptiHug [26], [27], a wearable haptic belt wrapped around the user’s torso, able to tighten/loosen to simulate a hug. A human subject study involving 300 participants showed the capability of this device to help convey emotions of happiness and relaxation. Ju et al. [6] worked on emotion recognition via vibrotactile feedback and highlighted some possible universalities in affective vibrotactile stimuli which could support transferring emotions via haptic feedback. Other examples of affective haptic systems have been designed to deliver heart rate feedback, which has been proven to affect the human’s emotional state [28].

III. METHODS

A. Apparatus

We used a wearable haptic system able to dynamically convey physiologically based feedback of heart beat and breathing. The physiological feedback were rendered according to Moullec et al.’s physiological model [29], that calculate cardiac and respiratory activity depending on the avatar’s physiological characteristics as well as its walking speed and the slope of the road. We use the same physiological characteristics for our physiological model to convey distinct stages of stress and anxiety.

1) *Heartbeat simulator*: Conveying heart-rate feedback has been proven capable of conveying emotions [27], [29]. We designed a heartbeat simulator able to simulate different heart-rate in a compact and comfortable form factor [2]. It is composed of a circular piezoelectric vibrating disc ($R = 6\text{ mm}$,

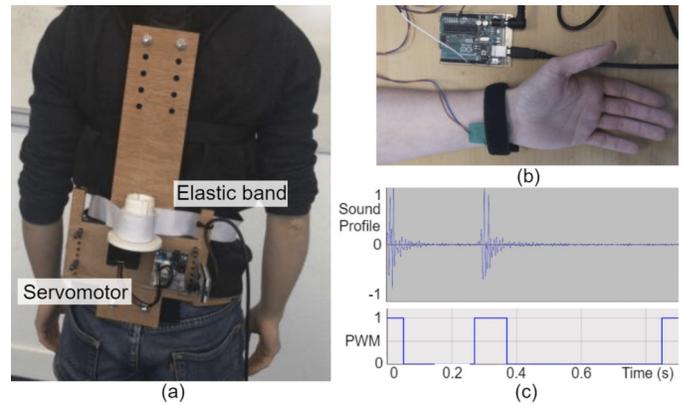


Fig. 1. Haptic setup for the experiment. (a) Compression belt, including the servomotor and the white belt wrapped around the waist. (b) Heartbeat simulator worn on the wrist, driven by an Arduino’s PWM. (c) Variation of sound profile and PWM during a cardiac cycle.

1 G acceleration) driven by Pulse Width Modulation through an Arduino board. An illustration of the vibrating feedback variation is visible in Figure 1c. The actuator is attached to the user’s wrist via a soft Velcro band, enabling contact between the actuator and the skin as well as easy adaptation to different wrist sizes (Figure 1b). This device is capable of simulating heartbeats varying in speed and duration, e.g., to simulate a faster heart rate, the period of the vibrations is reduced; to simulate stronger/more intensive beats, the duration of each vibration is increased. Both changes are used in the experiment to simulate heart rates comprised between 50-220 bpm (calm-high stress [30]) with a vibration/beat duration of 0.1-1 s.

2) *Breathing simulator*: The breathing simulator device was created by Moullec et al. [29]. It is composed of a strap-based vest that users can wear and easily adjust to their own torso. An elastic belt is fastened around the user’s waist, actuated by a servo motor to control the belt length so as to apply pressure and simulate breathing patterns. Figure 1a shows a user wearing the device. We control the speed and depth of the tightening and untightening action of the belt to simulate different breathing patterns, e.g., the stronger the belt tightens, the deeper the breaths are; the faster the belt tightens, the faster the breaths are. The range of the breath rates is between 6 and 60 breaths per minute with a wrapping/unwrapping speed between 0.4 and 4 m/s (calm-high stress [30]). At the beginning of the experiment, the belt is calibrated according to each user’s body morphology.

3) *VR environment*: The experiment was designed using Unity3D. Participants were asked to wear a HTC Vive Pro VR headset to visualize the scene and hold two HTC Vive controllers to move around and interact with it. We used an internal avatar database for the users and the virtual agents, animated using an internal Unity3D add-on. Additional details about the content of the scene are reported below.

B. Experimental design

Participants were asked to attend a presentation in the context of a virtual professional meeting, where a female virtual presenter introduced the latest COVID-19 governmental

guidelines. This study was carried out in early 2022, when this topic was very common. During the presentation, the virtual presenter experiences a series of issues, making her increasingly stressed as the presentation advances. Physiologically based (affective) haptic feedback is provided to the human participant to convey the emotional status of the virtual presenter, using the haptic interfaces described in Secs. III-A1 and III-A2. By analyzing the differences in terms of the participant's sense of presence, embodiment, anxiety, and empathy when using the proposed affective haptic rendering or not, we can analyze its role in fostering these feelings in the considered environment.

1) *VR scenario*: The scene is shown in Fig. 2. It is set in a virtual meeting room, composed of a large table, chairs, and a white screen, where the presentation is shown. Four male colleagues sit around the table while the female presenter stands next to a white screen. The avatar of the human participant also sits at the table, opposite to the other colleagues. Participants were able to select their best-matching avatar from 10 models (2 genders, 5 ethnicities). The verbal interactions in the scene, including the presentation, happened in our country's native language, which was the language spoken by the subjects involved in the experiment. For clarity, in this paper, we report the translated versions of these interactions. The presentation summarizes a new set of governmental guidelines designed to face the COVID-19 pandemic, such as social distancing.

Throughout the presentation, the presenter faces a series of stressors. Since the beginning and throughout the whole presentation, the four male colleagues do not appear to be interested, chatting, looking away, and working on their laptops instead of listening to her. Other stressor events [E] make the presenter increasingly stressed and anxious as the presentation proceeds, but the human participant can intervene [H] to help the presenter and reduce her stress level:

- At $t=100$ s, the laser pointer used by the presenter runs out of battery, making it impossible for her to switch slides [E]. The participant can hand the presenter a new laser pointer, which lays on the table [H].
- At $t=180$ s, the presenter experiences a dry throat, making it difficult for her to speak [E]. The participant can hand the presenter a bottle of water [H].
- At $t=250$ s, two of the four male colleagues make rude remarks regarding the usefulness of the presentation and its excessive length (“Honestly, I don’t really see the point of this meeting, you’re wasting our time.”, “Sigh, is this over yet?”) [E]. The participant can ask questions and give positive feedback about the content of the talk [H].

The full presentation and the related human user's actions can be seen through the submitted supplementary materials. The presentation lasted 4 minutes and 27 s in total.

2) *Physiologically based affective feedback*: Haptic feedback is employed to communicate the presenter's stress level to the human participant. When the presenter's stress increases in response to one of the above mentioned stressors, the heartbeat simulator accelerates and grows stronger while the breathing simulator conveys quicker and shallower breaths. On the other

hand, when the presenter's stress diminishes in response to the human participant's calming/reassuring actions, the heartbeat simulator slows down and gets weaker while the breathing simulator conveys slower and deeper breaths. This evolution is shown in Fig. 3.

3) *Experimental protocol and conditions*: The human subject is asked to seat comfortably on a revolving office chair and wear the VR and haptic systems described in Sec. III-A. Before starting the VR scenario described in Sec. III-B1, we immersed the user in the same virtual room, but without any virtual agent. We asked the user to familiarize with the environment by looking around the room while remaining seated. Users could see where the presentation will be held as well as be aware of the presence of a laser pointer on the table in front of them and bottles of water on a cabinet next to their chair. These items will be useful during the interaction with the presenter, as described in Sec. III-B1. After this familiarization step, we asked users to rotate towards their right, where they could look at their own avatar in a mirror attached to the wall. Moving their arms and head in the real world and seeing the same movements replicated by their virtual avatars strengthens their feeling of presence and embodiment [12]. These familiarization and embodiment exercises lasted between 3 to 5 minutes.

As the user completes the above steps, the scene populates with the virtual agents (as in Fig. 2) and the presentation starts. Each user experienced the scene and its corresponding interactions twice, receiving (in a counterbalanced order) two types of feedback:

- *Dynamic/Sympathetic*: The haptic feedback changes with the level of stress of the presenter, as described in Sec. III-B2 and shown in Fig. 3 (blue solid line).
- *Constant/Indifferent*: The haptic feedback does not change with the stress of the presenter; it always conveys a sensation of relaxation, regardless what happens in the scene (heartbeat: 60 BPM with 0.1 s vibrations, breathing: 15/min with a wrapping/unwrapping speed of 4 s), as shown in Fig. 3 (red dashed line).

4) *Subjects*: Thirty-eight subjects participated in the study (27 males, 11 females). None of the participants reported any deficiencies in their visual or haptic perception abilities. The experimenter explained the procedures and spent about two minutes adjusting the setup to be comfortable before the subject began the experiment. Participants signed an informed consent, including the declaration of having no conflict of interest. The study was approved by the authors' institutional ethical review board.

5) *Evaluation criteria and metrics*: Participants answered to three sets of questionnaires: pre-, mid-, and post-experience. The English translation of the questionnaires is available as supplementary material.

The objective of the **pre-experience** questionnaire was to analyze the user's background, experience, and potential to empathize with the presenter. To do so, we devised an adapted and translated version of the Interpersonal Reactivity Index

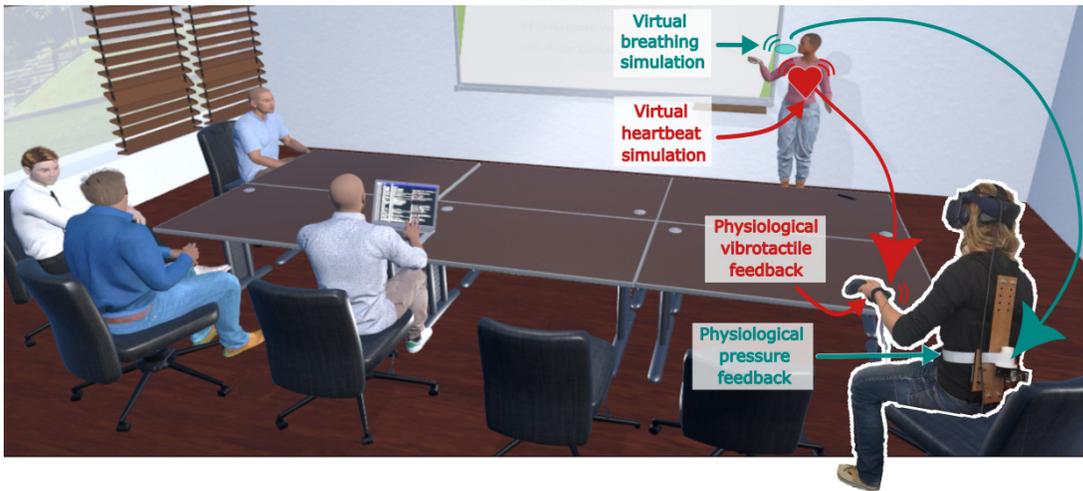


Fig. 2. User experiencing the scenario in VR while wearing the haptic system. He is artificially connected to a virtual presenter by means of a physiologically based haptic feedback. He can “feel” the presenter’s stress and relief through a virtual breathing and heartbeat rendering achieved using the compression belt wrapped around the torso and the vibrotactile feedback on the left wrist.

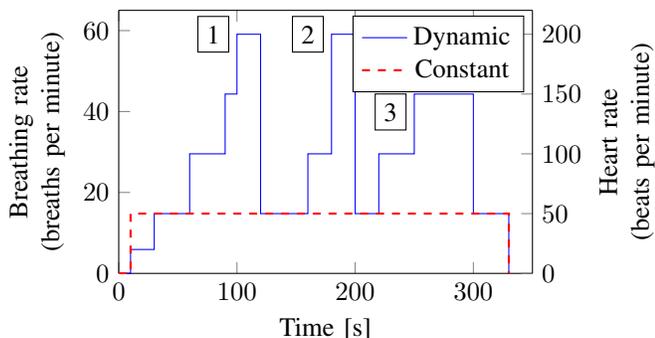


Fig. 3. Evolution of the haptic feedback intensity and speed during the “sympathetic” haptic condition (dynamic) and the “indifferent” haptic condition (constant). The three peaks correlate to times the presenter’s laser pointer runs out of battery (1), she experiences a dry throat (2), and she receives rude comments from her coworkers (3), as described in Sec. III-B1. The belt (left vertical axis) and vibration (right) feedback intensify accordingly. Each step is sharp to ensure a clear perception of the rising intensity.

(IRI) questionnaire, which is commonly used for measuring empathy (see Sec. II-B).

Since users went through the same scenario twice, we provided a **mid-experience** questionnaire at the end of both rounds. Questions centered on user’s feelings of empathy, anxiety, presence [31] and embodiment [32]. The questionnaires on empathy and anxiety were adapted from [14] to evaluate users’ sense of connection to the presenter and her situation. Questions on user anxiety included statements such as “*What happened worried me*” and “*What happened made me uncomfortable*”. For empathy, users were asked to rank statements like “*I felt sympathy for the presenter*”, “*I was touched by the presenter*”, “*I felt connected to the presenter*”.

The objective of the **post-experience** questionnaire was to evaluate the user’s overall perception and feeling of the experience as well as the role of the haptic feedback. We directly asked users to compare their feelings of empathy, immersion, and anxiety between both conditions, as well as the differences they felt, and their preferences in terms of haptic feedback, notably regarding the belt. To not bias users towards

the sympathetic and against the indifferent feedbacks, the questionnaires referred to them as “dynamic” and “constant”.

Eventually, the user was given the possibility to write feedback about the experience as a whole in open questions.

In addition to the above-mentioned questionnaires, we also considered additional behavioral metrics. We recorded the users eye gaze so as to analyze the focus of their attention, and their reaction time in helping the presenter (e.g., the time elapsed between when the presenter asks for the water and when the user hands her the bottle, see Sec. III-B1).

C. Hypotheses

We consider three hypotheses. H1 states that the dynamic/sympathetic haptic feedback, communicating to users the current emotions of the presenter, leads to users feeling more empathetic and connected towards the presenter. It would support other results in the literature where haptic feedback has been proven to help foster empathy and social abilities [26], [33], although in a different context and employing distinct haptic sensations. H2 states that the dynamic/sympathetic haptic feedback leads to users feeling higher anxiety and stress. H3 states that the dynamic/sympathetic haptic feedback leads to users feeling more immersed and present in the virtual environment and experience.

IV. RESULTS

We analyze the results with respect to the three main hypotheses presented in Sec. III-C, then we analyze the correlation between the different metrics.

A. Analysis of our hypotheses

1) *Subjective questionnaires*: Unless otherwise stated, all answers were rated on a 7-point Likert scale, and all questionnaire results were analyzed using Wilcoxon signed-rank or rank sum tests. For parametric data, we used paired t-tests.

Regarding **empathy (H1)**, results from the mid-experience questionnaires revealed no significant differences between the

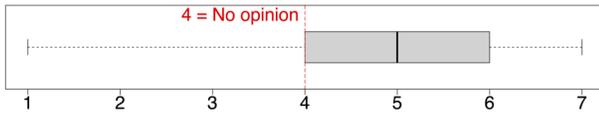


Fig. 4. Haptic preferences in terms of empathy felt (1 = Indifferent feedback, 7 = Sympathetic feedback).

feelings of empathy reported by users when comparing the sympathetic feedback vs. the indifferent one ($W = 760.5$, $p = 0.69$, $r < 0.005$). Overall, users reported relatively high feelings of empathy towards the presenter regardless of the condition (median (MD) = 5.6; interquartile range (IQR) = 1.25). This result therefore does not support H1, where we postulated that sympathetic haptic feedback would lead to a higher connection/empathy towards the presenter. However, when questioned about their preference regarding the two conditions, participants reported a significantly higher preference for the sympathetic feedback in terms of the empathy they felt (see Fig. 4, $V = 1897$, $p < 0.001$, moderate effect size), supporting H1. A Welch Two Sample t-test revealed no significant difference between empathy levels according to user gender ($t(29.576) = 1.6448$, $p > 0.1$). Similarly, ANOVA tests revealed no significant difference in empathy depending on user age ($F(1, 74) = 0.28$, $p > 0.5$) and technical experience ($F(1, 74) = 2.07$, $p > 0.15$).

Regarding **anxiety (H2)**, the feelings of anxiety reported for the two feedback conditions were not significantly different ($W = 758$, $p = 0.71$, small effect size), which is not in accordance with H2. Users also mostly rated the belt as not harrowing, with a score significantly lower than “4 – No opinion” ($V = 800$, $p < 0.05$, small effect size). In contrast, the rising intensity of the belt’s feedback was perceived by most users, with a score significantly higher than 4 ($V = 2829$, $p < 0.001$, large effect size). Users assimilated intensity with feeling “*anxious*” and “*stressed*”: words in the semantic field of intensity (“*intense*”, “*strong*”) were used 25 times by users in the open questions. For anxiety, words such as or similar to “*stress*”, “*felt bad*”, “*sad*”, “*unease*”, “*awkward*”, “*uncomfortable*”, “*anguish*” were used 78 times for the whole experiment. Finally, five users commented that they felt “*oppressed*” during the experiment, with one participant comparing it to “*being underwater*”: they reported having “*the feeling of wanting to intervene, without quite knowing how*”, talking about stopping the colleagues from talking badly to the presenter. The feeling was usually reported to be more intense during the sympathetic haptic feedback: no feelings of stress or anxiety were relayed for the indifferent condition in the open questions, as opposed to the open questions on the sympathetic condition (11 words around “*unease*”, 5 around “*stress*” and “*anxiety*”, 6 around “*intensity*” of the feedback and the feelings). These results support H2.

Finally, regarding **presence and embodiment (H3)**, no significant differences were observed between the two feedback conditions (presence: $W = 786$, $p > 0.5$; embodiment: $W = 780$, $p > 0.5$). Overall, the scores for “presence” were moderately high ($MD = 5$; $IQR = 1.1$), and the scores for “embodiment” were close to the middle point

($MD = 4.2$; $IQR = 1.4$). However, the feeling of presence was shown to be significantly different between experiences with respect to the order they were presented to the users. Participants relayed a lessened sense of presence ($W = 979$, $p < 0.01$, moderate effect size, mean (M) = 5.25 and 4.72; standard deviation (SD) = 0.94 and 0.80) during the second run of the experiment. The distributions were presented respectively for the first and second runs. Simultaneous Tests for General Linear Hypotheses from an ART ANOVA revealed that there is a significant difference in feelings of presence for users who went through the sympathetic haptic condition in first and those who went in second: there is an interaction effect between the order of the walk-throughs the participants experienced and the haptic feedback from each condition ($F(1, 36) = 21.07$, $p < 0.001$). For participants who started the experiment with the sympathetic condition, the difference between the presence they felt during that first walk-through and the second (with indifferent haptic feedback) was significant ($t(36) = 4.32$, $p < 0.001$). No other order effect was significant as revealed by ANOVA tests ($F(3, 73) = 14.29$, $p > 0.88$) for the empathy, the anxiety and the embodiment factors.

2) *Objective behavioural measures*: As mentioned earlier in Sec. III-B5, we also collected the users’ reactivity in helping the presenter as well as their gaze. The user reactivity was calculated as the time elapsed between the moment the presenter asks for help and when the user helps her (see Sec. III-B1). Results did not highlight any significant difference between the two feedback conditions with respect to this metric. The range of reaction times were [0.19; 14.13] s ($MD = 8.41$; $IQR = 2.19$) and [0.12; 14.88] s ($MD = 12.89$; $IQR = 5.31$) for the laser and the bottle, respectively among all participants.

We measured the time percentage users spent watching key elements of the virtual environment. As a Shapiro test ($W = 0.91$, $p < 0.001$) showed the data to not be normally distributed, we carried out an Aligned Rank Transform (ART) ANOVA target vs % of time. The results showed that there were significant differences between the time spent looking at each target ($F(5, 74) = 740$, $p < 0.001$). Post-hoc pairwise comparisons (Tukey correction) revealed that the main target was the presenter ($MD = 64.22$; $IQR = 18.91$), followed by the colleagues and the slides, ($MD = 10.86$; $IQR = 10.86$), the mirror and the laser, ($MD = 3.57$; $IQR = 3.39$) and finally the bottles ($MD = 0.63$; $IQR = 1.91$) (all differences among these groups being significant ($p < 0.001$)).

B. Correlations between empathy and other factors

1) *Subjective questionnaires*: Correlations between the answers to the mid-experience questionnaires are reported in Fig. 5. Additional correlations are reported on the same figure with respect to their answers on the pre-experience questionnaire regarding the IRI reviewed in Secs. II-B and III-B5.

The highest correlation is found between the empathy and the anxiety users felt during each condition with a correlation of 0.74 ($t(74) = 9.57$, $p < 0.001$) over the two factors.

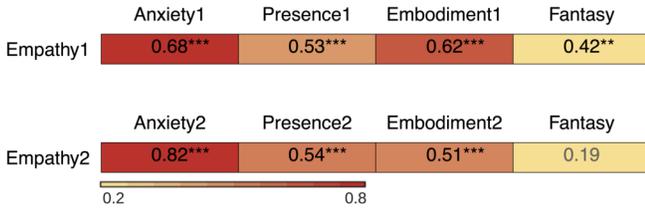


Fig. 5. Results. Correlations between participant feelings of empathy and other factors from the mid-experience questionnaires, and their results from the Interpersonal Reactivity Index. The two conditions corresponds to empathy felt during the **sympathetic** (dynamic) feedback (1), and during the **indifferent** (constant) feedback (2). *** denotes significant differences ($p < 0.0001$), and ** means $p < 0.001$.

Additionally, while the difference between the empathy felt by participants for each feedback condition was not significant (see Sec. IV-A1), there are some correlations between the Fantasy coefficient of the Interpersonal Reactivity Index participants filled before the experience, and the empathy felt for each condition. As shown in Fig. 5, users who rated a higher Fantasy coefficient were more receptive to the sympathetic haptic feedback than the indifferent feedback. An Olkin’s test, which compares two overlapping correlations based on dependent groups, revealed that the empathy felt by participants with the sympathetic feedback was significantly more correlated to the Fantasy coefficient than the empathy felt from the indifferent feedback ($z = 2.6313$, $p < 0.005$). Anxiety levels were also found to be more significantly correlated to the reported levels of empathy during the ‘constant’ (2) condition compared to the ‘dynamic’ (1) condition, according to an Olkin’s test ($z = 2.5870$, $p < 0.005$).

2) *Objective behavioural measures*: Participant empathy and anxiety and the time they spent looking at the presenter was significantly correlated (0.26 for $t(74) = 2.24$, $p < 0.05$, and 0.40 for $t(74) = 3.64$, $p < 0.001$ respectively).

V. DISCUSSION

Reported feelings of empathy for each walk-through were overall relatively high (5.6 out of 7), as seen in Sec. IV-A1. This suggests a ceiling effect that did not allow for a significant difference between the two conditions, while the preference for sympathetic feedback was significant in reference to the empathy users felt. Likewise, although users did not seem to find the belt to be anxiety-inducing, they did find the scenario more intense/harrowing when receiving sympathetic haptic feedback, and commented more on their anxiety and distress after the sympathetic condition walk-through. Hence, while the results are contrasted, the first two hypotheses are supported by user feedback. The lack of large differences between participant feelings for each scenario could also be explained by user bias. As Carey et al. [34] highlighted, users often have trouble scaling their feelings during an experience, which can in turn make data harder to analyse. The last hypothesis (H3) on a stronger sense of presence was not supported by a majority of participants. The decrease in presence between the first run with sympathetic feedback and the second with constant feedback could be explained

by the similarity between the two scenarios. Since the only difference between the two runs of the experience was the haptic feedback provided, users had time to get acclimated to the scene, which could have changed how they felt about their sense of place illusion and plausibility [31], [35]. It is also possible that users felt a stronger difference in their sense of presence since the experience appeared less intense to them without the sympathetic haptic feedback. In the future, using multiple different scenarios and VE between the two conditions and more exhaustive tutorials might help mitigate this effect. Considering the contrasted results, it seems that participants might be divided into groups according to their reception of sympathetic haptic feedback. For example, participants who rated higher on the Fantasy coefficient of the Interpersonal Reactivity Index generally tended to be more susceptible to sympathetic haptic feedback, in intensity, presence, or even empathy. It might be interesting to study this distinction further, and find what type of haptic feedback works best for each type of person. This is especially important as these results were strengthened by the behavioural measures which correlated accordingly. Additionally, the strong correlation between the empathy and the anxiety felt by participants could be a useful tool in future experiments.

There are several types of future works to consider from this paper. Firstly, the paper did include some limitations. The empathy measurements were simple, and the study had no ‘haptic-less’ control group. As a study on emotions, the number of participants ($N=38$) was small. We could also explore the characteristics that make users react differently to affective haptic feedback and study the effect of new haptic sensations with our current devices. Instead of using the compression belt to simulate breathing, it could be used as physiological pressure feedback, compressing the user’s torso. Furthermore, we could focus on the link between visual emotion cues and affective haptic feedback to explore the possibilities of feedback plausibility.

VI. CONCLUSION

This paper studied the role of physiologically based haptic feedback in fostering feelings of connection and empathy during an immersive VR experience, comparing two different affective haptic feedback. The first one made the user feel the heartbeat and breathing patterns of a virtual agent experiencing a series of stressful interactions, transmitting/communicating her anxiety and stress to the user. The second feedback provided no such information, with the user experiencing constant heartbeat and breathing patterns regardless of what the virtual agent was experiencing and feeling. Results of a user study involving 38 participants showed that stress, relief, and anxiety could be communicated through affective haptic feedback, making, to a certain extent, participants feel closer to the agent haptically connected to them. These promising results show the viability of using haptic feedback to foster empathy in social VR scenarios. Taken together, they promote the use of empathetic haptics within VR applications in which inducing positive relationships plays an important role.

REFERENCES

- [1] I. Marin-Lopez, I. Zych, R. Ortega-Ruiz, C. P. Monks, and V. J. Llorent, "Empathy online and moral disengagement through technology as longitudinal predictors of cyberbullying victimization and perpetration," *Children and Youth Services Review*, vol. 116, 2020.
- [2] C. Pacchierotti, S. Sinclair, M. Solazzi, A. Frisoli, V. Hayward, and D. Prattichizzo, "Wearable Haptic Systems for the Fingertip and the Hand: Taxonomy, Review, and Perspectives," *IEEE Transactions on Haptics (ToH)*, 2017.
- [3] M. A. Eid and H. Al Osman, "Affective haptics: Current research and future directions," *IEEE Access*, 2016.
- [4] P. Kourtesis, F. Argelaguet, S. Vizcay, M. Marchal, and C. Pacchierotti, "Electrotactile feedback applications for hand and arm interactions: A systematic review, meta-analysis, and future directions," *IEEE Transactions on Haptics*, 2022.
- [5] C. Pacchierotti, "Cutaneous haptic feedback for robotics and Virtual Reality," Habilitation à diriger des recherches, Université de Rennes 1 (UR1), Rennes, FRA., 2022.
- [6] Y. Ju, D. Zheng, D. Hynds, G. Chernyshov, K. Kunze, and K. Minamizawa, "Haptic empathy: Conveying emotional meaning through vibrotactile feedback," in *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*, 2021.
- [7] A. Kitson, M. Prpa, and B. Riecke, "Immersive interactive technologies for positive change: A scoping review and design considerations," *Frontiers in Psychology*, 2018.
- [8] A. Kim, M. Chang, Y. Choi, S. Jeon, and K. Lee, "The effect of immersion on emotional responses to film viewing in a virtual environment," in *IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, 2018.
- [9] B. S. Hasler, B. Spanlang, and M. Slater, "Virtual race transformation reverses racial in-group bias," *PLOS ONE*, no. 4, 2017.
- [10] T. C. Peck, S. Seinfeld, S. M. Aglioti, and M. Slater, "Putting yourself in the skin of a black avatar reduces implicit racial bias," *Consciousness and Cognition*, 2013.
- [11] S. Seinfeld, J. Arroyo-Palacios, G. Iruretagoyena, R. Hortensius, L. E. Zapata, D. Borland, B. de Gelder, M. Slater, and M. V. Sanchez-Vives, "Offenders become the victim in virtual reality: impact of changing perspective in domestic violence," *Scientific reports*, 2018.
- [12] N. Yee and J. Bailenson, "The proteus effect: The effect of transformed self-representation on behavior," *Human Communication Research*, 2007.
- [13] F. Schoeller, F. Zenasni, P. Bertrand, L. Gerry, A. Jain, and A. Haar Horowitz, "Combining virtual reality and biofeedback to foster empathic abilities in humans," *Frontiers in Psychology*, 2019.
- [14] F. Herrera, J. Bailenson, E. Weisz, E. Ogle, and J. Zaki, "Building long-term empathy: A large-scale comparison of traditional and virtual reality perspective-taking," *PLOS ONE*, 2018.
- [15] M. H. Davis, "A multidimensional approach to individual differences in empathy," *JSAS Catalog of Selected Documents in Psychology*, 1980.
- [16] R. Butters, "Meta-analysis of empathy training programs for client populations," 2010.
- [17] D. Neumann, R. Chan, G. J. Boyle, Y. Wang, and R. Westbury, *Measures of Empathy*, 2015.
- [18] F. F. d. Lima and F. d. L. Osório, "Empathy: Assessment instruments and psychometric quality – a systematic literature review with a meta-analysis of the past ten years," *Frontiers in Psychology*, 2021.
- [19] N. Eisenberg and P. Miller, "The relation of empathy to prosocial and related behaviors," *Psychological bulletin*, 1987.
- [20] E. Bouzbib, G. Bailly, S. Haliyo, and P. J. Frey, "'Can I Touch This?': Survey of Virtual Reality Interactions via Haptic Solutions," *ArXiv*, 2021.
- [21] M. Slater, "A note on presence terminology," 2003.
- [22] D. Tsetserukou, A. Neviarouskaya, H. Prendinger, N. Kawakami, and R. Tachi, "Affective haptics in emotional communication," in *3rd International Conference on Affective Computing and Intelligent Interaction and Workshops*, 2009.
- [23] K. Salminen, V. Surakka, J. Lylykangas, J. Raisamo, R. Saarinen, R. Raimo, J. Rantala, and G. Evreinov, "Emotional and behavioral responses to haptic stimulation," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2008.
- [24] L. Bonanni and C. Boulanger, "Affective TouchCasting," 2006.
- [25] G. Huisman, A. D. Frederiks, J. B. F. van Erp, and D. K. J. Heylen, "Simulating affective touch: Using a vibrotactile array to generate pleasant stroking sensations," in *Haptics: Perception, Devices, Control, and Applications*, F. Bello, H. Kajimoto, and Y. Visell, Eds., 2016.
- [26] D. Tsetserukou, "Haptihug: A novel haptic display for communication of hug over a distance," in *EuroHaptics*, 2010.
- [27] D. Tsetserukou and A. Neviarouskaya, "World's first wearable humanoid robot that augments our emotions," 2010.
- [28] F. Arafsha, K. M. Alam, and A. E. Saddik, "Emojacket: Consumer centric wearable affective jacket to enhance emotional immersion," in *International Conference on Innovations in Information Technology (IIT)*, 2012.
- [29] Y. Moullec, J. Saint-Aubert, J. Manson, M. Cogné, and A. Lécuyer, "Multi-sensory display of self-avatar's physiological state: virtual breathing and heart beating can increase sensation of effort in VR," *ISMAR*, 2022.
- [30] E. V. Devy Widjaja, Michele Orini and S. Van-Huffel, "Cardiorespiratory dynamic response to mental stress: a multivariate time-frequency analysis," *Comput Math Methods Med.*, 2013.
- [31] R. Skarbez, F. P. Brooks, Jr., and M. C. Whitton, "A survey of presence and related concepts," *ACM Computing Surveys*, 2017.
- [32] M. Gonzalez-Franco and T. Peck, "Avatar embodiment. towards a standardized questionnaire," *Frontiers in Robotics and AI*, 2018.
- [33] M. Hoppe, D. Neumann, S. Streuber, A. Schmidt, and T.-K. Machulla, "A human touch: Social touch increases the perceived human-likeness of agents in virtual reality," 2020.
- [34] K. Carey, E. Saltz, J. Rosenbloom, M. Micheli, J. Choi, and J. Hammer, "Toward measuring empathy in virtual reality," 2017.
- [35] M. Slater, "Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments," *Philosophical Transactions of the Royal Society B: Biological Sciences*, 2009.