Persuasive Vibrations: Effects of Speech-Based Vibrations on Persuasion, Leadership, and Co-Presence During Verbal Communication in VR

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Figure 1: We investigated whether reinforcing speech with vibrotactile feedback displayed in users' hand could improve perceived persuasion, leadership, and co-presence when users listen to agents (left) or when users talk to agents (right) in Virtual Reality.

Abstract

In Virtual Reality (VR), a growing number of applications involve verbal communications with avatars, such as for teleconference, entertainment, virtual training, social networks, etc. In this context, our paper aims to investigate how tactile feedback consisting in vibrations synchronized with speech could influence aspects related to VR social interactions such as persuasion, co-presence and leadership. We conducted two experiments where participants embody a first-person avatar attending a virtual meeting in immersive VR. In the first experiment, participants were listening to two speaking virtual agents and the speech of one agent was augmented with vibrotactile feedback. Interestingly, the results show that such vibrotactile feedback could significantly improve the perceived co-presence but also the persuasiveness and leadership of the haptically-augmented agent. In the second experiment, the participants were asked to speak to two agents, and their own speech was augmented or not with vibrotactile feedback. The results show that vibrotactile feedback had again a positive effect on co-presence, and that participants perceive their speech as more persuasive in presence of haptic feedback. Taken together, our results demonstrate the strong potential of haptic feedback for supporting social interactions in VR, and pave the way to novel usages of vibrations in a wide range of applications in which verbal communication plays a prominent role.

Index Terms: Audio, Haptic, Vibrotactile feedback, Speech, Co-Presence, Leadership, Persuasion

1 Introduction

With the development of collaborative environments, verbal communication is becoming increasingly important in Virtual Reality (VR). But challenges remain for such an environment to provide an interesting substitute to face-to-face interactions [41]. People tend to work harder when they are not alone [45] but such an impression is harder to generate in remote environments [41]. Interactions between users are also more difficult in VR, so effective leadership is difficult [37]. Finally, the physical distance between remote users reduces their ability to be persuasive [11]. In this paper, we investigate if speech synchronized with vibrotactile feedback can augment users' social experience of co-presence and their abilities of leadership and persuasion in VR.

Haptic is a synonym for the term "touch-base" [35] and haptic technologies can be divided into two parts : force feedback technologies that stimulate muscles and joints and tactile feedback technologies that stimulate the skin. Vibrotactile feedback refers to the transmission of vibrations to the skin and such feedback is closely related to sound. When we speak, we make our body vibrate. At a concert, we feel vibratory feedback if we get close to a speaker. At the neural and behavioural levels, studies showed that there is an intuitive integration of vibrotactile and auditory inputs [5, 43, 50] This close relationship has enabled the successful implementation of vibrotactile devices capable of representing speech signal in scenarios with low audio quality [17]. In the context of speech synchronized with vibrotactile feedback, the vibrations emphasize the sound feedback so it seems an interesting way to influence leadership and persuasion.

Leadership is about the ability to influence others and is related to persuasion, the act of convincing an audience of a particular point of view. Persuasive speech is broadly used in verbal communication, for instance in meetings, advertisements, informal discussions among friends, etc. Being able to modulate speaker leadership or persuasion in a collaborative environment could be of interest to increase inclusivity (e.g., of shy participants) or to solve conflicts. Previous studies have suggested that leadership is influenced by visual feedback [27, 60]. For example, users with greater immersion in a head-mounted display tend to be viewed as leaders, compared to those with less immersion and viewing a screen [60]. Leadership can also be modulated by audio feedback [30, 34, 40, 62]. For example, lowered pitch voice seem to increase leadership [34]. Reinforcing speech with vibrotactile feedback could be an interesting alternative as it preserves the user's immersion and identification in the virtual environment (e.g., appearance, voice).

Leadership seems to be correlated with co-presence [60]. Researchers have conceptualized the notion of co-presence as a sense of being together in the virtual environment [15, 25, 60, 66]. Displaying realistic haptic feedback, such as the force exerted by another

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person, can have a positive influence on co-presence during a collaborative task [52]. However, providing such haptic feedback is not possible in all scenarios (e.g., during a formal meeting). It also has a mixed result in simulation involving audio feedback [53], whereas audio is essential in a collaborative environment. Vibrotactile feedback reinforcing speech could then be an interesting alternative since it can be integrated into any collaborative environment involving verbal communication. The direct relation between sound and vibrotactile feedback could also facilitate its integration in scenarios involving audio.

This paper investigates how speech reinforcement through vibrotactile feedback influences persuasion, leadership and co-presence. To this end, we conducted two user experiments where participants embodied an avatar and faced two agents (virtual human controlled by a computer algorithm). In the first experiment (Section 3), participants listened to the agents and the speech of one of them was augmented with vibrotactile feedback. In the second experiment (Section 4), participants spoke and received vibrotactile feedback corresponding to their own speech when they spoke to one of the agents. The influence of the vibrotactile feedback on co-presence, leadership and persuasion was studied using questionnaires.

2 Related work

In the past, vibrotactile feedback has been used to convey information unrelated to speech. For example, abstract messages have been coded with different vibrations (frequency, duration, amplitude, etc.) [13] or emotions have been simulated by transmitting vibrations of different frequencies [4]. Vibrotactile feedback has also been synchronized with speech, but for the purpose of improving speech perception of impaired people (e.g., [6, 14, 16, 18, 20, 24, 28, 48]).

In the following, we discuss how speech synchronized with vibrotactile feedback might influence users' social experience of co-presence, leadership, and persuasion. Since few studies on the topic of co-presence have focused on vibrotactile feedback, we included work related to the influence of haptic feedback (tactile and force feedback).

2.1 Influence of haptic feedback on co-presence

2.1.1 Influence of force feedback

The sense of co-presence is related to the sense of togetherness, which has been studied during collaborative tasks [3, 29]. In a study by Basdogan et al. [3], two participants located at remote sites cooperated to perform a common task in virtual reality and the results showed that simulations involving force feedback from virtual objects resulted in a significantly higher sense of togetherness than simulations without force feedback. Togetherness also appeared to be enhanced by the transmission of more communicative force feedback cues, such as a handshake, kiss, or thumb press [23, 42, 54].

Co-presence seems to be positively correlated with presence [60], the subjective experience of "being there" in a virtual environment [58, 59]. Previous studies suggest that force feedback (e.g., [36, 39, 44, 63]) enhance this sense of presence in remote environments. Similar conclusions were drawn for collaborative environments where participants simultaneously manipulate objects while receiving force feedback representing contact with those objects [51–53].

Co-presence is also related to the concept of social presence, which refers to the feeling of being socially present with another person at a remote location. Social presence is a multidimensional construct that includes perceived co-presence, psychological involvement, and behavioral engagement [7,8,56]. Sallnas et al. [52] studied social presence in a virtual object passing task. Results revealed a significant improvement in social presence when force feedback of virtual objects was displayed.

Together, these studies suggest that haptic feedback, in the form of force feedback, has a positive influence on co-presence. However, these works did not involve audio feedback [23, 52]. In a study where participants jointly manipulated virtual objects while communicating via audio [53], force feedback did not significantly improve perceived social presence. The authors of this study explained that the effect of the audio communication between participants may have overshadowed the impact of the haptic communication during the interaction. In their experiment audio and haptic were used to transmit distinct information. Vibrotactile feedback synchronized with audio speech are both related to the same information, so the effect could be different.

2.1.2 Influence of vibrotactile feedback

While the previous section discussed the influence of force feedback, this section focuses on vibrotactile feedback. The influence of vibrotactile feedback on co-presence has been studied in the past by Jung et al. [31] who evaluated its effect during a multi users game. In this game, users shooted on each other and recieved or not vibrotactile feedback corresponding to the impacts. The results suggest a higher sense of co-presence when vibrotactile feedback was presented to users. Vibrotactile feedback also seem to increase the sense of presence (e.g., [12, 22, 32]). For instance in a study by Garcia et al. [22], participants wore a vest containing vibrotactile actuators and received or did not receive feedback when they collided with avatars in a VR scenario. Results showed a higher sense of presence with than without tactile feedback. Vibrotactile feedback also appears to increase social presence for instance when accompanying a text message [26]. Together, these studies suggest that vibrotactile feedback has a positive influence on the sense of co-presence.

However, these studies were conducted in specific contexts (e.g., shooting game, collision with objects) and the influence on co-presence of vibrotactile feedback synchronized with speech has not been evaluated. To our knowledge the only study that was performed on speech-based vibrations was led by Banakou et al. [2], who study the effect on the sense of embodiment, the feeling of being inside a virtual body [33]. In this study, participants embodied an avatar that spoke while they remained silent and a vibrotactile stimulation synchronized with the avatar's speech was transmitted to them or not. Results show that vibrotactile feedback synchronized with speech increased the sense of embodiment of participants. The sense of embodiment can be correlated with the sense of social presence [61], that is itself correlated with the sense of co-presence, but the direct influence on the sense of co-presence has not been demonstrated.

2.2 Influence of vibrotactile feedback on leadership and persuasion

Studies have shown that vibrotactile feedback can improve users' attentional focus [26, 57]. Users who received vibrotactile feedback synchronized with instructions appeared to respond more to those instructions [64]. Vibrotactile feedback synchronized with speech could also influence users' subjective perception of the speaker's strength, competence, and trustworthiness [65]. Weill et al. [65] showed that the effects depend on the gender of the listener and that vibrotactile feedback increase perceived competence but decrease confidence between the male speaker and the male listener. Vibrotactile feedback also appear to improve perceived strength for both male and female speakers but decrease perceived competence for female listeners. These results indicate that vibrotactile feedback can have both a positive and negative influence on leadership and persuasion.

Like co-presence, perceived leadership could be influenced by the sense of presence. In a study by Slater et al. [60], a group of participants performed a collaborative task in VR while receiving visual feedback with varying degrees of immersion (screen or head-mounted display). At the end of the simulation, participants were asked to identify who they thought was the leader and they chose the participant with a higher degree of immersion. As discussed in the previous paragraph on co-presence, haptic feedback appears to have a positive effect on presence (e.g., [12, 32, 36, 39, 44, 63]), so that it might in turn positively affect leadership.

The actual effect of speech-synchronized vibrotactile feedback on leadership and persuasion has not been studied in the past. Related studies ([64, 65]) did not evaluate persuasion nor leadership and have been conducted outside of VR while visual display may affect perceived leadership (e.g., [46, 60]). Previous studies have also focused on the case of the listener but verbal communication is a two-way interaction [19]. Exploring the case of the speaker where haptics reinforce the user's speech could therefore be interesting but it has never been done before.

3 Experiment I: Reinforcing the speech of others

We conducted an first user study to evaluate the influence of speech synchronized with vibrotactile feedback on the social experience when users listen to other agents. The procedure of the experiment was approved by the ethics committee of Inria Rennes.

3.1 Overview

Seated participants wore a head-mounted display and embodied a first-person gender-matched avatar. They attended a VR meeting with two twin agents (male or female) who could only be distinguished by their shirt color (Figure 2).

Figure 2: Male (left) and female (right) twins as seen from the participants' perspective.

In a predefined simulation, the twins debated and tried to convince participants to follow their idea for a research topic. They spoke alternately and provided arguments for one idea or the other. The speeches were vague and symmetrical so as not to bias participants in favor of one idea (see Section 3.3.1). Participants received audio feedback corresponding to the speeches, and the arguments of one of the agents were augmented by vibrotactile feedback (Fig. 3). The vibrations were displayed by a tactile actuator held in the participants' right hand. A simulation lasted about 3 minutes. At the end of the simulation, participants were asked to rate their perception of the two agents' co-presence, persuasiveness, and leadership using a questionnaire.

3.2 Hypotheses

We had three hypotheses regarding the outcome of the first experiment. Previous work suggests that tactile feedback could have a positive influence on co-presence if correlated with audio feedback. Haptic feedback also seems to increase presence which in turn could have a positive effect on leadership or persuasion. We therefore expected that when listening to an agent :

- **(H1L)** Speech-based vibrations enhance co-presence.
- **(H2L)** Speech-based vibrations reinforce agents leadership.
- **(H3L)** Speech-based vibrations enhance agents persuasion.

Previous work suggests that aspects related to leadership may depend on the gender of the listener/speaker [65]. However, both positive and negative effects seem to be elicited for all gender combinations. Therefore, we hypothesized that the results will not differ by gender of the listener/speaker.

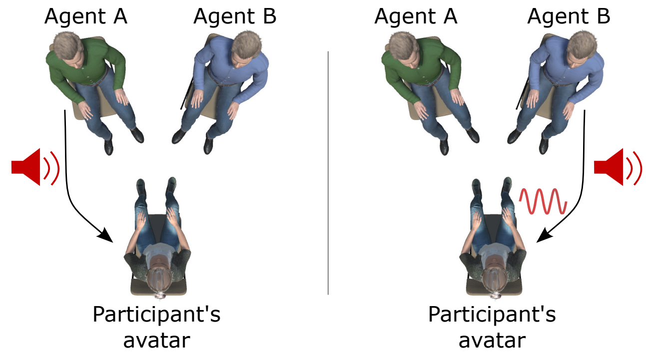

Figure 3: In the first experiment, participants received audio feedback from one agent and audio feedback synchronized with vibrotactile feedback from the other agent.

3.3 Experimental set up

The virtual environnement was a virtual meeting room (Fig. 1 implemented in Unity 3D (Version 2020.3.23f1). Visual feedback was provided to participants via an HTC *Vive Pro* head-mounted display (2880 x 1600 pixels) (Fig. 4). The orientation of the embodied avatar's head was controlled by the orientation of the head-mounted display inferred by two lighthouses.

Figure 4: The setup for Experiment I which includes a visual headset, an audio headset and a vibrotactile actuator.

3.3.1 Speeches

The agents' speeches were vague so as not to bias the participants. For example, the blue agent's first sentence was "I think the first idea is more interesting, it could demonstrate useful things", while the green agent responded "I don't think so, I find the second idea more innovative and it has never been tested in the past". The agents provide several arguments, each defending his idea without specifically mentioning what that idea was.

The speeches were also symmetrical so that the agents both provided the same argument for the same idea. To this end, the agents formulate their arguments and at one point, one of them proposes to integrate the work of a colleague: "Anna proposes to integrate her project with our ideas". The agents then change their point of view. The blue agent replies, "The second idea would be more innovative and has never been tested in the past," while the green agent says, "I think Anna's project would fit better with the first idea. It would be more interesting and could demonstrate useful things".

The agents' texts were converted to English speech by a converter from the Internet (voicemaker.in website). Both twins had the same voice. The peak pitch for the male avatars was 130 Hz and 200 Hz for the female avatar. Occulus lip sync was implemented on the agents to display lip movements.

3.3.2 Audio feedback

The audio feedback was displayed by an NVidia HD Audio computer sound card. It was transmitted to the participants through a Hyper X Cloud noise isolation headset (Fig. 4). The headphones included in the head-mounted display were not used because they do not cover the noise produced by the vibrotactile actuator. Sound was displayed in Unity by an audio source located at the mouth of the speaking agent. An audio listener was located on the avatar embodied by the participants. All parameters of the audiosource were set to their default values. The sound was rendered by an audio mixer (Volume = 13 dB, Threshold = -12.5dB, Ratio = 722%, AttackTime/Release time = 100 ms, Make Up Gain = 0dB, Knee = 13dB, SidechainMix = 0%). The audio level of the Windows setting has been set to 14. All these characteristics were chosen empirically for the vibrations to be comfortable.

3.3.3 Vibrotactile feedback

Vibrotactile feedback was delivered by a HapCoil-Plus actuator from *Actronika* (France). It is a small cylinder of 3.5 cm height and 1 cm radius (Fig. 4). With this actuator, amplitude and frequency can be controlled separately to generate a fine tactile signal. Controlling the amplitude and frequency independently was not possible with the vibrators embedded in the HTC Vive controllers. The HapCoil-Plus bandwidth of 10 Hz to 1000Hz covers the haptic band and most of the audio band.

To generate the signals, a single to dual jack splits the audio output into two identical signals, one for the headphones and one for the vibrotactile actuator. To activate/deactivate the vibrotactile between the green and blue agent, a relay module was used (Sunfounder, 5V). The audio signal was amplified by a digital amplifier board (TDA3116D2, 50W) powered by a power supply (45W, 6V) before being sent to the vibrotactile actuator. No signal processing was done so that the vibrations correspond to the complete audio signal.

3.4 Data collected

Participants completed a questionnaire on co-presence, leadership and persuasion at the end of each simulation. The co-presence was assesed by questions proposed by Bailenson et al. [1], the leadership was measured with the question proposed by Slater et al. [60] and the persuasion with question suggested by Hanus et al. [27]. When I was speaking to the X agent, I felt ...

- (Q1) like that the agent was in the room with me.
- (Q2) like the agent was aware of my presence in the room.
- (Q3) that the agent had a great leadership.
- (Q4) that the agent was convincing.

Participants answered these questions on 7-point Likert scales for each avatar (green and blue). At the end of the experiment, we also asked participants if they perceived the vibrotactile feedback and if so, what it was related to and whether or not it was disturbing.

3.5 Participants

A sample of 20 volunteers (13 men; mean age: 27.2 ± 5.3 years) participated in the first experiment. All participants gave written informed consent before testing and were not compensated for their participation. They reported no visual, auditory, or haptic impairments that would have affected the experiment. A total of 21% of participants reported never using virtual reality technology, 25% used it sometimes, and 54% used it often.

All participants tested a simulation with male twins and a simulation with female twins. These simulations were tested in a random order. The presentation of the tactile conditions was also randomized across participants: some received tactile feedback corresponding to the blue agent's speech and others to the green agent's speech.

3.6 Results

The normality assumption was not met for most of the data, as is often the case with Likert scales. We used linear modeling to test the influence of agent gender and participant gender on the dependent variables and found no significant effect on the models. The results of Experiment 1 are then reported in Fig. 5 and analyzed considering the type of vibrotactile feedback only. We analyzed the data using the Wilcoxon signed-rank test. The Holm-Bonferroni correction was applied on the p-values to counteract the problem of multiple hypothesis comparisons. In the results presented below, "m" represents the mean,"std" the standard deviation, "p" the p-value, and "r" the effect size calculated using the formula proposed by Rosenthal et al. [49] for nonparametric data.

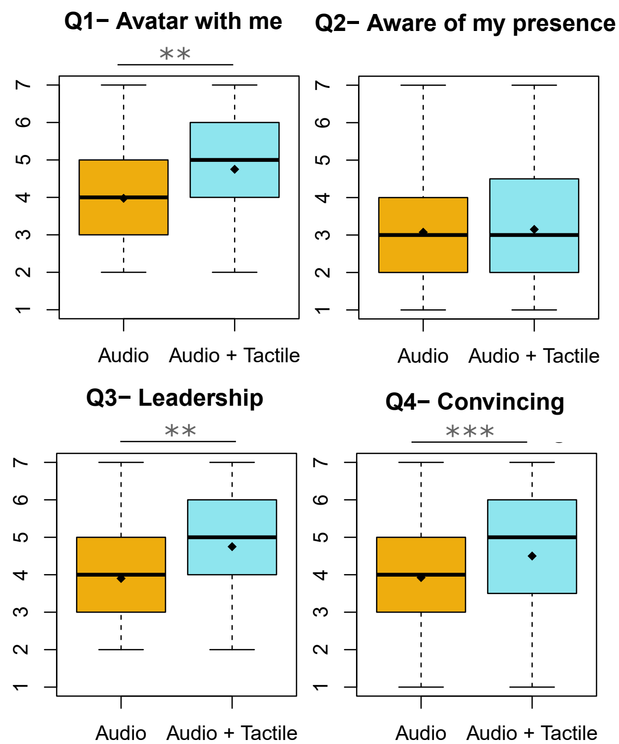

Figure 5: Results from Experiment 1: Participants' responses rating their co-presence and agent leadership. Boxplots represent medians and dispersions. Dots indicate means. ** means ($p < 0.01$) and *** means ($p < 0.001$).

The participants' impression that the agent was in the room (Q1) was significantly higher with ($m = 4.8, std = 1.5$) than without tactile feedback ($m = 3.9, std = 1.5, p = 0.001, r = 0.54$). The participants' impression that the agent was aware of their presence in the room (Q2) was not significantly different with ($m = 3.2, std = 1.7$) and without tactile feedback ($m = 3.1, std = 1.6, p = 0.37$). The participants' impression of leadership (Q3) was significantly higher with ($m = 4.8, std = 1.4$) than without tactile feedback ($m = 3.9, std = 1.4, p = 0.003, r = 0.47$). Finally, the participants' impression that the agent was convincing (Q4) was significantly higher with ($m = 4.5, std = 1.6$) than without tactile feedback ($m = 3.9, std = 1.4, p < 0.001, r = 0.56$).

Spearman's rank correlation was calculated to assess the relationship between the variables. It suggests a positive correlation between agent leadership and persuasion ($r(40) = 0.47, p = 0.002$).

For questions regarding the perception of tactile feedback, all participants responded that they perceived it and that it correlated with the agents' speech. A total of 4 participants found the tactile feedback uncomfortable. Half of these participants still felt a positive effect on co-presence and leadership, the other half felt no effect.

3.7 Conclusion of the Experiment I

Overall, the results of Experiment 1 indicate a positive impact of speech-synchronized vibrotactile feedback on co-presence, leadership and persuasion of other agents. These results will be discussed in Section 5. Since vibrotactile feedback can influence social interactions with agents, we went a step further by performing a second experiment to evaluate the influence on the participant's own speech.

4 Experiment II: Reinforcing My Speech

We conducted a second user study to evaluate the influence of speech-synchronized vibrotactile feedback on the social experience when users talk to other agents. The procedure for this second experiment was also approved by ethic committee of Inria Rennes.

4.1 Overview

The virtual scene was the same as that with the male twins in Experiment I (see Section 3.1). During a simulation, participants embodied an avatar and alternately addressed the blue and green agent to discuss each other's ideas. The speeches were pre-written and posted on signs in front of the agents (Fig. 6). Participants were asked to

Figure 6: The twins with the signs displaying the speeches in front of them. The texts are in French as in the experiment, it did not bring much information to display them in English.

read these signs. In the same vein as in Experiment I, the speech focused on the discussion of research ideas, and was vague and symmetrical so as not to bias participants (see Section 4.3.1). Participants received natural audio feedback corresponding to their speech, and arguments to one of the agents were augmented with vibrotactile feedback (Fig. 7). The vibrotactile feedback was displayed by the same actuator as in Experiment 1. The duration of the simulation varied according to the participants but was around 3 minutes. At the end of the simulation, we asked participants to rate their perception of co-presence, their own leadership, and their own persuasion using a questionnaire.

4.2 Hypotheses

To our knowledge, augmenting the participant's own speech with vibrations has not been investigated in the past. We then decided to make the same hypotheses than in the listening scenario but when speaking to other agent :

- **(H1S)** Speech-based vibrations enhance co-presence.
- **(H2S)** Speech-based vibrations reinforce users leadership.
- **(H3S)** Speech-based vibrations enhance users persuasiveness.

These hypotheses were only tested for male agents as a first step, as the case of speakers had not been studied before.

4.3 Experimental set up

The experimental set up was almost the same than in the first experiment. In what follows, only the differences are described.

4.3.1 Speeches

The speeches were in French so that the participants, whose native language was French, would be more comfortable and less focused on reading. The speeches were similar to those in the first experiment. However, the text was modified to be consistent for one speaker (the participant) speaking to two listeners (the agents). For example, the first sentence for the blue agent was "I think the first idea is more interesting, it could demonstrate useful things" while the next sentence for the green agent was "I find the second idea less innovative, it has been tested in the past". Participants provided several arguments like these. The speeches were again vague so as not to bias the participants.

As in the first experiment, the speeches were also symmetrical so that participants provided the same arguments for both ideas. Participants formulated their arguments and at one point proposed to integrate a colleague's work: "Alternatively, Anna proposed to integrate her project with our ideas". The participants then changed their point of view. They replied to the blue agent: "In this case, I think the first idea would be less innovative, it has already been tested in the past", while they told the green agent: "The second idea would become more interesting, it could demonstrate useful things".

4.3.2 Audio recording and feedback

Participants voices were inferred with a microphone (Shure SM58) connected to a preamplifier (*Focusrite Scarlett* 2i2 3rd Gen, buffer size 192). The microphone input was recorded directly by the preamplifier. The sound was transmitted to the amplifier/tactile actuator using the jack output of the preamplifier, with direct monitoring to limit delay and the gain set to 100%. No signal processing was performed so as vibrations corresponded to the complete audio signal.

The participants could hear themselves speak but their words were not transmitted to avoid the echo due to the time needed to generate the signal. The latency between audio input and vibrotactile output was measured with another audio recording system and was 0.54 ± 0.023 ms. The participants still kept the headphones on to isolate them from the sound of the actuators.

4.4 Data collected

At the end of the simulation, participants completed a questionnaire about co-presence, leadership, and persuasion. The questions were similar to those in the first experiment, except that the questions focused on perceptions of their own leadership and persuasion: When I was speaking to the X agent, I felt ...

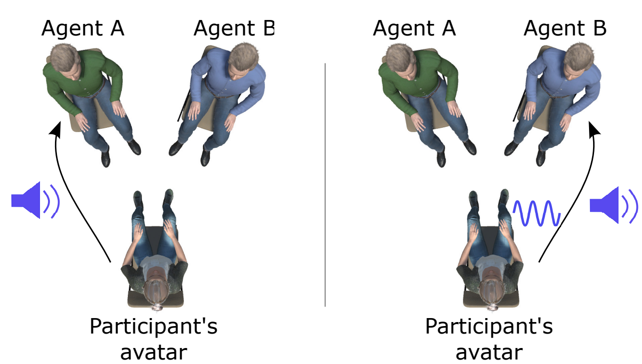

Figure 7: In Experiment 2, participants received audio feedback when talking to one agent and audio feedback synchronized with vibrotactile feedback when talking to the other agent.

- (Q1b) like the agent was in the room with me.
- (Q2b) like the agent was aware of my presence in the room.
- (Q3b) that I had a great leadership.
- (Q4b) that I was convincing.

Participants answered these questions on a 7-point Likert scale for both green and blue agents. We also asked participants if they perceived the vibrotactile feedback and if so, what it was related to and whether or not it was disturbing. The vibrotactile feedback question ensured that participants were holding the actuator correctly and that no hardware problems have occurred (e.g., a disconnected wire, power supply issue).

4.5 Participants

A total of 20 volunteers (15 men; mean age: 27.9 ± 5.2 years) participated in this experiment. They were not the same participants than in the first experiment. They all gave written informed consent prior to the test and were not compensated for their participation. They reported no visual, auditory, or haptic impairments that would have affected the experience. A total of 5% of participants reported never using VR technology, 55% used it sometimes, and 40% used it often.

Participants all spoke while receiving vibrotactile feedback corresponding to their speech when speaking to an agent. The presentation of the tactile condition was randomized across participants so that some participants received tactile feedback when speaking to the blue agent and others to the green agent.

4.6 Results

The normality assumption was not met for most of the data. We used the same procedure as in Experiment 1 to analyze the data. We used the same method as in Experiment 1 to test the possible influence of participants' gender on the results. The gender of the participants did not have significant effects on the models. Participants' responses are reported in Fig. 8.

The participants' impression that the agent was in the room (Q1b) was significantly higher with ($m = 5.1, std = 1.5$) than without tactile feedback ($m = 4.3, std = 1.5, p = 0.013, r = 0.37$). The participants' impression that the agent was aware of their presence in the room (Q2b) was significantly higher with ($m = 4, std = 2$) than without tactile feedback ($m = 3.2, std = 1.7, p = 0.01, r = 0.41$). The participants' impression that they have a good leadership (Q3b) was not significantly different with ($m = 4.4, std = 1.6$) and without tactile feedback ($m = 3.8, std = 1.6, p = 0.27$). Finally, the participants' impression they were convincing (Q4b) was significantly higher with($m = 4.5, std = 1.6$) than without tactile feedback ($m = 3.5, std = 1.2, p = 0.009, r = 0.41$).

Spearman's rank correlation was calculated to assess the relationship between the variables. It shows a positive correlation between Q1b (the agent was in the room with me) and Q4b (I felt convincing) ($r(40) = 0.48, p = 0.033$). There is also a positive correlation between leadership and persuasion ($r(40) = 0.67, p = 0.001$).

For the questions regarding the perception of tactile feedback, all participants responded that they perceived it and that it correlated with their speech. A total of 4 participants found the tactile feedback uncomfortable but 3 of them still found a positive effect of the vibrotactile on copresence and/or persuasion, the last one found no difference.

4.7 Conclusion of the Experiment II

The results of Experiment 2 show a positive influence of vibrotactile feedback synchronized with speech on co-presence. They also show that participants perceive their own speech as more persuasive with vibrotactile feedback. These results are discussed in the next section.

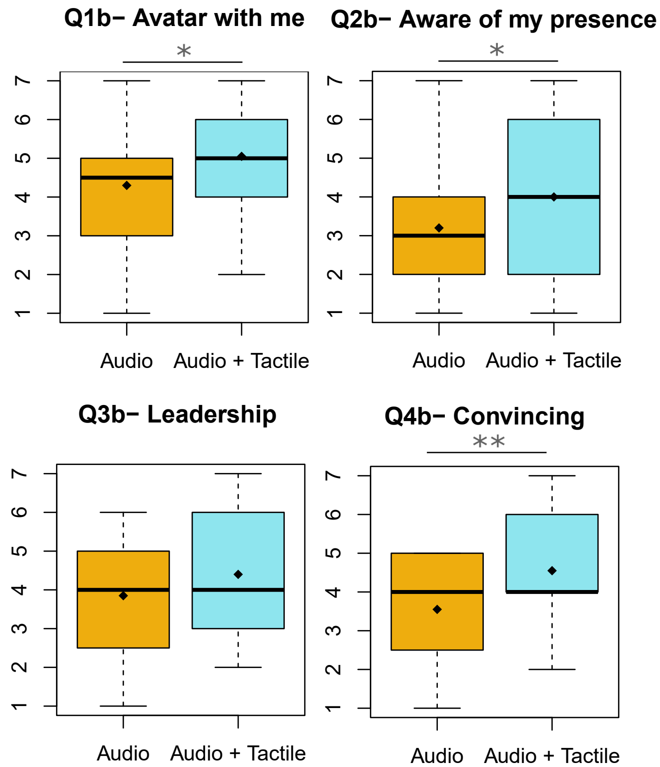

Figure 8: Experiment 2 results: participants' responses rating their co-presence, leadership, and persuasiveness when talking to agents. Please refer to Fig. 5 for more details on the boxplot displays.

5 Discussion

5.1 Improvement of co-presence

The first experiment investigated the influence of vibrotactile feedback synchronized with speech on co-presence when listening to other agents speak. The results suggest that the co-presence is enhanced by vibrotactile feedback, supporting the hypothesis **(H1L)**. In the past, the influence of haptic feedback on co-presence in a collaborative environment was investigated in a study by Sallnas et al. [53]. The haptic feedback that displayed object collision did not have a significant impact on co-presence, but the authors suspected that audio feedback might overshadow haptic feedback. Our results indicate that when haptic feedback and auditory feedback are congruent, haptic feedback can improve co-presence, even when displayed with auditory feedback.

In the first experiment, the vibrotactile feedback had a significant effect on the impression that the agent was in the room with the participants (Q1) but not on the impression that the agent was aware of their presence (Q2). This lack of effect in Q2 is understandable since the vibrotactile feedback was displayed on the agents and not on the participants.

The second experiment also examined the influence of vibrotactile feedback on co-presence, but this time when participants were talking to other agents. The results suggest that co-presence is enhanced when participants' speech is synchronized with vibrotactile feedback, which supports the hypothesis **(H1S)**. Vibrotactile feedback had a positive effect on both aspects of co-presence: the impression that the agent was in the room with the participants (Q1a) and the impression that the agent was aware of the participants' presence (Q2b). The effect on (Q2b) was still variable among participants as shown by the size of the corresponding boxplot, indicating that it did not influence everyone. This impression seems to depend on individual traits of the participants that our experimental protocol does not allow to highlight.

Interestingly, the influence of vibrotactile feedback on co-presence was different when listening to other agents and when speaking. We expected the speaker's co-presence to be reinforced by vibrotactile feedback (Q1) in the first experiment and (Q2b) in the second experiment. However, the feeling that the agent was with me in the room (Q1b) was also impacted in the second experiment. This suggests that when I am the source of the feedback, the vibrotactile feedback has a greater influence and can affect the presence of both parties: the speaker and the listener.

5.2 Improvement of leadership and persuasion

The influence of vibrotactile feedback on leadership and persuasion was investigated in the first and second experiments. The results of the first experiment showed that both leadership and persuasion of other agents were enhanced by vibrotactile feedback, supporting the hypotheses **(H2L)** and **(H3L)**. A positive correlation was found between leadership and persuasion, which is not surprising since the ability to be persuasive is a quality of a leader. In the past, results from a study by Weill et al. [65] suggested that vibrotactile feedback has both positive and negative effects related components (strength, competence, and truthiness). Our results contribute to show that vibrotactile feedback affects leadership and persuasion.

The results of the second experiment suggest that participants feel more convincing when their speech is augmented with vibrotactile feedback. The hypothesis **(H3S)** is then supported. However, although a positive correlation was found between persuasion and leadership, no significant difference was found for leadership. Therefore, the hypothesis **(H2S)** is not supported. The fact that leadership was improved in the first experiment but not in the second could be explained by different factors. Perhaps participants were more intransigent with themselves than with others. Leadership could also have been impaired because participants had to read the speeches in the experiment and may not feel comfortable with this process, which is quite unnatural. It would be interesting to conduct further investigations on this point to identify if the lack of difference is due to the experimental protocol. This would mean that leadership could be affected in more usual scenarios.

The results of the second experiment suggested a positive correlation between co-presence and persuasion. This finding is consistent with previous work that demonstrates that higher interactions have been associated with higher presence and better outcomes in persuasive communication [21]. Our result demonstrates that the correlation holds for vibrotactile augmentation.

Previous studies suggest that perceived leadership may depend on the gender of the listener and speaker [34, 65] whereas the results were not significantly different between genders in our experiments. Our experimental protocol was not designed to directly investigate the influence of agents gender. For example, male agents were directly compared to each other in the first experiment, but the male agent was not directly compared to a female agent. It would be interesting in the future to obtain more information on this point by mixing the genders. Regarding the influence of the users gender as listener, positive and negative effects were found on leadership-related components in the past [65]. In our experiment, the resulting leadership does not seem to depend of the gender suggesting that that these effects could counteract each other. The influence of the gender of the listeners in the second experiment has not been studied, but it would be interesting to test whether female avatars lead to a different perception of one's own leadership and persuasion.

Comments from some participants at the end of the second experiment indicated that the vibrotactile feedback synchronized with speech was distracting when they were speaking. They explained that the vibrotactile acted as an echo to the audio feedback and that it was difficult to focus on what they had to say. These comments may again be due to the experimental protocol of the second experiment and could be different in more usual scenario. Indeed, sign reading might involve more cognitive mechanisms than free speech [55] and therefore require more attention from the users, who may in turn feel overwhelmed by the vibrotactile feedback. Further investigations are needed to study this assumption.

5.3 General discussion and perspectives

Overall, vibrotactile feedback synchronized with speech had a positive effect on social interaction. Such a result was not guaranteed since the information transmitted in the virtual environment consists of an augmentation of the usual sensory information in the real world. Since verbal communication is likely to occur in a virtual environment involving agents or avatars, the experimental results provide valuable insights for many applications.

The vibrotactile feedback could be displayed symmetrically on the speaker and listener when someone speaks so that everyone has a similar experience. Interestingly, even if the participant themselves do not feel a higher sense of leadership when speaking with vibrotactile feedback, the people listening may feel that way if they receive the vibrotactile feedback. The speakers' leadership abilities are then increased, even if they are not aware of it.Vibrotactile feedback could also be used could be used selectively on certain speakers. For example, it could help reduce biases during verbal communication, such as increasing persuasion and co-presence of shy participants or women who are often perceived as less dominant than men [10, 30].

The vibrotactile feedback was quite short and discreet in our experiments as it was turned on and off between agents. Interestingly, social interactions were still modulated, indicating that users' perception is changed quickly, without the need for long exposure to stimulation.

The actuator displaying vibrations in the user's hand was also sufficient to enhance the perception of co-presence and leadership. We can imagine using the actuators available in commercial VR controllers to display vibrotactile feedback in future applications. However, the signal quality would not be the same because the amplitude and frequency cannot be controlled independently with these actuators. It would be interesting in the future to further explore the parameters of the signals that affect social interactions. Vibrotactile signals can be encoded with different parameters (e.g., timbre, frequency, amplitude) [13] and it would be interesting to identify which part of the signal is important. In our experiments, the complete audio signal was transmitted to the actuator. If simpler signals could be used, others actuators could be considered.

It would also be interesting to study whether the location of the vibration is important, for example, vibrating near the chest might be better than vibrating on a leg. A haptic vest containing multiple actuators could for instance be an interesting alternative but it is harder to guarantee that the vibrotactile actuators are in contact with the skin. We tested a configuration with the actuator implemented at the head in a VR headset because it is close to the mouth. However, the actuators display high quality signals that generate audio feedback but with a small delay that disturbs the original audio feedback. This location is therefore not suitable.

In our studies, participants hold the vibrotactile actuator in the right hand while receiving vibrations corresponding to the right or left agent depending on the counterbalanced conditions. It would be interesting to study whether the spatial relationship between the vibrotactile actuators and the agents can influence the interactions. For example, an additional actuator in the left hand could be used to interact with the agent located on the left side. It would also be interesting to test whether vibrations have a direct influence on persuasion and leadership or whether mediating parameters exist. For example, vibrotactile feedback can improve users' attentional focus [26, 57] and people seem to focus their attention on the leader when communicating [47]. Identifying these parameters would help to understand the underlying process of persuasive vibrations.

In this paper, we were interested in increasing co-presence, leadership and persuasion but it might also be interesting to decrease them. For example, if participants monopolize the floor, their leadership could be modified. In the context of virtual walking simulation, a study by Matsuda et al. [38] compared presence with tactile feedback representing foot/ground contact displayed synchronously or asynchronously with visual feedback of foot movements. Their results showed that asynchronous tactile feedback decreased presence in the virtual scene, vibrations could be displayed asynchronously to the user's speech to decrease co-presence or leadership.

In both experiments, the scores for questions (Q2) and (Q2b) related to the agent being aware of the participants' presence in the room were quite low without tactile feedback. This can likely be explained by the lack of nonverbal interaction between participants and agents. For example, the agents did not change their gaze direction or facial expression, which made them look a bit like robots. This issue could be the reason why no correlation were found between co-presence and persuasion in the first experiment, when participants were particulary focused on agents. Scenes involving more natural agents (e.g, different appearance, voices) could result in different outcomes. A next step would also be to test vibrotactile feedback in scenes involving avatars since they can transmit more natural interactions. Previous work has investigated whether agents (virtual humans controlled by computer algorithms) and avatars (virtual humans controlled by humans) elicit different levels of social influence [9] and avatars elicit stronger responses than agents. It would also be interesting in the future to extend our study to conversational avatars. This could be an opportunity to test the effect in realistic conversations. The influence of vibrotactile feedback during turn-taking communication, when feedback is displayed on both the listener and the speaker, could be tested. Simulations involving avatars would also be interesting to address other aspects of social interaction, such as the effect on social presence. Social presence includes co-presence, but also psychological involvement and behavioral engagement [8], which could be explored.

Our study was conducted in Virtual Reality, because communication in this context is complicated. In the future, we may wonder if the vibrotactile strategy could work in other contexts, for example in video conferencing or in real life communication.

6 Conclusion

We presented two user studies investigating the influence of speech-synchronized vibrotactile feedback on perceived persuasion, leadership and co-presence when listening to or talking to virtual agents. The results suggest that vibrotactile feedback improves co-presence, persuasion, and leadership when reinforcing the speech of other agents. They also show that it improves co-presence when it reinforces the user's speech and increases the user's perception of his own persuasion. In the future, speech synchronized with vibrotactile feedback could be used to improve co-presence and modulate leadership and persuasion during verbal communication in VR (e.g., meetings, collaborative tasks, informal discussions).

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