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Research report

Comparison of people's responses to real and virtual handshakes within a virtual environment

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ABSTRACT

In this paper we present a method for evaluating a haptic device which simulates human handshakes interfaced via a metal rod. We provide an overview of the haptic demonstrator and the control algorithm used for delivering realistic handshakes. For the evaluation of this handshake demonstrator we introduce a 'ground truth' approach, where we compare the robot handshakes with handshakes operated by a human via the same metal rod. For this, an experiment was carried out where the participants entered a virtual environment, i.e. a virtual cocktail party, and were asked to perform a number of handshakes, either with the robot operating with one of two control algorithms operating the metal rod – a basic one for comparison or the proposed new advanced one, or with a human operating the metal rod. The virtual environment was represented only through audio and haptics, without any visual representation, i.e. the subjects participated blindfolded. The evaluation of each handshake was achieved through the subjective scoring of each of the handshakes. The results of the study show that the demonstrator operating with the proposed new control scheme was evaluated significantly more human-like than with the demonstrator operating with the basic algorithm, and also that the real human handshake was evaluated more like a real human handshake than both types of robot handshakes. Although the difference between the advanced robot and human handshake was significant, the effect sizes are not very different, indicating substantial confusion of participants between the advanced robot and human operated handshakes.

1. Introduction

A critical feature of most immersive virtual environment (IVE) applications is their lack of physicality. People can bump into virtual walls and feel nothing, pick up objects but feel nothing of their texture and weight, and interact with virtual humanoid characters but with no physical contact. While there have been significant advances in haptics technology, haptics is typically not integrated into VE applications in general, but each application becomes a special case, with a specific type of haptic interaction that has a correspondingly specific device.

One of the most interesting and useful types of IVE application involves interactions between people, whether real online people with avatars that represent their activities within the VE, or agent based systems that are fully programmed. The latter has a wide variety of applications in rehearsal, training and various types of psychotherapy [12]. The work described in this paper is premised on the notion that the addition of physical contact between participants in an IVE and the virtual characters with whom they interact would greatly enhance the probability of participants responding realistically to situations and events within the VE, which in turn would enhance their suitability for training and rehearsal.

Here we concentrate on handshakes between a real and virtual person. Our ultimate goal is for a person in an IVE to be able to interact in all modalities (visual, auditory and haptic) with other virtual characters. This can be realized by looking at a virtual human through a head-mounted display but simultaneously interacting with a physical robot. Hence, for example, if the virtual human wants to perform a handshake with the participant, the participant can feel interaction forces at his hand. This would be accomplished by a robot physically interacting with the participant's hand in temporal and spatial registration with the virtual human.

Handshaking is a social behavior between two people [3]. In [8] authors created a tele-handshake system using a simple linear device, while [11] generated handshake animations from a vision system. However, very few have viewed handshaking from

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a force/motion interaction aspect, until very recent work reported in [15], where the authors take the oscillation synchronization approach to realize human–robot handshaking; and in [26] the authors focused on the approaching and shaking motions of a handshaking robot. In [7], experiments are reported on participants differentiating human and computer generated handshakes through a haptic device. The study of handshaking in a haptic interaction context, however, is lacking in existing literature to the best of our knowledge.

This paper describes an experiment that compares people's responses to simulated handshakes between a robot and a real person. The handshake was mediated through a metal rod that was held at one end by the experimental participant with the other end attached to the robot, and manipulated either by the robot itself or by one of the experimenters moving it directly. In this sense it was not a true handshake but a simulated one, and for simplicity we will use the term 's-handshake' to refer to this simulated handshake. After each s-handshake the participant was asked to infer whether they had just interacted with a person or with a robot, based solely on the haptic responses since they were blindfolded throughout. The purpose was to evaluate the degree of similarity of the robot s-handshake with a human one. The robot s-handshakes were controlled either by a *basic robot* without any attempt to model the true haptic interaction involved in a handshake, or a more *advanced robot* that embodied our best current haptic model of human action under these circumstances. Furthermore, two more control conditions were introduced in the experiment, regarding the auditory feedback. In one group the sound recording representing the cocktail party was recorded in stereo mode and the other as recorded binaurally.

Our hypotheses were that the advanced robot should be indistinguishable from the human handshake and both of them distinguishable from the basic robot, and also that the binaural sound condition would improve the chance that the robot would be evaluated as human.

To evaluate the similarity of robot s-handshakes and human handshakes the concept of 'presence' in immersive virtual environments is adopted. The original meaning of this term was derived from the concept of telepresence in teleoperator systems [23], that is the extent to which the user of a remotely located robot feels as if they were in the remotely located place. This concept was transplanted to immersive virtual environments in the early 1990s were it was taken to mean the illusion of being in the environment depicted by the virtual reality displays [22,14,27,24,13,10], and for a review see [5]. Typically the degree of presence has been assessed mostly by questionnaires, for example, [16,17,1], and there have been critiques of questionnaires used as the only method of assessment [19,20]. Physiological responses have also been used typically using anxiety as a surrogate for presence [4,25,9], and approaches that combine the use of subjective, physiological and behavioral methods, for example, [18]. In [12] it was argued that presence should be defined operationally as the extent to which participants respond realistically to virtual events and situations. This leads to the idea of comparison with 'ground truth', in other words successful presence is demonstrated when participants responses to a situation in virtual reality are similar to how they would have been expected to respond were it in physical reality.

The concept of presence has recently been decomposed into two different dimensions. The first is the original meaning of the term that we call 'place illusion' – the illusion of being in the place depicted by the virtual reality. This is a static component referring to the extent to which the participant feels as if they are in a place, and that the objects there are actually there (even though they know this to be an illusion). The second concept refers more to the dynamic aspects, the events that are occurring in the virtual environment – and the extent to which there is the illusion that these are actually happening (again, in spite of knowing that nothing is really happening). These ideas are described in [21]. The experiment described here mainly focuses on plausibility – where participants are asked to judge – is this handshake 'real' (i.e. caused by a human)?. There is also some reference to the overall degree of 'place illusion' engendered by the portrayed auditory and haptic environment.

2. Materials and methods

To investigate differences in human responses when performing handshakes with a real person or a robot, a virtual cocktail party scenario was chosen. Participants entered a cocktail party which was represented through audio and haptic cues. No visual cues were provided to avoid participants being influenced in their judgment by the quality of the visual rendering. Audio cues were rendered through a pair of noise-cancelling headphones (for covering any machine or lab noise), whereas haptic cues were rendered via a handshake robot as illustrated next.

2.1. Rendering of haptic cues

A first, very basic robot handshake controller that imitates human arm behavior when performing handshakes was presented in [23]. In this preliminary work we programmed the robot to imitate a very dominant handshake partner. This was achieved by recording handshake trajectories observed during human–human interaction which were then replayed on the robot.

To improve naturalness of interaction, an admittance filter

$$f = M\ddot{x} + B\dot{x} + K(x - x_0) \quad (1)$$

was additionally implemented, which allowed to simulate human arm mass M and to provide compliance K during interaction (x_0 means the equilibrium position of the implemented spring, while B is the damping factor).

Provided that human participants are good followers, this basic handshaking controller can perform competent handshakes. However, it lacks the ability to realize full interactive handshakes, since the robot can only playback trajectories as predefined. This is clearly different from human–human handshaking, where the arms can provide compliance during interaction, while the participant can select different strategies with respect to adaptation to his/her partner's style of handshaking. To overcome this limitation a more interactive handshaking controller, in the following referred to as *advanced handshake controller*, has been implemented.

The advanced handshake controller, first presented in [24], is based on the assumption that humans select between two different strategies when performing handshakes with a partner. Either they act passively by following as best as possible the lead of their interaction partner and adapt to his/her style of handshaking or they act actively by commanding the handshake trajectory without taking into account their partner's behavior. Our advanced handshake controller assumes that the current human interaction strategy can be estimated from measured force and motion data and given this strategy, the robot is forced to take opposite roles. Depending on the personal style of handshaking, humans switch between the two aforementioned strategies while performing a handshake. This again means that the robot needs to continuously estimate the actual human interaction strategy to achieve realistic human–robot handshakes.

To realize this robot behavior a double-layered control scheme that not only alters the admittance parameters, but also the reference trajectory has been implemented, see Fig. 1. While a low-level controller (LLC) implements the compliant robot behavior, a high-level controller (HLC) is responsible for (i) estimating the preferred human interaction strategy, (ii) for updating the admittance parameters and (iii) changing the reference trajectory to be executed by the LLC. As the preferred human interaction strategy is not directly measurable, a special estimator based on a hidden-Markov model has been implemented, which was trained to distinguish between the two aforementioned interaction strategies. In case the estimation results indicate the human selected the passive strategy, the robot takes over the lead, the admittance parameters are set to high values and the trajectory planning algorithm commands a predefined trajectory. However, when the estimation result indicates the human having selected the active strategy, the robot tries to follow as best as it can the human lead, the admittance parameters are set to low values and the trajectory planning algorithm adapts the amplitude and frequency of the commanded robot trajectory to minimize the interaction force between human and robot. Interested readers are referred to [24] for implementation details of this advanced robot controller.

To evaluate the performance of the proposed controller human–robot experiments were carried out using the LLC only as well as using the combination of LLC and HLC. Performance of both approaches is assessed by measuring force and position trajectories. The results are encouraging when comparing the results shown in Figs. 2 and 3: while for the LLC, compliance is only provided by the virtual impedance model of the robot, for the HLC, the robot can synchronize to the leading human as illustrated in Fig. 3.

Both controllers were implemented onto a 10 degree-of-freedom (DOF) robotic arm ViSHaRD10, see [22], as shown in Fig. 4. A high performance 6 DOF force/torque sensor is mounted on the robot to measure the dynamical forces during interaction.

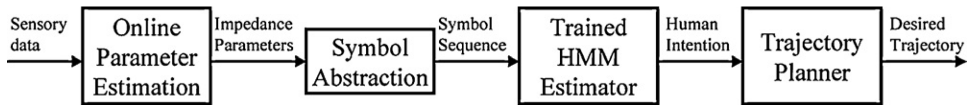

Fig. 1. Overall controller scheme. Intention estimator and trajectory planner form the high-level controller that provides reference trajectory for the low level controller.

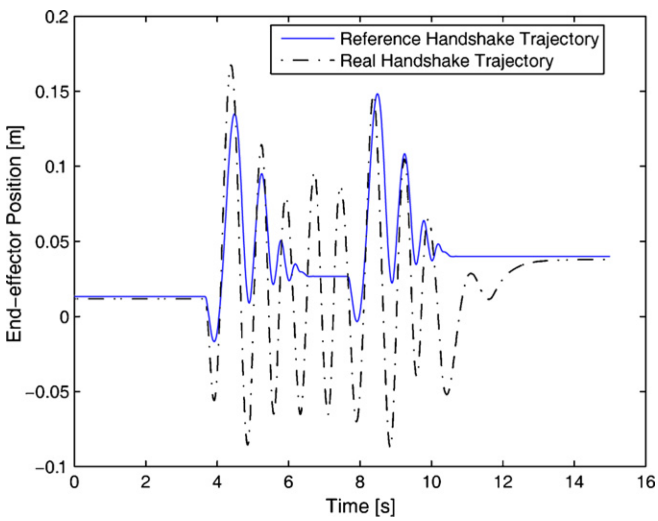

Fig. 2. Experimental results of human–robot handshaking using LLC only. Reference trajectory is not changed according to the human input.

As only human arm dynamics is considered, a metal rod is used as the end-effector of the robot.

2.2. Rendering of audio cues

The cocktail party sound was recorded through a stereo recording device. Two types of sound recordings – stereo and binaural – were used, and the purpose of this was to examine whether these influenced overall reported place illusion. Stereo was recorded through the microphones of the stereo recording device alone. The binaural recording was performed by the stereo recording device, through two microphones placed inside the ear cavities of a custom made dummy head. Both recordings were exactly the same in terms of content, i.e. only the recording procedure was different.

2.3. Experimental design

In the given cocktail party scenario the two types of audio recordings were distributed randomly among the participants, with half of the participants listening to the stereo recording and the other half to the binaural one. The recordings began with some music and people chatting in the background. After a few seconds a person approached and greeted the participant. This was repeated 21 times with 21 different voices, with a gap of approximately 15 s between each one. The voices consisted of 10 female and 11 male voices in the following sequence, where M = male and F = female:

For the haptic mode the s-handshake robot was used, utilizing only one degree of freedom, the vertical axis, i.e. up-down movement. Three haptic conditions were used:

- The s-handshake performed by the robot operating in its advanced mode (henceforth termed as ‘advanced’ robot condition). This consists of the robot operating according to the algorithm described in Section 2.1. In this condition the robot waited for the participant to initiate the s-handshake.
- The s-handshake was performed by the robot controlled by the basic controller as described in Section 2.1 (henceforth termed as ‘basic’ robot condition). This consists of the robot in position controlled mode performing a sinusoid motion of 3 cycles, upon initiation by the participant.
- The s-handshake performed by the human experimenter (henceforth termed as ‘human’ condition). This s-handshake was performed by the experimenter by directly manipulating the haptic robot programmed to follow the human with minimal resistance, as shown in Fig. 5. The experimenter used the opposite end of the same end-effector as the participant. The reason for performing the human s-handshake through the robot was to try to equalize all the conditions apart from the factors of interest (i.e. the two machine algorithms and the actual human s-handshake).

Given the above description the purpose of the experiment can be restated specifically as investigating the extent to which the demonstrator in its advanced operation mode (advanced robot) can ‘fool’ the human participants into thinking they are shaking hands with a real human. The evaluation method can be considered as comparison of the robot performance with ‘ground truth’ which was in this case the perceptions of the s-handshakes that were carried out by the humans.

2.4. Human subjects

Upon obtaining an ethical approval from the ethical board of the clinical centre of Großhadern, Ludwig-Maximilian University of Munich (LMU), a total of 35 partic-

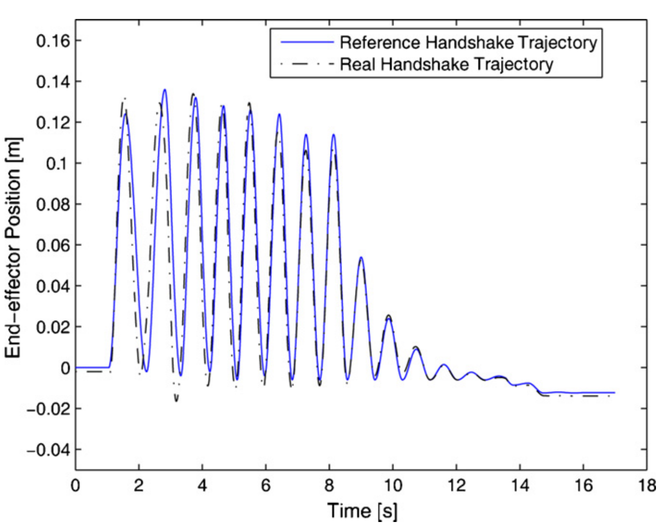

Fig. 3. Experimental results of human–robot handshaking using HLC. Reference trajectory is modified according to the human input.

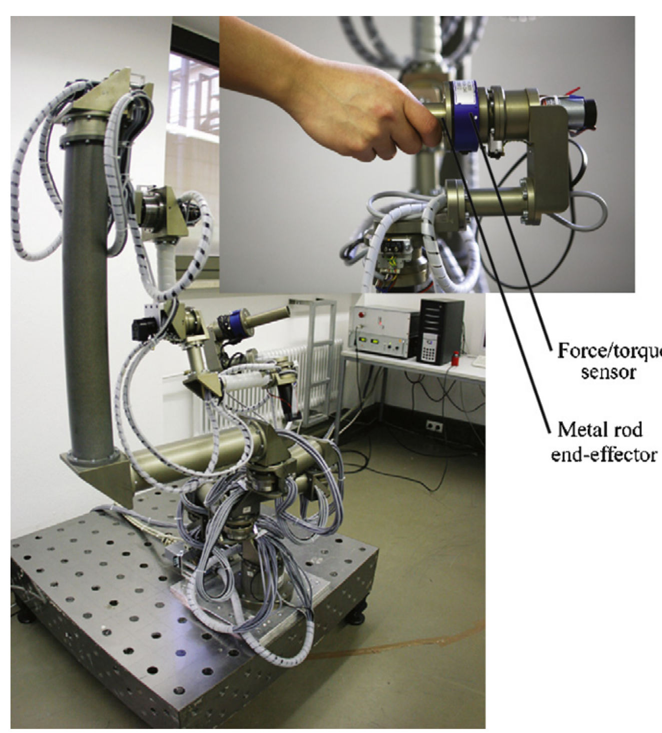

Fig. 4. The 10DOF robotic arm ViSHaRD10 used for handshaking with human participants.

Fig. 5. The experimenter performing a 'human' s-handshake with a participant 'through' the robot.

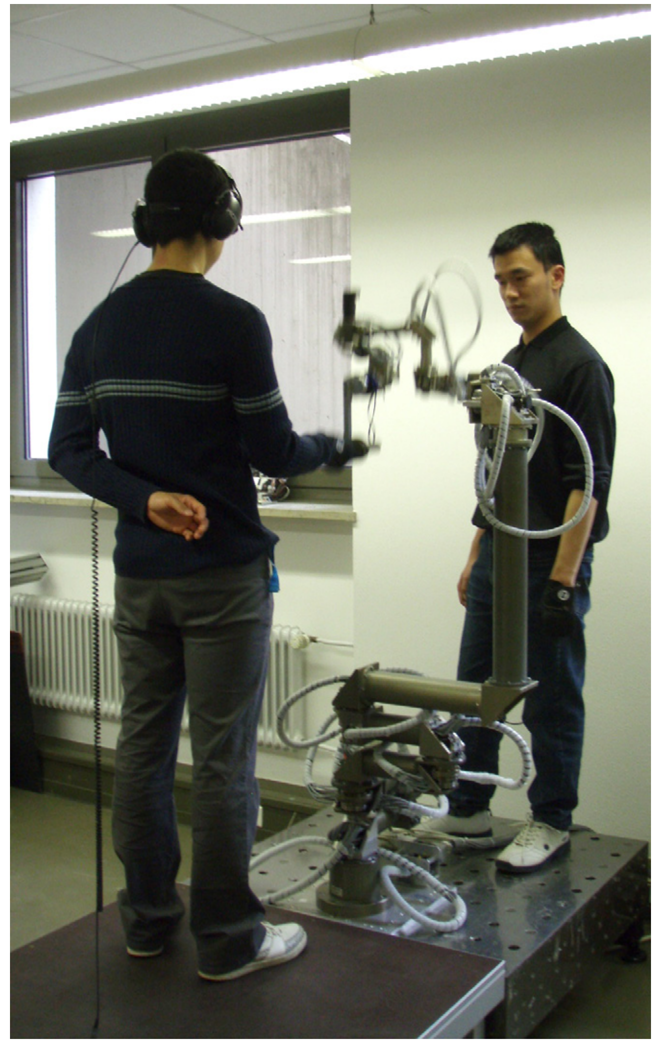

Fig. 6. Subject performing s-handshakes during training session.

ipants were recruited for the experiment (29 male and 6 female). The participants were mostly students of the Technische Universität München (TUM), aged between 19 and 30 years old. Prior to the experiment the participants were informed about the task they were to perform. After this the participants were asked to sign a consent form acknowledging their understanding of their tasks and approval of the terms of their participation in the study. At the end of the experiment, which lasted about 30 min, they were compensated for their participation with 5 Euros.

2.5. Experimental procedures

The participants were blindfolded prior to entering the laboratory and guided by one of the experimenters onto the platform in front of the robot – the blindfolding ensuring that they had no idea regarding the physical appearance of the robot. Once placed in front of the robot they were fitted with an ordinary glove to reduce the tactile sensation of the metal rod. They were also fitted with a pair of noise cancelling headphones. They were then asked to perform a few s-handshakes in order to become familiarized with the handshaking procedure. They were informed that they should initiate an s-handshake after the experimenter had guided their hand to grasp the metal rod. They were to perform an s-handshake and then place their hand back on their side, until the next time their hand would be guided to the rod again. After these instructions, some background music was introduced through their headphones and they were guided by the experimenter to perform 4–6 s-handshakes (Fig. 6).

After reporting that they felt confident with the haptic interface they were asked to perform the same task, however now they would give a score after each s-handshake, evaluating it. They would do so by saying out loud an integer between 1 and 10, where 1 would indicate that the s-handshake they performed felt as if it were performed by a robot and 10 would indicate that it felt as if it were performed by a human. The in-between values should indicate a likelihood scale between the two extremes. Then they performed another set of s-handshakes (4–6) while listening to the background music, this time giving out a number after each s-handshake.

After they had finished with these s-handshakes they were informed that the training session had finished and the main experiment was about to begin, where they would have to perform the same procedure as in the last part of the training. Throughout the training session only the two robot conditions were used, i.e. the advanced and the basic robot condition.

The main experiment started with the cocktail party sounds playing through the headphones that faded in background music and chatting and after a while the first voice approached and greeted them. The experimenter at that point guided the hand of the participant to grasp the rod who then initiated an s-handshake. After placing their hand on the side they called out their score.

The sequence of s-handshakes consisted of 7 for each condition – 7 s-handshakes for the normal robot, 7 with the basic and 7 with the human – the order being random for each subject. The distribution of the types of s-handshakes was almost equal between male and female voices in the recording to avoid association of a specific type of s-handshake with a gender. The same voice sequence was used for all the participants, as described in Section 2.3.

The responses of the participants, along with the sequence of the s-handshake conditions were recorded by the experimenters. Upon completion of the experiment, participants were guided into a separate room, where their blindfold was removed and they were asked to complete a post-experimental questionnaire, which consists of:

- 4 questions of basic demographic data (dominant hand, sex, age, nationality),
- 1 question for evaluating the level of place illusion and the following 3 questions concerned more with the degree of plausibility experienced by the subject within the virtual environment:
  1. (real bar): Indicate your experience of being in a real bar on a scale from 1 to 7, where 7 represents a normal experience of being in a real place.
  2. (socializing) On a scale from 1 to 7, how often did you have the feeling that you were socializing with real people?
  3. (real person) On a scale from 1 to 7, how often did you have the feeling that you were shaking hands with a real person?

Table 1
Means and standard deviations of the scores in the three conditions. An individual score is an assessment out of 10, where 10 means that the participant fully believes that the s-hand shaker was human and 0 that it was a robot.

Condition	Mean score (max 10)	Standard deviation	*n*
Basic robot	3.3	2.1	242
Advanced robot	5.9	2.2	244
Human	6.8	2.1	245

4. (type of person) On a scale from 1 to 7, throughout the experiment how often did you think about the type of person you might be shaking hands with?
- 3 questions for evaluating the validity of the responses given throughout the experiment:
5. (number of human s-handshakes) In how many of the 21 s-handshakes did you think you were shaking hands with a human?
6. (number of robot s-handshakes) In how many of the 21 s-handshakes did you think you were shaking hands with a robot?
7. (number of different robots) How many different robots do you think you were shaking hands with?

After having answered these questions, they returned to the laboratory with the s-handshake robot and provided further comments.

2.6. Statistical methods

The data were initially considered as a three-way analysis of variance with the response variable being the scores and the factors as type of sound (two levels, stereo or binaural), the gender of the speaker (2 levels), and the type of s-handshake (basic robot, advanced robot or human). The latter is the fundamental variable of interest. It should be noted that although there were 7 trials of each of the three types of s-handshake, 4 of these scores were not recorded, and therefore the design is not strictly balanced. However, the analysis of variance (ANOVA) technique allowed for this.

Since the gender of the speaker did not prove to be significant at all, this is not considered further, so the ANOVA results reported here are two-way. The ANOVA requires that the residual errors of the model fit follow a normal distribution, but a Jarque-Bera [6] test marginally rejected normality ($P = 0.04$). To overcome this problem we used a Box–Cox transformation [2] which resulted in the transformed variable $y = (score + 1)^{1.12}$. Since this transformation is monotonically increasing with respect to *score*, any inferences based on y apply equally to *score.* The Jarque–Bera test does not reject the hypothesis of normally distributed residual errors in this case ($P = 0.12$). In fact the results are qualitatively the same whether using the original *score* or *y*.

3. Results

Table 1 shows the means and standard deviations of the scores under the three conditions. The number of trials for each is the number of subjects (35) times the number of handshakes of the given type (7), except that there were a small number of missing values in two of the conditions. It is clear that the difference between the basic robot and the other two conditions is large, and although the difference between the advanced robot and human is smaller, the difference between these two is still significant.

This is confirmed by an analysis of variance (Table 2) on the transformed score variable (y), with two factors: type of s-handshake (basic robot, advanced robot and human) and type of sound (stereo or binaural).

The results show overwhelmingly that there is a difference in scores among the three conditions. Moreover there is some evidence of an interaction effect between type of s-handshake and type of sound. A multiple contrast analysis (at an overall 0.01 level of significance) shows that

- There is a significant difference between each of the s-handshake means with mean(human) > mean(advanced robot) > mean(basic robot)

When the basic robot is used there is no significant difference between the scores for the different types of sound. This is also true for the advanced robot and the human s-handshake. However, the basic robot mean scores for both types of sound are significantly less than all the other mean scores. This is illustrated in Table 3, which shows the breakdown of scores by sound type (see also Fig. 7).

From Table 3 it is also clear that although the differences between the human and advanced robot is formally significant, the effect size difference is small. The advanced robot was almost judged the same as the human, and in fact the scores for the human are far from the maximum of 10. Since there was considerable uncertainty in rating the human as human, this also adds to the point that the advanced robot was ranked nearly the same as the human.

Table 4 shows the mean and standard deviations of the subjective scores provided in the post-experimental questionnaire. There are no significant differences between binaural and stereo. If we consider the proportion of people who gave relative high scores (scores of 5, 6 or 7 out of a maximum of 7) then there is evidence that overall participants tended to subjectively have the illusion of being in a bar. Considering the question 'real bar' 21/35 people

Table 2
Analysis of variance of the variable with factors type of s-handshake and type of sound.

Source	SS	df	Mean SS	*F*-ratio	Sig. level
S-handshake	3042.49	2	1521.24	180.36	0
Sound	0.08	1	0.08	0.01	0.9232
S-handshake*sound	62.86	2	31.43	3.73	0.0245
Residual	6115.1	725	8.43		
Total	9199.91	730			

Table 3
Means and standard deviations of the subjective scores for the two sound conditions.

Condition	Basic Robot		Advanced robot		Human	
	Mean	Std	Mean	Std	Mean	Std
Binaural	3.6	1.4	5.7	1.3	6.7	1.5
Stereo	3.0	1.4	6.1	1.8	6.9	1.3

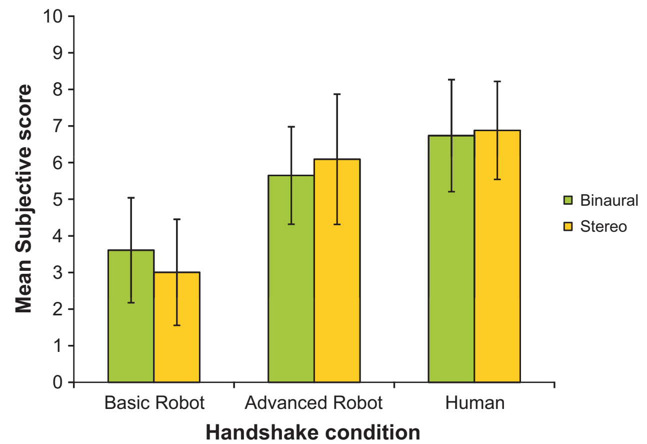

Fig. 7. Means and standard deviations of the experimental subjective scores for the two sound conditions.

Table 4
Means and standard deviations of the subjective scores for the four post-experimental questionnaire, for the two sound conditions. The maximum score in each case was 7.

Condition	Real Bar		Socializing		Real person		Type of person	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Binaural	4.3	1.4	3.2	1.7	3.3	1.9	4.7	1.9
Stereo	4.9	1.5	4.2	1.4	3.8	1.3	4.8	1.6

Table 5
Means and standard deviations of the subjective scores for the three last questions of the post-experimental questionnaire, for the two sound conditions.

Condition	No of human s-handshakes		No of robot s-handshakes		Types of robots	
	Mean	Std	Mean	Std	Mean	Std
Binaural	6.8	4.4	12.6	4.6	3.3	2.3
Stereo	5.9	3.0	10.7	4.6	3.8	1.6

gave a score of at least 5, and against the null hypothesis that the scores were randomly assigned, this has a significance level of 0.03 (using the binomial distribution). However, they did not have the illusion of socializing with real people (here there were 11 out of 35 who recorded high scores), nor shaking hands with a real person (9 had high scores). However, 23 of them did give high scores in relation to often thinking about the type of person they were shaking hands with ($P = 0.005$) – but this was not surprising since it was their actual task.

Table 5 shows the means and standard deviations of the scores provided by the participants in the post-experimental questionnaires regarding the three questions regarding their overall view of the numbers of human and robot s-handshakes. There were 3 people who said that the number of human s-handshakes was more than 10 out of the 21 possible s-handshakes, but 21 who said that there were more than 10 robot s-handshakes. In other words there is a clear overestimate of the number of robot s-handshakes, which is again evidence that the difference between some of the real human s-handshakes and robot s-handshakes were blurred. It is not that the robot felt like a human but that the human felt like a robot.

From this we can see that the subjects under the binaural sound condition, seem to have responded more accurately than the subjects under the stereo conditions, as the actual number of human s-handshakes is 7, the actual number of robot s-handshakes is 14 and the real number of types of robot is 3 (basic, advanced and human).

4. Discussion

The purpose of this experiment was to provide a method for evaluating the ability of a haptic interface in inducing the feeling that the participants were actually shaking hands with a human. The results from this experiment show that the human s-handshake is perceived as more human than the robot s-handshakes and also that the robot operating in its advanced mode is scored considerably higher than the robot operating in its basic mode. However, there is also evidence that there was considerable confusion between the human and advanced robot. This can be attributed to the fact that the haptic feedback was implemented through a metallic rod instead of an expected hand when performing an s-handshake, even for the human. It also reflects the fact, as some of the participants remarked, that the motion of the handshake was purely up and down rather with no lateral movement at all. Furthermore the sound condition did not affect significantly the results, which might be attributable to the quality of the binaural recording itself.

The results of this experiment are to be used as feedback for an improved version of the control algorithm of the s-handshake robot. Furthermore the next step would be to introduce visual cues in the experiment through an immersive projection system such as a Head Mounted Display, as this would eliminate the use of an experimenter guiding the hands of the participants to reach the ‘hand’ of the robot and may increase the levels of plausibility experienced by the subjects. Furthermore to increase the level of place illusion an improved binaural recording should be considered, through the use of an appropriate algorithm to enhance spatial auditory localization. Also, an alternative to the metal rod end-effector of the s-handshake robot is under construction in order to bring the tactile interface closer to reality and increase the plausibility of the experience.

Conflict of interest

The authors declare that they have no competing financial interests.

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