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Influences of Haptic Communication on a Shared Manual Task

ABSTRACT
With the advent of new haptic feedback devices, researchers are giving serious consideration to the incorporation of haptic communication in collaborative virtual environments. For instance, haptic interactions based tools can be used for medical and related education whereby students can train in minimal invasive surgery using virtual reality before approaching human subjects. To design virtual environments that support haptic communication, a deeper understanding of humans' haptic interactions is required. In this paper, human's haptic collaboration is investigated. A collaborative virtual environment was designed to support performing a shared manual task. To evaluate this system, 60 medical students participated to an experimental study. Participants were asked to perform in dyads a needle insertion task after a training period. Results show that compared to conventional training methods, a visual-haptic training improves user's collaborative performance. In addition, we found that haptic interaction influences the partners' verbal communication when sharing haptic information. This indicates that the haptic communication training changes the nature of the users' mental representations. Finally, we found that haptic interactions increased the sense of copresence in the virtual environment: haptic communication facilitates users' collaboration in a shared manual task within a shared virtual environment. Design implications for including haptic communication in virtual environments are outlined.

KEYWORDS
Haptic communication, Common ground, Collaborative virtual environments, User-centred design, HCI.

1. INTRODUCTION

Collaborative Virtual Environments (CVEs) are digital spaces that allow remote users to work together sharing virtual objects [1]. CVEs are used in many applications such as surgery, CAD and architecture. They offer new interaction possibilities by allowing users to share virtual workspaces. However, the design of CVE that support collaboration remains an open issue. For instance, interactions in current CVE rely predominately on vision and hearing. However, little attention has been focused on haptic interaction. Haptic interaction is suited to accomplish shared manual tasks. Our objective is to show that supporting functional haptic interactions in CVE can improve the users' collaborative performance in such tasks. For that purpose, we used a user-centred design methodology to build a CVE that support a shared manual task. Finally, a user study was conducted to evaluate the system and to study haptic communication in CVE.

2. LITERATURE REVIEW

2.1. Collaboration and communication

Collaboration is defined as a synchronous common work in which partners share resources and problems to accomplish a common task [2]. When two operators collaborate, they try to share a common mental representation of the situation. This is referred to as the common frame of reference [3] or the common ground [4]. Common ground allows the partners to understand each other and to organize their common work. Thus, they can perform different but complementary actions. It is constructed and updated by the Grounding Process [4]. This process consists of an ongoing exchange of information and understanding signs between partners to update their common ground. It helps them to understand the partner's actions and to plan their shared actions. The choice of the appropriate communication channel to build the common ground is dependent on the situation. In this context, manual tasks involve invisible elements such as haptic sensations. Therefore, they are hard to exchange only through a verbal description and require the use of additional communication means like the haptic channel. Our objective is to investigate the role of haptic interactions for the common ground construction when two operators perform together a manual task.

2.2. Haptic Communication

Unlike other nonverbal communication forms such as facial expressions and eye contacts, little attention has been focused on haptic communication. With the advent of new technologies, the research community has given new consideration to the haptic dimension of mediated communication [5].

Compared to vision or hearing, haptic feedback is a more direct human-human interaction. It can be used to express feelings of closeness or intimacy with another person [6]. Several researches show that the sense of touch increases social interactions [7] and trust [8]. For instance, it has been shown that a person is encouraged to participate in a course when touched by a teacher [9].

Beyond this social dimension, one can consider the functional dimension of haptic interactions to communicate complex motor behaviors. Indeed, Rasmussen [10] distinguishes three categories of human behaviors; skills, rules and knowledge. The sensory-motor performances are situated in the skills level. This level of knowledge is considered as an inexpressible or a reflex behavior: "We can show the ability, but cannot explain the way to achieve it" [10]. Actually, verbalizations can permit to communicate the correct rules to accomplish a manual task (declarative knowledge). However, it can hardly be used to communicate efficiently haptic sensations: information about the forces and the movements they perform (procedural knowledge). Operators use then the haptic communication channel to exchange such information. This can be observed in several manual tasks such as lifting a table together or guiding the partner's hand to teach motor skills [11]. In these situations, physical contacts represent a shared symbolic meaning for the person who initiates the touch and the person who receive it [7]. This allows them to synchronize their actions towards a common goal. It helps them also to develop an efficient haptic common ground when performing the manual task.

To design haptic collaborative systems, it is important to understand how distant interactions can influence haptic communication. This will be discussed hereafter.

Several existing systems support mediated haptic communication. These applications can be divided into two main categories:

2.2.1. Human-computer interaction systems

Haptic devices can serve as an input device as well as a force display device, enabling users to physically interact with virtual objects and to feel the environment feedback. Thus, they are used to transmit a wide range of information to the users.

Haptic devices are used in HCI to transmit simple information to the users such as spatial/directional information by means of vibrotactile stimuli [12, 13, 14]. They are also used to teach motor skills in virtual spaces such as: handwriting [15], a crane-moving task [16] or to help users to memorize a force sequence [17].

However, human-computer interaction systems neglect the communicational dimension of haptics. In this paper, we try to overcome this limitation by focusing on human-human haptic interaction and communication.

2.2.2. Interpersonal haptic communication systems

Compared to other modalities, haptic communication requires physical contacts to transmit information. However, physical contacts are hard to reproduce faithfully at a distance. This can limit the use of touch for mediated interpersonal interaction. With the advent of new devices, haptic communication becomes feasible, even remotely. We talk than about the metaphor of haptic mediated communication. It is defined as: "the ability of one actor to touch another actor over a distance by means of tactile or kinesthetic feedback technology" [7]. In this paper we focus mainly on haptic interaction in CVE. For a survey of existing communication media that support social haptic interactions see [7].

In the area of CVE, few studies addressed haptic communication. Researches in this domain focus mainly on the effects of this communication modality on task-performance [18, 6]. These studies show that haptic communication can improve users' performance in manual collaborative tasks. They show also that haptic interactions have positive effects on the sense of presence in virtual environments [6] and the sense of copresence with a remote partner in a CVE [18]. Partners enjoy the communication experience through the haptic sense and feel more confident when interacting with each other. In [19], the author described a system that allows two remote artists to work together on a common virtual sculpture. However, only a subjective evaluation of the system was presented.

Most of the previous works focus exclusively on the effects of haptic communication on task-performance and on presence. However, there are several other issues that still need to be addressed in CVE: (i) nature of information being exchanged through the haptic channel, (ii) meaning people give to this information and (iii) effects of this information on collaboration. The paper aims to addresses these questions.

3. WHAT YOU FEEL IS WHAT I FEEL: WYFIWIF

Several benefits of mediated haptic communication are mentioned in the literature. According to [20], the haptic channel can compensate the loss of non-verbal cues that results from the use of current communication media. The media richness approaches go further by claiming that the addition of more communication channels will always enrich communication. However, this is dependent on the task [21]. Indeed, [22] show that the effects of haptic communication depend on the context in which it is used. The additional haptic information must then contribute to the development of the common ground to enhance communication. Otherwise, it becomes a source of ambiguity and incomprehension between partners. We believe that the combination of communication channels do not only contribute to increase the amount of the exchanged information, but must also allow the partners to develop a more efficient common ground. This requires partners to develop a shared meaning for the exchanged haptic information and to consider the functional dimension of touch.

3.1. Paradigm description

In order to design a haptic communication system, one must consider the users' roles and the characteristics of the collaborative task in which they will be involved. In this paper, we present a user-centred design for a CVE that takes into account these parameters.

To support haptic communication, a system based on the WYFIWIF (What You Feel Is What I Feel) paradigm [23] was developed. WYFIWIF (Fig.1) allows two users to exchange haptic information (forces and movements) even remotely. It supports also other communication forms (visual and verbal) in the CVE. One user (the actor) interacts directly with the virtual environment using the master tool, while his partner (the supervisor) can follow and observe the actor's actions handling the slave tool. A spatial mapping between the master and the slave tools creates the illusion of handling a shared object: the virtual tool. This enables physical interpersonal interaction and communication between the actor and the supervisor.

Depending on the task, haptic communication can be one-way or bidirectional. Partners can be collocated or distant. Thus, several scenarios can be supported.

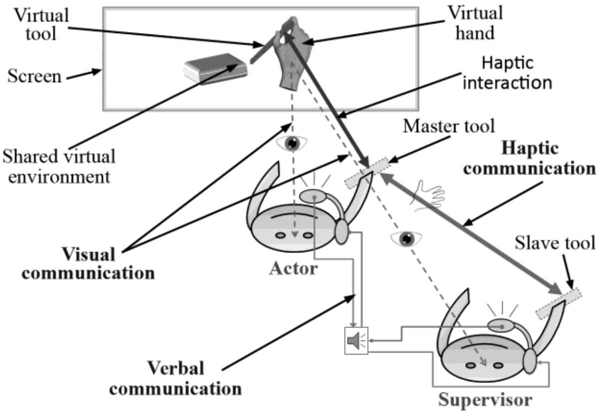


Fig.1. WYFIWIF to support haptic communication in CVE

By using WYFIWIF, we hypothesize that a CVE that supports different interactions channels helps the partners to exchange more accurate information about their common manual tasks and enhances the collaborative performance. We expect also that the WYFIWIF will enhance haptic interactions and mutual understanding between the actor and the supervisor.

4. SYSTEM DESIGN

4.1. Task

In order to study haptic communication in CVE, a training system for a Minimal Invasive Surgery (MIS) procedure was designed. MIS procedures are chosen as a test task because of their dependency on haptic information (for motor control and identification of organs). They consist of percutaneous needle insertions that require a high haptic sensitivity and fine motor skills development. The value of studying this kind of procedures in CVE is twofold:

- Currently, experts in MIS (radiologists) have no specific training tools for these procedures. Speed of movements, accuracy, sharpness of touch and safety are still learnt through observation. Our study can show the importance of haptic communication to transmit knowledge in such situations.
- A collaborative system can be used as a diagnostic and planning tool between distant experts for *hard cases* treatment, bringing new interactive situations. Our study can help to design efficient systems that support collaborative interactions.

In order to determine the characteristics of the MIS procedures, a task-analysis was conducted.

4.1.1. Biopsy procedure analysis

A common task in MIS is tissue biopsy which is commonly performed by radiologists to collect a suspicious cells sample for analysis. The task analysis was conducted at the radiology department in a teaching hospital. It was based on different techniques: observation, video recordings, questionnaires and self-confrontation interviews sessions for radiologists.

The analysis permits to make a detailed description of biopsy procedures characteristics. It is to be noted that this description is simplified. Indeed, we only focus on the operating steps (the pre-operating and post-operating procedures are not described here).

4.1.2. Biopsy procedure description

To carry out a biopsy, radiologists perform very accurate movements by manipulating a specific needle. Biopsy operations are made in two steps:

- **The planning phase:** the radiologist uses CT-scan images to locate the tumor. After that, he defines an entry point and an insertion path in order to reach the tumor with respect to some constraints (Fig.2, a).
- **The needle insertion phase:** By following the defined path, the radiologist inserts the needle inside the patient's body in order to remove a cells sample from the tumor. However, the needle is inserted "blindly": no real-time visual feedback of the needle inside the body is provided (Fig.2, b). Hence, the expert relies mainly on haptic sensations and on the offline images memorization to insert the needle.

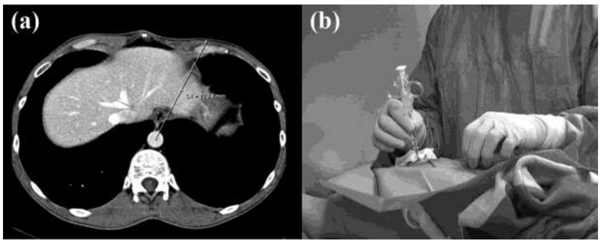


Fig.2. Biopsy operation (a) Planning; (b) needle insertion

The task analysis allows us to design the training system for the biopsy procedures. The design choices based on the users and task characteristics are described hereafter.

4.2. Review of existing haptic based MIS training systems

Surgical training is traditionally based on the "see one, do one, teach one" learning model [31]. In this model, experts try to transfer their knowledge by demonstration: a visual model of the correct skill to perform. Novices try then to imitate the expert's skill. With the advent of new surgical techniques (MIS, for instance), new approaches for skills transfer in surgery are needed.

Recently, the relevance of VR technologies based simulators is increasing in the field of medical education for both practical and ethical reasons. Several training simulators are designed for different procedures. In this context, the role of haptic information for learning is still an open issue [24]. While some authors show the importance of haptic information for teaching motor skills [25, 26], others question the necessity of this information [27, 28]. We present in this section a review of haptic based applications for needle insertion training.

Gorman et al. [29] developed a haptic training system for lumbar punctures. In this system, the needle was attached to a haptic device and passed through a human mannequin torso. The system allows medical students to practice the procedure freely. In [30], authors present a prototype of a lumbar puncture VR simulator. The system includes a virtual environment with a Proxy-based haptic volume rendering. However, only a subjective evaluation of the system was presented. Zhou et al. [31] compared two Laparoscopic Suturing learning systems. The results of their study show that the haptic based simulator enhances the users' performance only for the initial stages of training (the cognitive level of the motor skill learning).

While the presented works showed the importance of haptic feedback for MIS procedures training, none of these studies addressed the issue of communication between the teacher and the learner. As communication is very important for learning a new skill, we believe that a successful leaning model must support an efficient communication tool. Furthermore, as shown in [31], haptic enhances the learners' performance for the initial training stages. Our approach, based on haptic communication is expected to enhance the haptic common ground between the expert and the novice and to improve the skills transfer for the needle insertion task especially in the cognitive level.

4.3. Design choices

4.3.1. *Virtual environment*

Compared to high-fidelity VR simulators, part-task simulators are less expensive and easy to design. Moreover, they have been shown to be effective for training if they provide the critical information with respect to performance outcome, aiding in problem-solving and decision-making [32].

According to the objective of our study (investigating haptic communication in a shared manual task), the graphical representations of the patient's anatomy were simplified. Indeed, the patient body was only composed of symbolic elements (Organs, tumors, bones, etc.). However, an appropriate visual feedback (skin and hepatic membrane deformations) was combined with the haptic feedback to reproduce haptic sensations.

4.3.2. *Haptic devices*

To support haptic interactions in the virtual environments, the *Virtuose 6D desktop* haptic arms from *Haption* were used. These devices are appropriate for our system because of their characteristics (6 DoF for position and force, small workspace, appropriate forces range, well adapted for medical applications).

The haptic arms were connected to the CVE and allowed users to manipulate the virtual needle and to feel the environment feedback. Finally, to make the haptic arm movements match those of a real needle, its initial posture was changed. Indeed, the arm was rotated so that its handle was in a vertical position.

The designed system was used in the following study to evaluate the effects of haptic communication on collaboration during a biopsy procedure.

5. USER STUDY

5.1. Hypotheses

In radiology, novices learn biopsy procedures: (i) through theoretical courses or (ii) by observing visually the experts performing real operations. In our study, these traditional learning methods are compared to the haptic communication based training. Hence, we hypothesize that:

H1. Each training method will influence differently the users' performance when performing the task in collaboration. Thus, the theoretical learning is expected to help the users to better respect the theoretical rules whereas the haptic communication learning will help the users to better perform the manual task in collaboration (better management of the haptic feedback, faster and more accurate movements, etc.).

H2. The way the partners learn a manual task has an influence on their verbal communications when they collaborate to perform the same task: According to the grounding process definition, partners exchange information and signs of comprehension about their common activity in order to develop their common ground. Studying verbal communications during a collaborative manual task is a way to investigate the contents of the common ground. We hypothesize that the learning method will have an influence on the communication focus during the collaborative task achievement. The theoretical learning is expected to help the users to focus on the rules (declarative knowledge) whereas the haptic communication learning is expected to help the partners to focus on haptic information (procedural knowledge).

H3. The haptic communication learning will enhance the users' feeling of presence in the virtual environment and **feeling of copresence (social presence) with the partner in the CVE**: As the haptic communication is expected to enrich the interactions between the partners, this will make them more involved in the collaborative achievement of the task and feel much more present in the virtual environment. The richer interaction between partners is expected also to make them feel more socially present with each other.

The following experiment was conducted to assess the validity of these hypotheses.

5.2. Participants

60 medical students (19-29 years old; 30 males, 30 females) participated in the experiment. Participants were randomly assigned to conditions with gender balanced across conditions. None of them had prior knowledge of MIS or of biopsy procedures. All of them had no experience either with CVE or with haptic arms. Finally, they received 30€ for their participation.

5.3. Apparatus

The setup (Fig.3) consisted of a main personal computer (Intel Pentium dual core 2.0 GHz, 2 GB RAM and a 3D video card) and two LCD screens (23 inches).

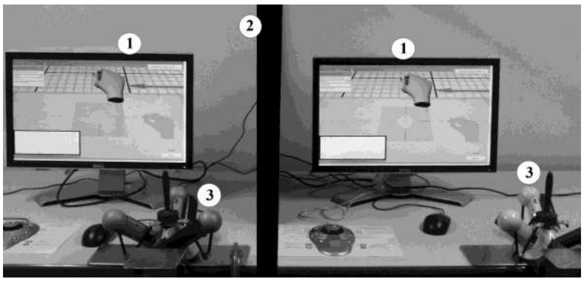
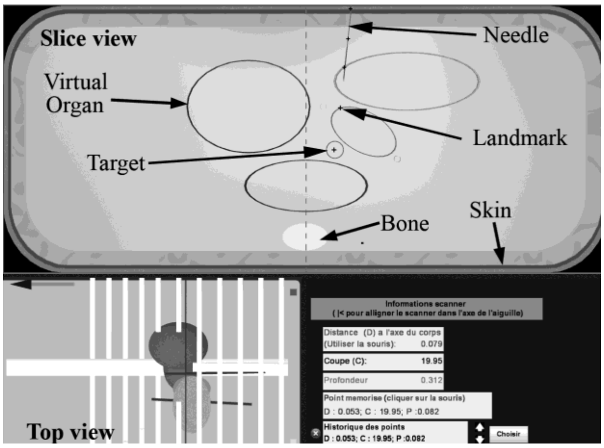


Fig.3. The haptic communication system with two screens (1) separated by a curtain (2) and two haptic arms (3)

To support haptic communication, *Virtuose 6D desktop* arms were linked to the computer via a low latency Ethernet connection.

The CVE was developed using *Virtools* from *Dassault system.* It consists of two graphic user interfaces (GUI):



Informations scanner
(|< pour alligner le scanner dans l'axe de l'aiguille)

Distance (D) a l'axe du corps (Utiliser la souris): 0.079

Coupe (C): 19.95

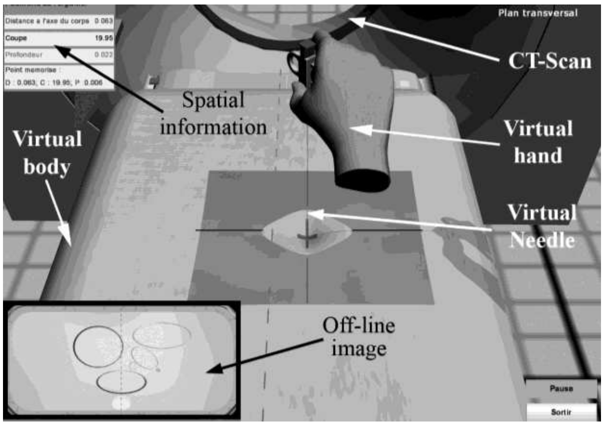
Profondeur 0.312

Point memorise (cliquer sur la souris)
D : 0.053; C : 19.95; P :0.082

Historique des points
D : 0.053; C : 19.95; P :0.082

Fig.4. Planning GUI: a slice view representing a scan image

- **Planning GUI:** it provides a slice view of the body (Fig.4) that permits to localize the target. The user can then define the insertion path by positioning landmarks on the slice view using a mouse,



Distance a l'axe du corps 0.063

Coupe 19.95

Profondeur 0.023

Point memorise :
D : 0.063; C : 19.95; P :0.006

Fig.5. Manipulation GUI: a virtual environment representing the radiologists working environment

- **Manipulation GUI:** it provides a three-dimensional view that allows the user to manipulate the virtual needle using the haptic arm (fig. 5). The user's action point is represented by a virtual hand handling a needle. In addition to the haptic feedback, information about the needle spatial position is displayed on the screen.

5.4. Task and procedure

All the volunteers participated successively to the three following sessions:

5.4.1. Starting session

The objective of this session was to familiarize the participants with the haptic devices manipulation and with the use of the CVE. During the session, the participants were allowed to perform a simple insertion exercise. At the end of the session, all of them were observed to feel comfortable with the experimental setup. The session duration averaged 25 minutes.

5.4.2. Training session

After the starting session, participants were taught instructed by an expert (one of the experimenters) how to correctly perform a biopsy (four different exercises). The learning process is divided into two steps:

- **The planning phase:** The first sub-task of this phase is to choose the entry point on the skin surface. The second sub-task is to position landmarks in the slice view to define the insertion path. This path is defined with respect to the planning constraints,
- **The needle insertion phase**: the objective of this phase is to insert the needle in the body to perform the biopsy. The user had then, to move the needle to reach the tumor with respect to the defined path.

The session duration averaged 30 minutes. During the session, subjects were divided into 3 training groups:

- **Paper Instructions training group (PI).** The instructor taught the rules and the motor skill to the participants through verbal instructions and with support of static images (Fig.6),

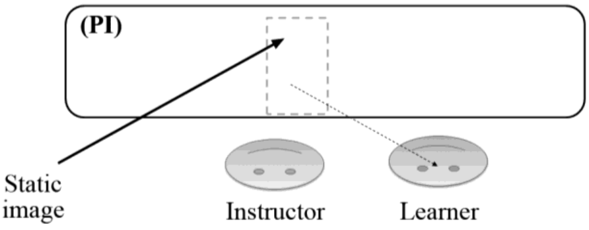


Fig.6. The Paper Instructions training (PI)

- **Visual training group (VI).** The instructor taught the rules and the motor skill through visual demonstration combined with verbal explanations. Novices observed directly the expert's hand manipulating the haptic device and saw the virtual needle moving on the screen (Fig.7),

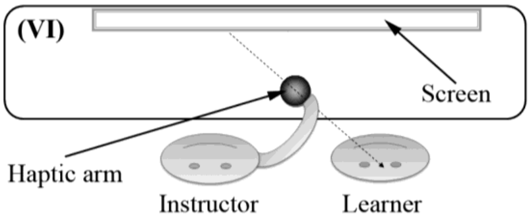


Fig.7. The Visual training (VI)

- **Visual-haptic training group (VH).** In addition to visual demonstration and verbal explanations, the teacher used haptic communication (WYFIWIF) to guide the novice's hand while manipulating the needle (Fig.8). The novice (supervisor) follows passively the expert's (actor) movements.

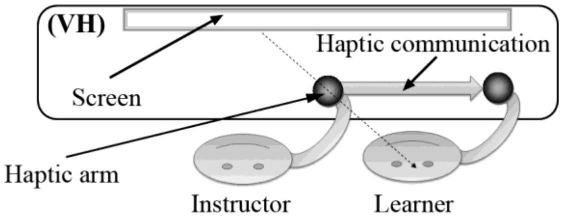


Fig.8. The Visual-Haptic (WYFIWIF) training (VH)

5.4.3. *Collaborative practice session*

After the training session, participants were regrouped into 30 dyads. Each pair was composed of two participants from the same training group. Partners were asked to perform together four new exercises. For each exercise, they were asked to perform the planning phase together. During the manipulation phase, one participant (actor) was asked to manipulate the needle using the master arm, while the other (supervisor) had to follow passively and to supervise the actor's movements using the slave arm (Fig.9). The partners' roles were reversed after each exercise.

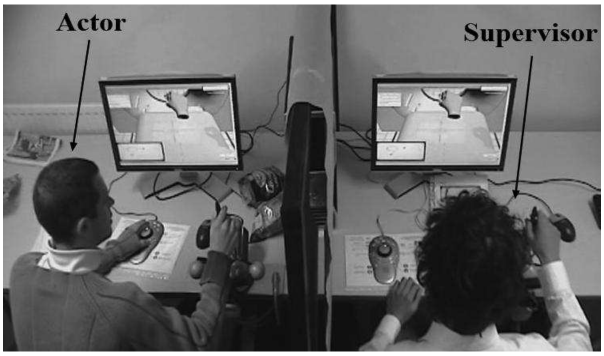


Fig.9. Collaborative practice session

Each participant was seated in front of a screen. The partners were instructed to perform the task in collaboration. Moreover, they were separated by a curtain to prevent them to see each other (Fig.9). Therefore, they could only communicate using the: (i) haptic communication channel, (ii) verbal communication channel or (iii) through the shared visual workspace (CVE). The session duration averaged 90 minutes. After completing the collaborative task, the partners were instructed to fill out individually a paper-and-pencil questionnaire asking for their assessment of the system and the collaborative performance.

5.5. Measurements

The independent variable was the training condition with three modalities: **PI, VI, VH**. Different dependent variables were used to compare the participants' performance in the collaborative practice session:

- **Task completion time**,
- **Final distance to the target**,
- **The number of planning landmarks**,
- **The number of displayed slice views (scan images):** Participants were instructed to minimize the number of displayed images in order to reduce the patient's exposure to the CT-scan X-rays,
- **The number of penetrations inside organs** and **the number of contacts with organs**: Participants were asked to minimize organs penetrations and contacts with organs in order to minimize the organs damage.
- **The length of the real insertion path**: in order to limit the body damage, participants were asked to minimize the insertion path length. We calculated the length of the real insertion (rather than the planned path) in order to evaluate the insertion performance.
- **The frequency of missed targets**,
- **The frequency of penetration of forbidden organs,**
- **The number of insertion segments**: during biopsy procedures, radiologists split their gestures into several small insertion movements (segments). This is used to characterize the insertion profiles,
- **The insertion segments average amplitudes**: this helps us to characterize the partners' insertion profiles,

Finally, each participant answered a questionnaire after the collaborative session. The questionnaire was used as a subjective measure for the system evaluation.

6. RESULTS AND DIUSCUSSIONS

The collected data were subjected to an ANOVA. Moreover, pair-wise t-test comparisons were performed (mean values, standard deviation values, F-values and t-values are provided in the tables below; the statistically significant values are provided with 0.05 alpha level). For verbal communication measures, non-parametric tests (Mann-Whitney U test) were used as the data did not meet the assumptions of normal distribution. Finally, the frequencies were compared using the Chi2-test (χ^2 values are provided and compared to the theoretical value $\chi^2_{(0.05;2)}$=5.99).

6.1. Performance

The participants' performance was regarded separately according to the two phases of the biopsy procedure:

6.1.1. *Performance for the planning phase*

The ANOVA shows an effect of the training condition on: the planning time, the number of used landmarks, the number of displayed slice views and the amount of organs penetration (Table 1).

Pair-wise comparisons (Table 2) indicate that pairs planned the procedure faster, used fewer landmarks and displayed less slice views to plan the path in the PI condition compared to pairs in the VI and VH conditions. No significant differences (Table 2) were observed between pairs in the VI and VH conditions.

Table 1: the planning performances

The planning performance	Experimental groups			ANOVA	
	PI	VI	VH	*F*	*df*
Planning time (seconds)	1422.0 (306.8)	2121.0 (399.7)	2054.1 (384.5)	9.9*	2,27
Used landmarks (points)	24.0 (6.7)	32.8 (8.0)	34.7 (9.6)	3.5*	2,27
Displayed slice views (images)	56.1 (10.7)	89.5 (27.12)	83.0 (13.16)	4.7*	2,27
Organs penetration (cm)	4.8 (.8)	6.1 (.4)	4.9 (1.1)	7.9*	2,27

Note. * = $p < .05$. Standard deviations appear in parentheses bellow means.

Pair-wise comparisons indicate also that partners minimized the amount of organs penetration in the PI and VH conditions compared to partners in the VI condition (Table 2). No significant differences were observed between pairs in the PI and the VH conditions concerning the amount of organs penetration (Table 2).

Table 2: pair-wise comparisons (planning performance)

Planning performance	t-values			
	PI/VI	PI/VH	VI/VH	*t-df*
Planning time	4.1*	3.8*	0.3	18
Used landmarks	2.1*	2.7*	0.2	18
Slice views	2.5*	2.8*	0.6	18
Organs penetrations	4.5*	0.31	3.2*	18

Note. * = $p < .05$.

6.1.2. *Performance for the needle manipulation phase*

The ANOVA shows an effect of the training condition on: the manipulation time, the final distance between the needle tip and the target center, the number of contacts with organs, the number of organs penetrations and the insertion path size (Table 3).

Pair-wise comparisons (Table 4) indicate that pairs inserted the needle faster, minimized the contacts with organs, minimized the number of needle penetrations inside organs and minimized the size of insertion path in the VH condition compared to pairs in the PI and VI conditions. No significant differences (Table 4) were observed between pairs in the PI and the VI conditions.

Pair-wise comparisons (Table 4) indicate also that pairs minimized the distance between the needle tip and target center in the PI condition compared to pairs in the VI and VH conditions. No differences (Table 4) were observed between pairs in the VI and VH conditions.

Moreover, all participants completed correctly the task by reaching the target. However, some of them needed more than one trial to hit the tumor. The χ^2 test (Table 3) reveals that partners had missed the target less frequently (12.5%) in the VH condition compared to partners in the PI (40%) and VI conditions (37.5%).

Table 3: the manipulation performances

Manipulation performance	Experimental groups			ANOVA	
	PI	VI	VH	*F*	*df*
Manipulation time (seconds)	1163.0 (429)	1090.0 (294)	692.8 (80)	5.5*	2,27
Organs contacts (contact)	11.2 (3.1)	22.4 (20.1)	5.7 (2.9)	4.6*	2,27
Organs penetrations	18.40 (9.21)	18.0 (8.62)	9.7 (2.72)	3.9*	2,27
Real insertion path (cm)	69.23 (23.6)	59.08 (16.8)	40.98 (11.4)	7.1*	2,27
Distance to the target (cm)	.6 (.1)	.8 (.1)	.8 (.1)	5.4*	2,27
Target missing (%)	40%	37.5%	12.5%	χ^2=8.80 >5.99*	
Forbidden organs penetration (%)	20%	20%	17.5%	χ^2=0.10 <5.99	

Note. * = $p < .05$. Standard deviations appear in parentheses bellow means.

Finally, the χ^2 test (Table 3) shows no significant differences regarding the forbidden organs penetrations.

Table 4: pair-wise comparisons (manipulation performance)

Manipulation performance	t-values			
	PI/VI	PI/VH	VI/VH	*t-df*
Manipulation time	.4	2.9*	3.3*	18
Organs contacts	1.6	3.9*	2.4*	18
Organs penetrations	.009	7.38*	7.57*	18
Real insertion path	1.72	11.55*	10.02*	18
Distance to target	3.0*	2.6*	.2	18

Note. * = $p < .05$.

6.1.3. *The needle insertion profiles*

The ANOVA shows an effect of the training condition on the number of insertion segments and on the average size of these segments (Table 5).

Pair-wise comparisons (Table 6) show that pairs reduced the number of segments in the VH condition compared to pairs in PI and in the VI conditions.

Table 5: the insertion profiles

Insertion profiles	Experimental groups			ANOVA	
	PI	VI	VH	*F*	*df*
Average number of insertion segments	28.25 (10.)	32.8 (13.9)	20.53 (4.3)	3.2*	2,27
Average size of segments (cm)	2.72 (.32)	2.31 (.35)	2.32 (.37)	4.*	2,27

Note. * = $p < .05$. Standard deviations appear in parentheses bellow means.

Table 6: pair-wise comparisons (insertion profiles)

Insertion profiles	t-values			
	PI/VI	PI/VH	VI/VH	*t-df*
Number of segments	.7	2.1*	2.5*	18
Size of segments	6.49*	6.05*	.002	18

Note. * = $p < .05$.

On the other hand, pair-wise comparisons (Table 6) show that pairs minimized the average size of the insertion segments in the VH and VI conditions compared to pairs in the PI condition.

6.2. Discussion of the performances' results

WYFIWIF training was expected to improve partners' performance during the insertion phase (H1).

6.2.1. Completion time

The results show that dyads in the PI condition planned biopsies faster than dyads in the two other groups whereas dyads in the VH condition performed the needle manipulation phase faster than dyads in the two other groups. This suggests that the training method influenced differently the task performances depending on the two biopsy phases. Indeed, paper instructions have been beneficial to improve the planning performances. On the other hand, haptic communication has been beneficial to improve the needle manipulation performance. This is discussed more in depth hereafter.

6.2.2. Planning performance

Regarding the planning phase, the results show that partners in the PI condition improved their performances compared to partners in the two other conditions. Indeed, they reduced: the amount of organs penetration, the number of displayed scan images and the number of landmarks used to plan the insertion path. This indicates that in this condition, they followed more strictly the theoretical rules. In fact, their performance show that they promoted the patient safety by reducing risks of organs damage (the amount of organs penetration) and by minimizing the patient expositions to the CT-scan X-rays (minimization of landmarks and displayed scan images).This can also explain why dyads spent less time to plan operations in this condition. These results suggest that verbal instructions with support of static images were sufficient to learn correctly theoretical rules. Indeed, according to Rasmussen's human behaviors classification [10], verbalizations can permit easily to communicate symbolic rules (declarative knowledge).

Conversely, partners in the two other conditions were less efficient during the planning phase. Indeed, they respected less strictly the theoretical rules compared to PI dyads. One possible explanation for this result is that partners were disturbed by the new technological devices (haptic arms, virtual environment, etc.). This prevents them from acquiring correctly the planning rules. Therefore, they were less efficient during the collaborative session compared to the PI group.

These results suggest that **the theoretical knowledge is more efficiently transmitted without unusual technological devices.**

6.2.3. Manipulation performance

Regarding the needle manipulation phase, the results show that partners in the VH condition improved their accuracy compared to partners in the two other groups. Indeed, they missed the target less often in this condition. This indicates that the haptic communication training helps them to be more accurate when manipulating the needle.

In addition, they reduced the contacts with organs, inserted the needle less often inside organs and reduced the real path size. This can be considered as a direct consequence of the accuracy performance. Indeed, as partners reached the target with fewer trials, they reduced the *back and forth* needle movements. This allows them to minimize the contacts and penetrations of organs and to reduce the size of insertion path. Moreover, this permits to decrease the needle insertion time. These results confirm that **WYFIWIF training improves the participants' accuracy when performing the collaborative needle insertion task.**

On the other hand, no difference was observed concerning the contacts with the forbidden organs. This indicates that all the participants tried as much as possible to avoid these organs. The respect of this safety rule was independent from the training condition.

Finally, participants were instructed to reach the center of the tumor. Partners in the PI condition succeeded to be more accurate by minimizing the final distance between the needle tip and the target center. On the other hand, partners in this condition needed more trials to reach the target than partners in the VH condition. This higher frequency of target missing indicates that accuracy in this case, is mainly due to the respect of theoretical instructions. Indeed, the additional trials helped the partners to reach the target center.

6.2.4. Insertion profiles

Two measurements are used to characterize the needle manipulation profiles: the average number of insertion segments and the average size of these segments.

The results show that partners minimized the number of segments in the VH condition. This can be linked to the size of the real insertion path. Indeed, as partners in the VH group decreased the size of the insertion path, they consequently reduced the number of insertion segments needed for this path. On the other hand, partners in the two other groups increased the size of insertion paths. We can consequently argue that this constraints them to increase the number of segments.

Regarding the size of the segments, the results show that compared to partners in the PI condition, partners in the VI and VH conditions minimized the segments size. One possible explanation for this result is that the real-time visual feedback provided to participants in these two conditions allows them to learn the correct characteristics of the movement. In fact, the small segments are regarded as a safety characteristic since they permit to be more careful when inserting the needle. The visual demonstration of the instructor's gestures helps the partners to acquire this characteristic. On the other hand, the partners in the PI group learnt the movements through static images. Since, the static images do not provide a real-time visual demonstration of the movement dynamics; participants did not learn the correct movement amplitudes. Consequently, they moved the needle using longer segments.

These findings permit to extract three different needle manipulation profiles that were the most observed during the manipulation phase:

Big-segments profile: in this profile, partners increase the size and the number of insertion segments and increase also the size of the insertion path. This profile characterizes mainly the PI group.

Multiple-segments profile: in this profile, partners minimize the insertion segments size. On the other hand, they increase the number of insertion segments and the size of real insertion path. This profile characterizes mainly the VI group.

Safety profile: in this profile, partners minimize the size and the number of insertion segments and the size of the insertion path. This profile characterizes mostly the VH group. It is considered as the optimal profile since it reduces the risks of organs damage**.**

These findings confirm that **haptic communication allows partners to learn the optimal needle insertion profile and to apply it during collaboration.** However, deeper analyses of the needle trajectories for each group must be used to extract more accurate insertion profiles that characterize each group.

6.3. Verbalizations

Verbalizations analyses were conducted using *Tropes* from *SoftConcept* (a specific program dedicated to speech analyses). This program was chosen because it permits to get a quick summary of the conversations properties (speech style, words categories and words frequencies). Verbalizations analysis gave some indications concerning the conversations contents between partners. The main significant differences observed between the groups are summarized below:

Table 7: verbalizations analysis

References to:	**Experimental groups**			**Mann–Whitney U-values**		
	PI	VI	VH	PI/VI	PI/VH	VI/VH
The perception	.8 (1.9)	2.4 (2.6)	5.8 (4.4)	68.5	92.5*	83*
The haptic sensations	.0 (0)	.0 (0)	2. (2.4)	-	80.*	80.*
The Places/ directions	26.6 (3.7)	28.5 (4.3)	24. (1.9)	65.	33.5	8.*
The space/ dimensions	13.9 (12.7)	.0 (0)	.0 (0)	20.*	20.*	-

Note. * = $p < .05$. Standard deviations appear in parentheses bellow means.

6.3.1. *References to perception of the virtual environment*

The results (Table 7) show that partners made more references to the perception of the environment ("touch the vain", "the view", "the red", etc.) in the VH condition compared to partners in the PI and VI conditions (Table 7). No significant differences were observed between the VI and PI groups (Table 7).

6.3.2. *References to haptic sensations*

The results (Table 7) show that the partners made more references to haptic sensations ("I feel", "I touch", "The smoothness", "collision", etc.) in the VH condition compared to partners in the PI and VI conditions. No significant differences were observed between partners in the VI and PI conditions (Table 7).

6.3.3. *References to places and directions*

The results (Table 7) show that the partners made fewer references to the places and the directions (up to, down to, forward, backward, etc.) in the VH condition compared to the partners in the PI and VI conditions (Table 7). No significant differences were observed between pairs in the PI condition and pairs in the VI condition (Table 7).

6.3.4. *References to spatial information*

The results (Table 7) show that partners made more references to space and dimensions (depth, length, height, etc.) in the PI condition compared to partners in the VH and VI conditions (Table 7). No significant differences were observed between partners in the VI and VH condition (Table 7).

6.4. Discussion of verbalizations' results

The training conditions were expected to influence verbalizations during the collaborative session (H2). The verbalizations analyses permit to extract some interesting characteristics of the partners' conversations.

The results show that the training session influenced the conversations contents. Indeed, after the VH training, partners made more references to haptic information. This indicates that the use of the haptic communication channel during the training session allowed partners to make use of this channel during the collaborative session. As partners were used to communicate through this channel, they tried to support their information exchanges using verbal communications. This is consistent with the grounding process theory. Indeed, the grounding process consists of an exchange of information and understanding signs. Haptic communication during the training session helped the partners to understand much better how to use this modality and to develop a shared meaning for the exchanged haptic information. Therefore, during the collaborative session, they used verbal communication to share this mutual understanding of the haptic information. This includes mainly the description of the actions when they manipulated the needle.

On the other hand, partners in the PI and in the VI groups made only few references to haptic sensations. As they were not trained to use this modality, they did not get a complete representation of haptic information in the virtual environment. Due to the lack of understanding of haptic feedback, they did not highlight haptic information in their discussions during the collaborative session. In fact, the results show that they preferred to use spatial information (like space, dimensions or directions) to describe their actions. This is coherent with the grounding process theory. Indeed, the instructor taught the correct movements only using (static or dynamic) visual demonstrations. Therefore, the participants' individual representations included mainly spatial descriptions of the movements to perform. When partners discuss with each other during the collaborative session, they mainly exchange information and signs of understanding about this shared knowledge.

This confirms that **the use of the haptic communication channel to teach new knowledge about manual tasks helps the users to develop a more complete individual representation of the haptic constraints.** This is coherent with the needle manipulation performance. Indeed, the partners improved the manipulation performance in this condition. However, a more in depth verbalisations analyses can permit to study more accurately the progress of the grounding process and give us an idea about the effects of haptic communication on collaboration.

6.5. Questionnaires

Questionnaires were used to evaluate the users' perception of: the GUI, feeling of presence and feeling of copresence in the CVE and collaboration. The results are described hereafter:

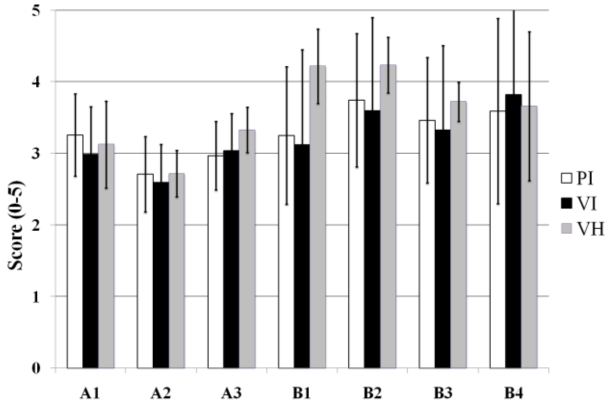


Fig.10. Questionnaires answers (see A1-B4 on Table 8)

6.5.1. Perceived quality of the system (A3)

Results (Fig.10) show that the participants' perceived quality of the system was increased in the VH condition compared to participants in the PI and VI conditions (Table 8). No significant differences were observed between the PI and VI groups (Table 8).

6.5.2. Feeling of copresence with the partner (B1)

Results (Fig.10) show that the participants' feeling of copresence with their partner was increased in the VH condition compared to participants in the PI and VI conditions. No significant differences were observed between participants in the PI and the VI groups regarding the feeling of copresence (Table 8).

6.5.3. Mutual understanding (B2)

Results (Fig.10) show an effect of the experimental condition on the users' feeling of mutual understanding: participants in the VH group expressed a higher feeling of mutual understanding with their partners compared to participants in the PI and VI groups (Table 8). No significant differences (Table 8) were observed between participants in the PI and the VI groups.

6.5.4. Feeling of common achievement of the task (B3)

Results (Fig.10) show that all the participants expressed a high feeling of common achievement of the task. However, no significant effect (Table 8) of the experimental condition on this measure was observed.

6.5.5. Feeling of enjoyment when working in a team (B4)

Results (Fig.10) show that all the participants express a high feeling of enjoyment of the collaborative achievement of the task. However, no significant effect (Table 8) of the experimental condition was observed.

It is to be noted that no significant differences were observed regarding the feeling of presence in the virtual environment (A1), the real world perception (A2).

Table 8: data comparisons for the questionnaires answers

Answers	ANOVA		Pair-wise comparisons			
	F	*df*	PI/VI	PI/VH	VI/VH	*df*
Presence in VE (A1)	.95	2,27	.17	.48	.48	18
Real world perception (A2)	.45	2,27	.48	.006	0.83	18
System perceived quality (A3)	3.69*	2,27	.17	7.97*	4.64*	18
Copresence in CVE (B1)	7.30*	2,27	.13	15.64*	11.86*	18
Mutual understanding (B2)	2.47*	2,27	.17	4.73*	4.42*	18
Common achievement of task (B3)	1.07	2,27	.16	1.63	2.11	18
Collaborative work enjoyment (B4)	.18	2,27	.30	.35	.17	18

Note. * = $p < .05$.

6.6. Discussion of questionnaire' results

Different measures were included in the users' subjective evaluation. The haptic communication training was expected to enhance (H3):

- the feeling of presence in the virtual environment,
- the feeling of copresence with a partner in the CVE,
- perception of the collaborative task achievement.

6.6.1. Presence in the virtual environment

The results show that the training condition neither improves the users' feeling of presence nor influences the users' perception of the real world. This indicates that all the partners were equally involved in the task achievement. On the other hand, the results show that the VH training improves the users' perception of the system quality. This indicates that although the VH training method did not affect the sense of presence it permits to increase the users' evaluation of the system. This can be linked to the needle insertion performances. Indeed, as partners in the VH condition performed the task more easily than the other dyads, they rated the system higher as compared the other groups.

6.6.2. Copresence and perception of collaboration

The results show that the training method neither influences the partners' enjoyment of the collaborative work nor their perception of the common achievement of the task. However, the results show that the VH training improves their feeling of copresence with their partner and improves their feeling of mutual understanding of their teammate. This indicates that all the participants enjoyed the collaborative achievement of the task. However, as the haptic communication training improves the users' collaborative performance, it improves also the mutual comprehension between partners. This increased also their feeling of togetherness with each other in the CVE. This confirms some previous other studies on the influence of haptic communication on the feeling of copresence [33].

7. CONCLUSION

The actual study aimed to show the importance of haptic communication to accomplish manual tasks in collaboration in virtual environments. We proposed a user centred approach for a virtual environment that supports haptic interactions between two users. The design approach was based on WYFIWIF: a haptic communication paradigm. The designed environment was evaluated through a user experimental study. Participants were asked to perform together a shared manual task after a training period.

The results show that the haptic communication training improves the users' accuracy when they perform in dyads the shared manual task. Partners developed different needle insertion profiles depending on the training method. The haptic communication training allows the users to choose the optimal profile.

In addition, the haptic communication allows the users to understand much better the environment haptic feedback. The shared understanding of haptic information was highlighted during the collaborative achievement of the manual task.

Finally, the haptic communication training enhanced the users feeling of copresence with the partner in the virtual environment and increased the users' perception of the system quality.

The design approach as well as the experimental results, is a step closer for formulating design guidelines for haptic communication devices in shared virtual environments. Here are some design recommendations that can be outlined:

In order to improve haptic communication in collaborative virtual environment the system:

1. Must permit to communicate information about the actions (forces, directions, speed, accelerations) performed by each operator,
2. Must not constraint the manual task execution: the haptic devices must fit to the manual task requirements.
3. Must not overshadow or neglect the other forms of communication between users.

These recommendations can permit to develop virtual environments that match the users' needs in terms of manual collaborative tasks performing.

In future, a deeper verbalization analysis is needed to explore more accurately the development of common ground between partners. This can allow us to better understand the influence of haptic communication on the grounding process in manual tasks. Furthermore, a system needs to be validated by expert radiologists in order to be introduced as an actual learning tool for biopsy procedures.

We are continuing to study the haptic communication paradigm in collaborative virtual environments. WYFIWIF can be used in other learning scenarios. One can imagine a training tool in which an expert radiologist can supervise novices during the practice. The benefits of this kind of scenarios are twofold: first, novices are more active during the learning process. Second, the teacher can provide more practical advices to students. This can permit to design training tools that fit the users' needs in the medical field.

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