Simulation training to prepare for robotic intervention in a hostile environment

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Abstract

There are work activities for which the action of intervener directly on the object of work is impossible, most of the time due to safety constraints. It is the case for example of a polluted industrial environment or, quite differently, the human body. In the first case, interveners may need to keep far from the restricted area due to chemical hazards or high radioactivity for example. The second case may be surgeons preferring to be as less invasive as possible in order to reduce anatomical damages; the aim is to help patients to recover health as fast as possible. Some cases allow a training in the real context and for others, the risk factor is important enough to imply training in simulated situation. This may be done on full scale or virtual simulator.

Comparing pilots of robotic devices for radioactive hostile environment at INTRA group on one hand, and physicians for mini-invasive surgery at IRCAD on the other hand, we points out the constraints of each profession and the consequences on the associated simulation training, with a focus on the first profession (to make it simple, we suggest to consider a work situation as a "simulation training" as soon as it is a training session AND a part of the situation at least is simulated, such as physical phenomena or environment for example). This was done on the basis of interviews of managers, trainers and trainees, and with the help of observations done in real and simulated situations.

Our findings show how the "hostile" character of the work for robotic device pilots of INTRA sizes the work activity while surgeons are mainly led and bounded in their work by the aim to keep the patient's life. The "hostile" character of the work induces a high probability of unpredictable facts and the consecutive risk of destruction of the robotic device which would make the mission fail. In terms of training, this means that the simulated activity is most of the time far from the real situation and thus makes the transference process of knowledge and know-how from simulation training to non-simulated activity more uncertain than for the mini-invasive surgery. INTRA group copes with this difficulty by training the pilots in a large diversity of cases on full scale simulation training, and through virtual simulation training using ITUCR[1] software. To go farther, the use of such a virtual simulator in order to offer to the pilot a lot of different possibilities of environments would be a real benefit.

1. Introduction

High risk work activities imply sometimes risks for the interveners (endorisk producer), for the people concerned directly or indirectly by the activity but not interveners (exorisk producer), sometimes for both. Astronauts for example are most of the times in the first category. Surgeons or anesthetists are mainly in the second category. Civil aircraft pilots are of the third category with risks concerning both themselves and people travelling in their plane.

For some professions and in some cases, specific constraints imply not to intervene directly in contact with the object of work activity.

Endorisk producing activities are the case of people operating in hostile environment. For example, deminers use robotic devices to approach the bomb susceptible to explode while they try to deactivate it. The same for operators involved in post nuclear accident who must check radioactive industrial equipment: we shall here be concerned by the group INTRA which has developed specific robots for this purpose (Fig. 1). INTRA has to conceive, to operate and to maintain a fleet of robotics machines 24 hours / 24 hours capable of intervening, in the place of human beings, in a major nuclear accident, in and around the industrial buildings of its members. It also assures the continuous training of pilots within the installations of companies members: EDF, CEA and AREVA. (web site: http://www.groupe-intra.com)

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http://www.groupe-intra.com

[1] ITUCR : Russian Agency of Nuclear Energy - Center of robotics (Moscow, Russia).

Fig. 1. Examples of INTRA robots driven in a simulated hostile environment with the control panel (middle).

For exorisk producing activities, the case of surgeons is interesting. They are involved to seek the least invasive intervention possible for the patient. To achieve this, mini-invasive surgery appears to be an appropriate solution as it is the least invasive manner of operating. Instead of opening up the body with large cuts and move the organs, small holes are done to insert surgical tools and camera for a very local operation. Since several years, IRCAD (Research Institute against Digestive Cancer, Strasbourg, France) has developed such a technology for the digestive apparatus based on the use of robotic devices (web site: www.ircad.fr). Among IRCAD digestive cancer research laboratories, there are a research and development department in computer sciences and robotics, and a training center in minimally invasive surgery (see for example Soler & Marescaux, 2011). In this frame, IRCAD welcomes surgeons in training sessions to develop the use of robotic systems (Fig. 2) such as those developed by Intuitive Surgery (web site: www.intuitivesurgical.com).

Fig. 2. The Da Vinci surgery facilities and the surgeon on the right engaged in the control unit.

In both aforementioned cases, interveners use robotic devices, or robots. Some cases allow a training in the real context and for others, the risk factor is important enough to imply simulation training. To make it simple, we suggest to consider a work situation as a "simulation training" as soon as it is a training session AND a part of the situation at least is simulated, such as physical phenomena or environment for example. This may be done on full scale or virtual simulator using part or full the robotic devices. A robot is here a tool that prolonged the intervener's body for him to act on the work activity object without direct contact. According to the Macmillan dictionary, "robot" is a machine that can do work by itself, often work that Humans do. We must had here the remote control character of the robot as the machine does by itself what Humans ask it to do.

Yet, if this definition may fit both of the aforementioned cases, the robot in each case is quite different. They are designed according to the work aim, to the environment, and to other constraints inherent to the profession specificities. As a matter of fact, the way the robots are piloted and the training associated are different.

The present study aims to analysis these differences and what are the consequences in terms of training design. The problematic is interesting because, at a macro level, both INTRA and IRCAD work activities can be described in a same manner: an operator intervenes within a risky framework in an environment where safety constraints lead to use a robotic device. In both cases, the interveners work inside the object of the work activity: the hostile environment for INTRA and the patient for IRCAD. But when we watch the details, they become quite different. INTRA is mainly led to keep on working the robot within a hostile environment: the loss of robot brings the mission to an end or implies a delay and the hostile character of the environment may contribute to the loss of the robot. IRCAD is mainly led to keep the patient alive with less damage as possible. If the robotic device fails (is found not suitable or does not work), then the surgeons can come back to the classic invasive technique and achieve the mission. This is not possible for INTRA since anyway the mission will be performed by a robot. Furthermore, the "hostile" character includes a priori the unknown dimension of the environment: while the human body is usually known for surgeons of IRCAD, the hostile environment contains a part of unknown configurations because hostile environments are most of the time hostile due to destruction. Comparing both professions and the associated training, we aim to identify what is done by each one and appears to be of great importance for one and not for the other. This will help to emphasize what appears as key points of the work activity in terms of pilot's skills and the comparative study will highlight why these are keys points. This will help the trainers to enforce some specific points and will help other professions or even newly concerned professions to conceive an adapted training according to their kind of robotized work activities.

2-Materials and method

For both work activities, interviews have been done with managers, trainees, trainers and observations have been carried out on simulation sessions only.

Trainees met are not novices: they are experienced professionals, who are trained to new technical specificities, new procedures, or just re-trained to maintain their skills.

For both professions, two kinds of situation have been seen:

- Simulation with virtual representation of the object of the work activity, which implies computer graphic conception.
- Simulation with a real representation of the object of the work activity: an experimental hall where move robots for INTRA, and an anesthetized pig for IRCAD.

Of course, for the first kind of situations, the whole simulator take a reduce form. And for the second, the case of INTRA presents a particularity: despite the simulated character of the simulation session, the loss of a robot (if happens) will be real: a robot falling from the stairs is really damaged and the waste of money may be up to 1Meuros.

Figures 4a & b show INTRA robot on full scale simulation and control panel. Figure 4c shows the virtual simulator for INTRA: the video images on the control screens used by the pilot are virtual while provided by cameras fixed on the robot in full scale simulator. Generated by the calculation software Robsim developed by ITUCR (Volov et al., 2002), they can reproduce any environment according to the programmer's desire. The trainee is thus sat in front of the real control panels, and all that concerns the robot and cables are absent.

Fig. 4 a) INTRA robot on full scale simulation session, b) INTRA contro panel during training session, c) The virtual simulator for INTRA with virtual images on the control screens generated by the calculation software developed by ITUCR.

Furthermore, for pedagogical purpose, ITUCR software provides additional views of the robot moving in the hostile environment (Fig. 5 a & b). This allows the trainer to have other arguments whilst explaining what is going on and helps the trainee to improve the feelings of what was done, making a relationship between what was viewed on screens and what can be seen from far.

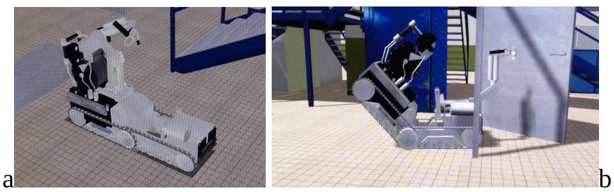

Fig. 5 a & b: Additional Robsim (ITUCR) views of the INTRA robot moving in hostile environment.

Figures 6a & b show the virtual simulator used in IRCAD: the video images on the control screens used by the pilot are virtual. Generated by the software developed by Intuitive Surgery, they reproduce the inside human body environment according to the anatomic laws. The trainee is thus sat in the real control panels, and all that concern the robotic device and cables are absent.

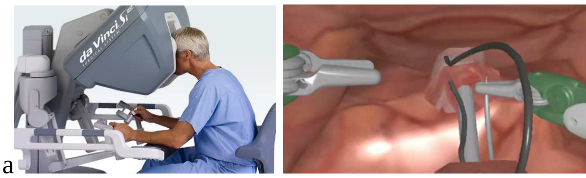

Fig. 6. The virtual simulator Da Vinci used in IRCAD and developed by Intuitive Surgery and a virtual simulation through Mimic software on 6b.

We shall consider trainees who know the job and who do not train on simulator for an initial training to learn the work activity as beginners. This choice is made in order to have comparable cases. This is necessary because while all INTRA pilots are concerned by an initial training on simulators, it is not the case of surgeons at IRCAD: they first learn their profession, practice, and then are concerned by the use of a robotic device.

For surgeons, observations have been done on simulation training sessions performed in IRCAD (Institute for research against cancer of the digestive apparatus, Strasbourg, France). We call here "simulation session" the training of surgery teams in the theatre where the human patient has been replaced by a pig (chosen for its close anatomical and physiological characteristics to human). The training session involved two surgery teams for mini-invasive digestive surgery, working on DA Vinci robot from the Intuitive Surgical company, currently the most used surgical robot worldwide. In this context, the surgeon works in specific conditions (see Fig. 2): the physician is sat in front of a control device (right hand side of the picture), the head is put on to the video box where he has a stereoscopic vision of the operative scene filmed by two cameras, his arms are sustained by a support for the hands to be involved in the manipulation of two rings per hand. Through these rings, the surgeon manipulates instruments introduced inside the patient's body and realizes the surgical operation.
Similar observations have been done with during simulation with virtual representation of the object of the work activity.

3-Results

The main result is interesting by the way it structures relationship between the work activity and the variales [organization, tools]. It claims that the object of the work activity is sizing most of the parameters and factors of the intervention because this object determines the endorisk or exorisk character or the activity. In fact, it is the classical finding that the work activity is organized to minimize the risks, taking of course into account cost and production objectives (Fig. 7). Other constraints may be added such as legal or technical constraints.

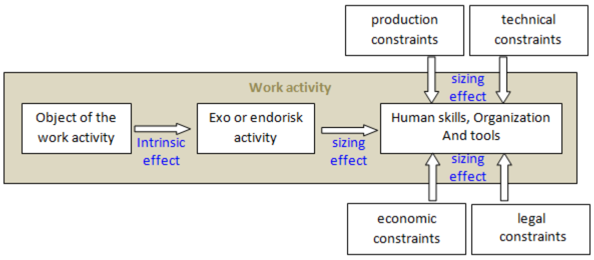

Fig. 7. The influence of the object of work activity in sizing organization and tools through the exo/endorisk characteristic.

In both cases (INTRA pilots and IRCAD surgeons), organization and tools contribute to minimize risks but produce nevertheless side-effect risks.
For example, INTRA pilots explain that the hostile character of the environment where they must intervene implies the robot device to be able to go far from them where no human being is expected to go (at least at the time they are called to be in the place). As the hostile environment is usually a damaged industrial plant (case of Fukushima nuclear accident in 2011 for example), a radio remote control is not possible as said above: the industrial plant are full of metal which interfere with radio waves, and nuclear plant have so thick walls that waves are stopped. Thus the robot unwinds cables whilst progressing in the environment which is usually damaged. The fact that the 350 meter-cable could be trapped somewhere and block the robot on the way back or damaged by anything falling down is what we call a side-effect risk. We could name it a consecutive risk.
At IRCAD, the mini robotic device is used to reduce pain and injuries of the patient. The robotic device does not progress within a large space: robotic tools are inside the patient's body, and their movements will be bounded within the space of the surgical intervention. Thus, the presence of cables or other robotic links is dealt with: everything is put in the right place at the beginning of the operation and then nothing is expected to move. If the surgeon loses the string used to sew the cut flesh, it may be difficult for him to recover it with the mini-invasive robotic device. After that, making a knot to stop the string is another difficulty for which he has to be trained in order to not injure the patient whilst handling the string. These are other examples of side-effect risks or consecutive risks. Nevertheless, the surgeon is close to the patient. S/He keeps in mind that any classical surgery remains available.
As we see, at INTRA, the intervener must care about the environment in the aim the keep safe the robot which will achieve the mission. At IRCAD, the surgeon must care about the environment in the aim to preserve it.
We shall discuss below the consequences in terms of stress for the intervener.

In both cases of robot piloting (INTRA pilots and IRCAD surgeons), interveners are concerned by:

- the same problem of piloting operation: movements are done according to cameras,
- minimizing risks implies simulation training,
- simulation facilities are partly based on virtual simulation and partly based on full scale simulation.

But an important difference concern the social support: while the INTRA pilot works with a co-pilot and a chief supervisor who can ask at any time the advice of colleagues who may help him concerning the choice to be done, on the contrary the surgeon is alone. In addition, most of the time, the surgeon's choice must be done at once, while the INTRA pilot has a minutes, sometimes hours to choose. It makes a huge difference in terms of decision making process.

4-Discussion

The sizing effect due to its exo or endorisk character has a direct influence on the intervener's state of stress. This appears clearly after observations and especially after interviews. Table I shows what we explain here after.

INTRA pilots explain that getting the robot to move forward is difficult: an obstacle or an unstable surface might knock over the robot or block the cable. In such configuration, the robot is immobilized and no other robot may be sent. Anyway, the best solution remains the one which will not involve human being in a local intervention. As a consequence, the pilot must do what is best to keep the robot operational and mobile. S/He cares about the objective of the mission and about the "life" of the robot. S/He keeps in mind that any mistake will abort the mission. "No more robot, no more mission" for the pilot. After such an issue, other people will take charge of the problem and have to enter the area while her/his objective is to avoid exactly that.
In the case of INTRA pilot, reaching the goal of the work activity is directly linked to the robot.

IRCAD surgeons explain that the main objective is to reduce pain and injuries of the patient. The robotic device is used in this aim, but any failure using this technique does not keep away from the possibility to come back to the classical surgery, a relatively easy shift as the patient is close to the surgeon with all the facilities available to do so. The "No more robot, no more mission" for the surgeon does not apply here.
In the case of IRCAD surgeons, reaching the goal of the work activity is not directly linked to the robotic device since the surgeon can change from the mini-invasive technique to the classical surgery.

From the psychological standpoint, the "No more robot, no more mission" implies consequences on the intervener's self-esteem. A mission success is more probable for the surgeon, or should we write a mission failure has a higher probability to occur for the INTRA pilot. As the pilot knows it, it is important for him/her to be self-confident enough in order to have a good but yet realistic self-perception of his/her skills and competence. This self-perception is directly link with the self-esteem as it contributes to foster it (see for example: Sainsaulieu, 1997; Lieury & Feunouillet, 1996).

Table I. Implications of the risk characteristic on the mission issue: each line induces the following.

	INTRA robot pilots	IRCAD surgeons
Risk characteristic	*Endorisk: hostile character of the environment*	*Exorisk: Reduce pain and injuries of patient*
Tool sizing	*Robotic device going far from the intervener*	*Mini robotic device close to the intervener*
One potential consequence	*If robot is lost, no human will go to deal with or do the job, or if so, with high health risks*	*In case of robot failure, human (surgeon, usually the intervener themself) will go to deal with or do the job*
Effect on the intervener	*A mistake may lose the robot and stop the intervener's contribution*	*A mistake may lose the patient, but if any robot failure, the intervener will cope with classic surgery*
Link robot-mission issue	*No more robot => no more mission*	*No more robot => alternative: classical surgery*

In this context, the virtual simulation is a necessity both from economic as from pedagogical standpoint. Both situations are high risk socio-technical system as defines elsewhere (De la Garza & Fadier, 2007; Fauquet-Alekhine, 2012a). As for any of such systems, INTRA robot pilots and IRCAD surgeons take advantage of virtual simulations because it avoids damaging robots or pigs resp. (which cost money and animal lives) and permits a broader diversity of training cases with a possibility of replay or a possibility to see what cannot be seen if not virtually simulated. This is well illustrated by the Robsim additional views on Fig. 5 which cannot be so easily available on full scale simulator.

As shown is previous works (Fauquet-Alekhine et al., 2011 & 2012), simulation training is expected to reduce the interveners' stress level. We showed how this reducing process could help the subject to work in the appropriate Human Functional States (Leonova, 2009; Fauquet-Alekhine, 2012b) with regards to the Yerkes & Dodson theory concerning performance versus stress (Yerkes & Dodson, 1908).
The variables potentially inducing stress are similar for a few of them and different or opposed for others. Table II exposes a list of the main variables producing increase of intervener's stress.

Simulation training appears then as an appropriate solution to reduce these stressful exogenous parameters (meaning that these parameters are due to external sources as defined by Fauquet-Alekhine, 2012b).
Especially virtual simulation gives the opportunity to build an environment as close as possible to the expected one. Even in case of damaged industrial plant, assumptions done about damages may help to elaborate the most probable environment for improving the intervener's knowledge which is possible with Robsim developed by ITUCR: computer simulator can be used to evaluate the feasibility of some operations; for example, by the virtual model of environment where accident happened can be checked the route for the robot and feasibility of technological operations. The same for surgeons in case of tumor: it can be added to the known anatomical environment the induced special disturbance within the virtual simulation. The surgeon is thus trained as closely as possible to the reality.

Table II. Main variables concerning intervener's stress.

	INTRA robot pilots	IRCAD surgeons
Shared stressful parameters	o *time pressure* o *cost pressure* o *safety / physical risks for others* o *physical discomfort due to the premises or position or noise or ambient temperature*	
Different stressful parameters	• *Risk of destruction of material by falling in holes or buildings falling* • *unknown environment => self-perception of skills & competence* • *unknown environment => high probability of unpredicable facts => self-perception of skills & competence* • *the weakness of the simulation training, not so close to non-simulated situation* • *a disturbed (not flat) environment source of obstacles which could block the robot; thus, a significant probability to lose the robot* • *possible loss of metrology, especially video* • *noisy, bad visibility environment* • *a unusual practice : the real situation happens very few times (*)*	• *Risk of patient death* • *Partly unknown environment* • *Alone for decision making* • *Very fast kinetic of phenomena* • *sometimes difficulties to watch with time if glasses needed (effect of sudation and tiredness)*

(*) *Since its creation, INTRA was never asked for an emergency in nuclear hostile environment due to an industrial accident. The few interventions concerned maintenance problems and where operated in order to reduce or avoid the radioactive exposure of workers.*

Thus, virtual simulation training reduces the intervener's lack of knowledge concerning the environment. By reducing the stressful intensity of this variable, the fear to lose the robot (INTRA) or to injure the patient (IRCAD) is reduced. It means that we obtain a consecutive decrease of another stressful variable. Thus, the intervener's internal resource becomes available to manage the other stressful variables and we obtain a global improvement of the intervener's Human functional State.

5-Conclusion

The present study has emphasized what are key points of the work activity in terms of pilot's skills and the comparative study has helped to highlight why these are keys points.

This might help the trainers to enforce some specific points and help other professions or some recently implicated by this problem to conceive an adapted training according to their kind of robotized work activities.

Additional interviews are planned to investigate the effect of the distance between the control facilities and the robotic devices: for example, do two meters give the same stress to the surgeon than 2000 km in case of tele-operating?

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