

Ethical Reflections on Health Care Robotics

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Abstract. The rapid developments of robotics technologies in the last twenty years of the XX century have greatly encouraged research on the use of robots for surgery, diagnosis, rehabilitation, prosthetics, and assistance to disabled and elderly people. This chapter provides an overview of robotic technologies and systems for health care, focussing on various ethical problems that these technologies give rise to. These problems notably concern the protection of human physical and mental integrity, autonomy, responsibility, and fair access to medical resources.

Keywords. medical robotics, ethics, fundamental rights, autonomy, responsibility, physical integrity.

Introduction

The rapid developments of robotics technologies in the last twenty years of the XX century have greatly encouraged research on the use of robots for surgery, diagnosis, rehabilitation, prosthetics, and assistance to disabled and elderly people. Research on surgical robotics aims at reducing the invasiveness of interventions, while ensuring high levels of accuracy (possibly extending beyond the capabilities of human surgeons). Research in health care robotics is additionally focusing on the development of diagnostic robots, which explore hard-to-access parts of the human body, thus reducing the invasiveness of diagnostic interventions and contributing to alleviate the physical and psychological discomfort of patients. Robotic systems are used for rehabilitation too, in order to cope with the growing demand of human and financial resources needed for rehabilitation, to introduce more efficient therapeutic protocols, and to reduce the fatigue of therapists. The aging of world population is requiring the allocation of ever increasing human and financial resources to home and hospital assistance of elderly people. Robotics research may contribute to cope with this challenge through the development of robots able to assist or even replace humans in performing repetitive and well-structured assistance tasks. Innovative prostheses used to restore lost sensory-motor capabilities through brain-computer interfaces may also greatly improve the quality of life of amputees or injured people. Health care robotics contributes to create new therapeutic opportunities in these various branches of medicine by developing devices provided with sensory, motor, and information

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processing capabilities which, in many applications, extend the perceptual, cognitive, and motor abilities of doctors and therapists.

Health care robotics is a multidisciplinary research field at the crossroads of robotics, medicine, and computer science. The design, development, and evaluation of medical robots gives rise to challenging scientific and technological problems. And challenging ethical issues arise too, notably concerning autonomy, responsibility, distributive justice, physical and mental integrity, personality change and even personal identity persistence issues. These issues will be selectively discussed here in connection with technologies and systems in the fields of robotics for surgery, diagnosis, rehabilitation, prosthetics, and personal assistance. A brief overview of these technologies is provided in section 1. The contribution that these technologies and systems afford in the way of promoting and protecting human rights to health care and physical integrity are discussed in section 2. Section 3 focuses on ethical issues of autonomy and responsibility connected to the limited capability of human designers and users to predict machine behaviours. Personal identity and personality issues emerging in connection with various kinds of human-robot interaction modalities are analyzed in section 4.

1. A brief overview of medical robotics

1.1. Surgery

Robotic systems can be used in various ways to support humans in surgical interventions (Jacob et al., 2003; Taylor et al., 2008).

First, robots provide different sorts of external support to surgeons, by performing tasks that are normally assigned to human assistants. The AESOP system (the first robot to be approved, in 1994, by the US Food and Drug Administration), which was able to move an endoscope inside the patient's body under vocal control, is a significant case in point. Systems of this kind are additionally used to perform 3D reconstruction of internal organs (see section 1.2 below). Broadband connection technologies pave the way to the development of "robotic consultants" too. A feasible possibility is to provide a tele-operated robotic system with a camera and communication devices, enabling a distant surgeon to interact with (e. g., to give advice to) surgeons in the operating room. RemotePresence-7, developed by InTouch Health, is a case in point (Agarwal et al., 2007).

Second, robotic systems may take more directly part into surgical interventions. For example, one may assign robots the task of manipulating heavy instruments (such as drills and mills for orthopaedic surgery). Several robots able to perform crucial stages of surgical interventions in a semi-autonomous fashion have been developed and used in hospitals. Consider the following scenario. First, the robot carries out a detailed 2D or 3D analysis of target and surrounding organs. This operation can be cooperatively carried out by robot and human surgeon: the latter can specify task requirements for the robot, e. g., by delimiting the area of interest on a monitor showing endoscope images, and pointing to regions to be kept intact. On the basis of this cooperative pre-operative analysis, the system plans and eventually executes the actions that are needed to carry out the intervention, while the surgeon monitors and possibly stops the process in order to change some of the robot parameters. A

procedure of this kind is used to interact with the PROBOT system, a robot specialized in prostate removal interventions developed at the Imperial College in London (Harris et al., 1997).

Third, there are systems like Zeus (Computer Motion) and da Vinci (commercialized by Intuitive Surgical) which are general-purpose, semi-autonomous surgical robots, unlike PROBOT and orthopaedic surgical robots, which have been specifically designed to perform special sorts of interventions. These general-purpose systems are provided with robotic arms, are tele-operated by a distal surgeon, and are equipped with various instruments (such as endoscopes, pincers, scissors). The human operator can control robot movements and observe endoscopic images from a console. The system CyberKnife (developed by Accuray) is able to carry out radio-surgical non-invasive interventions: similarly to da Vinci, it is provided with robotic arms which move in the vicinity of (but externally to) the patient's skin, and irradiate cancerous cells with high precision (Adler et al., 1997).

Finally, at the current frontiers of research in the field of surgical robotics is nano-robotics, which aims at building extremely small robots able to operate at molecular levels. The idea is to build so-called 'molecular machines', that is, molecular structures whose motion is to be controlled on the basis of their electrical and chemical properties. Robots of this kind might be deployed to reconstruct damaged tissues or to identify and destroy cancerous cells. It is often claimed that research in the field of nano-robotics will grow and develop extensively in the course of the 21st century (Drexler, 2004).

1.2. Diagnosis

Robots are being used to carry out both invasive and non-invasive diagnostic tasks. External diagnosis systems typically consist of robotic arms able to move probes in the vicinity of the skin or in direct contact with it. Ecographic robotic systems are a case in point. The doctor drives their movements by means of a joystick which, in some cases, provides some kind of force feedback from the patient's body (Courreges et al., 2008; Martinelli et al., 2007). Control of robot movements can also be shared with computational support decision systems which take into account background knowledge about the patient, and data acquired on-line in the course of the diagnostic process.

More invasive diagnostic robots are, for example, the robotic endoscopes included in the ZEUS and da Vinci systems, which are able to move probes inside the patient's body (Horgan et al., 2001). Research is currently focusing on the development of internal diagnostic robots endowed with locomotion abilities. Various solutions are being developed and tested. One can endow the probe with small wheels adhering to an organ internal surface. Alternatively, one can exploit insect-like solutions to locomotion problems: for example, forward motion through the colon or other sections of the intestine may be achieved by rhythmical compression and expansion of pneumatic rings, imitating locomotion in worms. Prototypes of colonoscopy systems based on this approach are being developed at CRIM, Micro-Engineering Research Center of Scuola Superiore Sant'Anna, in Pisa (Quirini et al., 2008). Major scientific and technological challenges that have to be addressed for the purpose of developing these systems include the design of miniaturized energy sources and wireless communication devices.

1.3.Rehabilitation

Patients affected by central or peripheral nervous system injuries (caused, for example, by strokes or spinal lesions) can suffer from severe limitations in the control of their own movements. Lost functionalities are sometimes recovered in various degrees by the activation of plastic adaptation mechanisms in central or peripheral nervous systems. These mechanisms gradually bring about long-term changes in the physiological properties of neurons and their connectivity. One attempts to trigger plastic adaptation mechanisms in the nervous system by performing distinctive motor exercises, in which the therapist moves repetitively an injured limb or asks the patient to perform movements by exploiting his/her residual motor control capacities.

Robotic systems supporting humans in performing this sort of therapy (Van der Loos and Reinkensmeyer, 2008) for upper and lower limb rehabilitation are extensively used in hospitals nowadays. Upper limb rehabilitation robots typically consist of arms provided with many degrees of freedom, whose endpoint is held by, or linked to, the patient's arm or hand. The position of the endpoint is often represented graphically on a computer screen. The MANUS system, developed at MIT, is a pioneering example of robotic systems developed in this field. These systems replace human therapists or support them in collaborative tasks. As in traditional rehabilitation therapies delivered by human personnel, the robot can either take full control of the patient's arm movements or else help the patient to perform motor exercises by using his/her residual capacities. These exercises typically consist in positioning tasks, whereby the tip of the robotic arm is moved towards some target point in space, represented on the monitor too. In collaborative exercises, the robot constrains user movements in various ways, e.g., by preventing deviations from desired trajectories, and by helping users initiate required movements.

Lower limb rehabilitation devices (such as the Lokomat system, produced in Switzerland by Hocoma and widely used in hospitals) typically consist of exoskeletons which harness joint leg movements. The role of these robots is to force subjects to assume 'correct' positions and gaits; collaborative human-robot interaction modalities may be adopted in this case as well (Jezernik et al., 2003).

It is worth mentioning that robotic systems are being used in cognitive rehabilitation therapies too, often delivered to autistic subjects. Cognitive rehabilitation robotic systems take on animal shapes (such as the seal robot Paro, developed at the National Institute of Advanced Industrial Science and Technology in Tokyo) or humanoid shapes (such as the F.A.C.E. system, developed at the Centro di Ricerca E. Piaggio, University of Pisa). These systems, provided with simple and intuitive communication interfaces, and often based on the simulation of facial expressions, are meant to stimulate the development of interaction and communication capabilities in their users (Wada et al., 2005; Pioggia et al., 2004).

1.4.Interfacing the nervous system for recovering sensory-motor capacities

Brain-Computer Interfaces (BCIs) enable one to connect human central nervous systems with computers and robotic devices (Lebedev & Nicolelis, 2006). So-called input BCIs are used to deliver signals from external devices to the brain; output interfaces enable one to acquire and process brain signals, which are then used to control external devices. Research in the field of brain-computer interfaces (BCIs) is

primarily motivated by the purpose of recovering lost motor functionalities in subjects affected by spinal lesions, amyotrophic lateral sclerosis, and other pathologies which may prevent the patient from executing any voluntary movement (“locked-in” subjects). These systems, which may be connected to robotic manipulators, wheelchairs, and word-processing systems, are able to classify user intentions (e. g., the intention to issue a grasp action, to choose a direction for a wheelchair, to select a key on a keyboard) on the basis of the analysis of neural activity. The system then plans and executes actions based on this analysis, in order to fulfil user goals.

A fundamental issue related to BCI design concerns the choice of the neural properties to be recorded and analyzed. The first generation of BCI systems relies on electrical signal analysis, in view of efficiency, cost, and signal interpretability motivations. Other crucial issues concern the degree of interface invasiveness. The electrodes enabling one to detect electrical signals can be non-invasively positioned on the scalp (as in EEG systems), under the scalp but externally to the cerebral cortex (as in electrocorticography apparatuses), or even inserted deep inside brain tissues. In a pioneering study, a locked-in patient was enabled to control domestic devices, interact with a word-processor, and drive movements of a robotic arm by means of a BCI involving electrodes implanted in the motor cortex (Hochberg et al., 2006). Invasive BCI technologies are largely based on studies performed on monkeys (Velliste et al., 2008). Non-invasive BCIs based on EEGs are suitable, in view of their non-invasive character and broad cost-benefit considerations, for wider classes of potential users.

Interaction with a BCI system requires various information processing steps. First, neural signals are acquired, amplified, and digitalized. Second, the system is trained (by means of some learning algorithm) to identify patterns in the digitalized signal, which are then associated to high-level commands for the external device. Third, these high-level commands are then executed, possibly after some planning step. Finally, the user estimates the behavior of the system on the basis of (visual, auditory, or tactile) feedback signals.

There are prosthetic applications based on invasive and non-invasive interfaces with the *peripheral* nervous system. An often adopted, non-invasive approach involves detecting the activation level of muscles through electrodes positioned on the skin (electromyography). This solution, adopted in the non-invasive hand prosthesis OttoBock, may enable users to control the movement of external devices by activating some intact muscles. Various kinds of invasive interfaces with the peripheral nervous system are realized by inserting subcutaneous electrodes in the vicinity of or in direct contact with nerves.

Invasive and non-invasive interfaces may enable one to develop input interfaces. In the non-invasive case, signals acquired by sensors located on the prosthetic device deliver mechanical stimulations on the skin of the subject, thus determining tactile perceptions corresponding to the activity of the device. Invasive interfaces allow one to deliver electrical stimulations, possibly coding signals from robotic sensory apparatuses, directly on the nerves of human subjects (Warwick, 2003).

1.5. Personal assistance

One of the major research trends in robotics concerns the development of semi-autonomous systems assisting disabled and elderly people in object manipulation and locomotion. Manipulation systems typically consist of robotic arms installed on desks: the Giving-A-Hand system, developed at Scuola Superiore Sant’Anna for the purpose

of feeding users impaired in their upper limb functionalities, is a case in point. Other systems, such as the already mentioned MANUS robot, are designed to be mounted on wheelchairs (Johnson et al., 2006). The MOVAID system (also developed at Scuola Superiore Sant'Anna) was instead able to move autonomously in domestic environments, and to carry out house cleaning and personal nutrition tasks (Dario et al., 2001).

Artificial intelligence technologies have been deployed in order to design semi-autonomous wheelchairs and locomotion support systems. NavChair (developed at the University of Michigan) is a wheelchair moving autonomously in planar environments, capable of following walls and avoiding obstacles. Some other systems (such as the PAM-AID, developed at Trinity College, Dublin) are more properly regarded as providing support to locomotion: passively pushed around by their users, these systems actively avoid unpredicted obstacles.

2. Promotion and protection of health care rights

A general framework for the identification and analysis of ethical issues in various areas of applied ethics is provided by national and international charters and treaties concerning the promotion and protection of fundamental rights. These documents often include sections and articles specifically concerning healthcare and medicine. Notably, Article 35 of the Charter of Fundamental Rights of the European Union states: "Everyone has the right of access to preventive health care and the right to benefit from medical treatment under the conditions established by national laws and practices. A high level of human health protection shall be ensured in the definition and implementation of all Union policies and activities". As the survey of robotic systems made in the previous section suggests, robotics can contribute to protect human health and to promote everyone's right to receive medical assistance in various ways. Notably, robots contribute to overcome limitations in the sensory-motor capabilities of human doctors; robots perform some surgery and rehabilitation tasks faster and with greater precision than human operators; properly used health care robots may alleviate both post-surgery pain in patients and the fatigue of health care personnel.

As discussed in section 1.2, semi-autonomous robotic systems can dispense doctors from performing *diagnoses* which involve repetitive, uncomfortable, and physically demanding movements. Moreover, these systems – and especially those including self-locomotion mechanisms – may perform minimally invasive diagnoses, more easily coping with the physical structure and arrangement of internal organs.

Rehabilitation therapies are physically demanding for human operators, insofar as these are delivered by performing (or monitoring) repetitive movements for a long time, and require high levels of attention and precision. Considerable efforts are often needed to control the patient's movements (especially in lower-limb therapies). Fatigue associated with rehabilitation tasks may result in errors by human operators and decreased efficiency of the overall process. For these reasons, robots supporting or even replacing human operators in rehabilitation tasks may support in useful ways the protection and promotion of health care rights.

Replacing humans with robots in *personal assistance* tasks is one of the more prominent goals of medical robotics. In addition to promoting the right to health care, these robotic systems may bring about novel ways of protecting the dignity of both

patients and their human assistants, by taking on unpleasant tasks (e.g., house cleaning), and allowing disabled or elderly people to perform basic everyday tasks (e. g., cooking, eating or self-cleaning tasks) without having to rely on human assistance. Robotic technologies may have a significant impact in preserving healthcare rights of disabled and elderly people in the near future: due to demographic growth and the ageing of world population, the need for rehabilitation therapies and personal assistance is increasing very rapidly.

It was pointed out that robotics may contribute to developing semi-autonomous, sensorized upper-limb and lower-limb *prostheses*, enabling one to restore sensory-motor functionalities in severely disabled patients. It is worth noting that non-robotic prosthetic systems developed in the second half of the XX century were typically endowed with a very limited number of degrees of freedom, which the user had to control one by one in non-intuitive ways. In contrast with this, present-day robotic technologies may enable one to control more versatile prosthetic devices through high-level commands: users issue simple commands (e. g., positioning the end-effector in the environment) while the system plans and performs every low-level action which is needed to fulfil high-level specifications. Moreover, direct integration with the nervous system may enable users to feel the robotic device as part of their own body, rather than as an external device. Plastic mechanisms play a crucial role in the integration of a prosthesis within the subject's neural representation of sensory and motor apparatuses: as shown in several experimental studies, the nervous system (especially when some feedback from the device is available) can gradually adapt to a robotic prosthesis, thus improving the efficiency of the control task.

As discussed in section 1.1, robots may be used to assist human operators in *surgical interventions*. An example is the aforementioned AESOP voice-controlled robotic assistant, used to move the endoscope inside the patient's body. The use of robotic assistants may allow one to reduce both units of personnel and costs involved in surgical interventions. Thus, in principle, reduced costs and units of personnel can be made available to widen the scope of medical services. Moreover, as already mentioned, robotic systems can help surgeons by handling heavy or uncomfortable instruments.

It is worth noting that robots may be particularly useful in connection with Minimally Invasive Technologies (MITs) for surgery. MITs aim at reducing the invasiveness of surgical interventions (and the associated pain and post-operative recovery time) by means of miniaturized instruments and endoscopes, which are introduced inside the patient's body through small incisions. Widely used since the last decades of the XX century, MITs raise, at the same time, great expectations and novel problems to solve. First, miniaturization has reduced the functionality of surgical instruments. Second, natural hand tremor is propagated, and even amplified, by the control mechanisms of MIT instruments. Tremor may decrease the stability of images returned by the endoscope and increase the probability of errors. Moreover, MIT tools are often unnatural to control. Many MIT instruments are indeed moved through long and thin tubes, whose pivot is located at the incision point: consequently, the direction of movement of the tool endpoint is opposite with respect to the direction of movement of the surgeon's hand. Robotics can help overcome these difficulties. Indeed,

- Systems like the da Vinci include instruments provided with a high number of degrees of freedom, which are often far more dexterous than standard MIT tools.

- Robotic MIT tools are electronically controlled. The control system can filter out natural hand tremors, thus obtaining fluid and precise movements. Moreover, the correspondence between the surgeon's hand and the tool endpoint movements can be restored by control algorithms. In addition to this, the surgeon can vary the ratio between joystick and tool movements: if high-level precision is needed, for example, one configures the system so that wide movements of the joystick correspond to very small movements of the tool.

It is often claimed that research on tele-operation technologies may contribute in significant ways to preserve everyone's right to receive medical assistance even in hostile environments and hospitals located in countries affected by a shortage of specialized personnel. Indeed, tele-operated robotic technologies can be used in connection with diagnosis, rehabilitation, surgery, and personal assistance tasks. The availability of a broadband (possibly wireless) connection virtually enables remote surgeons to control robotic systems positioned in distant surgery rooms. This possibility was concretely tested in 2001, when a surgeon situated in New York performed a cholecistectomy on a patient located in Strasbourg, by means of a tele-operated ZEUS robot. As discussed in (Martinelli et al., 2007), robotic diagnostic systems might be remotely controlled by a distal doctor too. However, a balanced evaluation of the advantages deriving from the use of robotic technologies in surgery requires one to take into proper account costs related to the installation and technical monitoring of medical robots. These costs may be extremely high, especially in connection with tele-operation: the transatlantic cholecistectomy carried out in 2001 has been estimated to be the most expensive intervention of this kind ever carried out, insofar as it required "\$1.5 million in equipment, 80 people to monitor the integrity of the equipment and signal, and \$150 million in research and development by France Telecom spent over the preceding 2.5 years achieving the remarkable telecommunication speed" (Marohn & Hanly, 2004). Briefly, the development of tele-operated robots may indeed contribute to reducing the personnel needed for surgical interventions; however, one should be careful to note that – in addition to costs related to the setting-up and performing of tele-operated interventions – one has to deploy in loco personnel devoted to the monitoring and maintenance of the robotic system. These considerations should be properly taken into account in order to evaluate whether (and if so, under which conditions) remote-controlled robotic surgery affords the promotion of fair access to medical care, especially in developing countries. Similar claims concerning the purported benefits flowing from the use of tele-operated robotic technologies are often made without providing a detailed argument with respect to the costs involved in deploying surgery robots and supporting the technological infrastructure required for their maintenance. If these costs become prohibitive for developing countries, then (tele-operated) surgery robots will be confined to the more affluent countries, and used there for the medical treatment of the more affluent segments of population only.

Of special interest, in connection with a cost-benefit analysis of medical robotics technologies, is the selection of criteria according to which performances and usefulness of medical robots are evaluated. The ROBODOC system is a case in point, analyzed in some detail in (Weber, 2008). ROBODOC (Integrated Surgical Systems,

Davis, CA) is an upgraded industrial robot that performs hip and knee replacement (Diodato et al., 2004). It was widely used in Germany and other European countries, whereas the Food and Drug Administration (FDA) did not approve this system for use in the U.S, pending an evaluation of long-term clinical trials. According to some evaluations of ROBODOC performances, the system failed on several accounts to fulfil the promise of surgery robots in the way of greater efficiency, precision, faster recovery, and other expected benefits for patients undergoing orthopaedic surgery (Bargar et al., 1998). In particular, ROBODOC compared unfavourably with conventional operations in the way of operation duration, blood loss, and post-surgery hospital stay. According to Grund (2004, as cited in Weber, 2008), ROBODOC operations, unlike conventional operations, affected the musculus gluteus medius in ways that may compromise hip stability and induce permanent limping.

ROBODOC is an interesting case-study for ethical reflections on medical robotics, showing that a wide variety of factors must be taken into account in the cost-benefit evaluation of medical robots, accuracy being only one of them. It is worth noting that in January 2007 a patient won the first law suit against an orthopaedic clinic in Germany, receiving a 30.000 Euro compensation, on account of the fact that insufficient information about relative advantages and disadvantages of ROBODOC surgery were supplied to the patient before the intervention took place. (Weber, 2008, p. 71)

3. Autonomy of health care personnel and patients

Various theoretical and practical factors set limitations to the capability of predicting precisely the actual behaviour of robotic systems. In general, this epistemic predicament affects users, designers, and manufacturers of robotic systems alike. For an epistemological analysis concerning the limited predictability of robotic systems and its import on robot ethics in general, the interested reader is referred to the chapter by G. Tamburrini in this volume. In the more specialized context of health care robotics, various aspects of this epistemic problem are aptly illustrated by reference to both tele-operated surgical robots and BCI systems.

Predictive limitations concerning tele-operated systems such as the da Vinci include the following.

- Learning algorithms are used in the voice-controlled systems that the da Vinci system is equipped with. These learning algorithms are used to teach the system to recognize characteristic features of the human surgeon's voice. The system may occasionally fail to perform correctly this recognition task on account of imperfect and hardly predictable training outcomes or else on account of untypical vocal items (see the chapter by G. Tamburrini in this volume for a more general discussion of predictability issues connected to learning algorithms).
- One can hardly achieve efficient tele-operation without some sort of sensory feedback acquired by sensors located on the robot. These sensors may be used to gather data about the organs involved in the surgical intervention; for example, one evaluates the stiffness of internal tissues by varying the stiffness

of the joystick used to manipulate surgical instruments (technologies for recognizing objects through touch are often called haptic perception technologies). If no such system is available, as in most tele-operated surgical robots, then the surgeon must rely on visual information only in order to estimate dynamic features of relevant organs.

- The use of robotic surgery systems often affects negatively communication between members of the medical staff. Da Vinci users are completely immersed in the command console, and typically cannot monitor the robot from the outside. Moreover, the shape and dimensions of the robot make it difficult for staff components to operate in the vicinity of patients.

The distance at which tele-operation is feasible is upper-bounded. This bound depends on the latency related to signal transduction speed and the efficiency of algorithms used to preserve the quality of signals along transmission lines. In particular, latency, which is proportional to distance between user and robot, may decrease system reactivity, and make human-robot interaction unnatural for the user.

BCI brain-to-computer communication protocols require an act of *delegation*, whereby human users transfer partial control of peripheral devices to a computational system. More specifically, the human user delegates both the identification of a high-level action intent and the control of its detailed execution to a computational system. Patients affected by severe motor disabilities trade-off this transfer of partial control for a restored procedural capability to act on their own desires. However, the promotion of autonomy afforded by BCI systems should be carefully evaluated in the light of possible subordination effects which, in general, “will probably become an increasingly serious problem as enabling technology is developed that exhibits more and more intelligent behavior” (Hansson, 2007, p. 264).

To an external observer, the operation of an output BCI provides evidence, if any, that its human user is endorsing the decision to share action control with a machine. However, by appeal to various possible sources of user intent misclassification, one may still question the conclusion that the observed machine behaviour does coincide with the action reflectively endorsed by its human user. These sources notably include temporally occurring changes in neural correlates of user intents and inadequate training of the BCI neural signal classification module (Tamburrini, 2009). One may appeal to the epistemic uncertainty affecting BCI classifications of user intents in order to question the binding value of BCI-enabled statements. After all, a misclassification of neural signals which convey a few bits of information may utterly change the meaning of sentences composed by means of a BCI-operated virtual keyboard. Thus, the right to exercise autonomous action by those who are affected by severe motor disabilities appears to be insufficiently protected by current BCI communication protocols, at least insofar as internet transactions, informed consent, and last will statements are concerned.

In concluding this section, let us notice that the distributed character of action control in many of the human-robot cooperative tasks mentioned in section 2 raises responsibility attribution problems concerning robotic engineers, manufacturers, health care personnel, and users of health care systems. In particular, extant limitations in our ability to predict exactly the behaviour of robotic systems require careful collection of evidence about damaging events involving health care robots for the purpose of

distinguishing between liability and moral responsibility issues. This problem should be carefully attended to throughout design, implementation, testing, and operational stages. For example, the design decision of including a “black box” recording device, enabling one to reconstruct human-robot interactions in cooperative surgery interventions, would make available a valuable source of information about the consistency of robotic actions with the intentions of human surgeons, and a valuable source of evidence for the proper allocation of responsibilities, liabilities, and fair compensations.

4. Protecting personality and personal identity persistence

Clearly, robotic prostheses enabling one to recover lost motor functionalities may contribute in significant ways to preserve the continuity of one’s own personality and perception of oneself, insofar as motor functionalities play a crucial role in shaping an individual’s interaction space with animate and inanimate entities in the environment. This continuity may be relevant even to preserve personal identity, insofar as identity persistence requires some kind of continuity in the narratives one makes about one’s own capabilities and interactions (Merkel, 2007).

A more crucial role in the way of protecting personal identity persistence is possibly afforded by output BCI systems for communication and action. This role is suggested by a recent finding concerning a group of patients affected by amyotrophic lateral syndrome (ALS), who were trained to communicate by means of a non-invasive BCI. Patients in this group who were trained after entering a complete locked-in state (CLIS) due to the progression of ALS were unable to acquire stable communication abilities (Birbaumer, 2006, p. 524). Two competing explanations have been advanced for this observation. According to the first explanation, the onset of CLIS is accompanied by a generalized decline of perception and thinking abilities, which jointly prevent CLIS patients from learning to use a BCI. According to the second explanation, the development and preservation of purposive thinking crucially involves a verification and reinforcement stage, concerning the intended consequences of actions. In a CLIS subject, the required reinforcement stage is hardly ever accessed, insofar as the chain thought-action-consequence-verification-reinforcement is altogether interrupted or else only occasionally completed by caretakers who happen to fulfil the patient’s current desire. Therefore, thinking is no longer sustained, and the related ability to learn and operate a BCI fades away in CLIS patients.

If the first explanation is correct, then the learning of BCI communication skills does not prevent one from suffering a generalized decline of perception, thinking, and attention abilities. If, however, the second explanation is correct, then learning how to use a BCI before the onset of CLIS due to the progression of ALS may prevent the extinction of thinking, insofar as the chain thought-action-consequence-verification-reinforcement is preserved through BCI operation. Accordingly, one should teach BCI operation to ALS patients before they enter a CLIS, in order to preserve their thinking abilities and ultimately to preserve their status of persons, to the extent that goal-oriented thinking is a central feature of a person. This conditional conclusion provides distinctive ethical motivations for pursuing scientific research on the empirical hypotheses from which the second explanation is inferred.

5. Concluding remarks

Current research on health care robotics gives rise to ethical issues concerning the promotion and protection of the right to physical integrity, autonomy and responsibility ascription problems for those robot actions that are jointly controlled by human being and semi-autonomous information processing systems, in addition to persistence of personal identity issues in patients connected to robotic devices through a brain-computer interface.

Health care robotic systems open up new perspectives in the way of promoting the right to physical integrity: robots may contribute to overcome limitations in the sensory-motor capabilities of human doctors; they may perform some surgery and rehabilitation tasks faster and with greater precision than human operators; properly used robots may alleviate both post-surgery pain in patients and the fatigue of health care personnel. Moreover, BCI technologies may play a significant role in contrasting extinction of thinking abilities in completely locked-in patients, thereby contributing to preserving their status as persons. Special informed consent issues arise when human beings and semi-autonomous information processing systems share control of the (surgical, rehabilitation, or diagnostic) robotic intervention. The high costs of tele-operation technologies for surgery, rehabilitation, personal assistance and diagnosis tasks may lead to digital divide problems and unfair access to health care technologies. Assistive and BCI (prosthetic) robotic systems may contribute to preserve personal autonomy, insofar as they allow disabled and elderly people to perform tasks that would have been prevented by their sensory and motor limitations; however, users' autonomy may get compromised in some cases, due to robotic behaviours that come unexpected in the light of present limitations in our ability to predict and control robots. A reflection on these issues, which have been examined here with reference to a brief overview of current health care robotic technologies and systems, is required for promoting the development of robotic health care systems fulfilling ethically motivated goals and constraints.

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