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15 Ambient Intelligence for Rehabilitation

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Abstract. According to the World Health Organization disability is a being condition in which people is temporarily or definitively unable to perform an activity in the correct manner and/or at a level generally considered 'normal' for the human being.
Following this vision, a critical reason for developing AmI assistive tools lies in their potential to compensate or expand the activity of a disabled subject through new forms of human-computer interaction.
In particular, AmI may offer new and more effective environmentally oriented interventions, adapt the complexity of a tool according to the characteristics of the user, or support the use of other assistive devices.
To clearly evaluate the potential of AmI for rehabilitation, the chapter also describes a possible scenario of for its use. The focus of our analysis will be *Anna*, a fictitious patient with a particular form of cognitive impairment: topographical amnesia.

Contents

15.1 Introduction

According to the Disability and Rehabilitation Team at the World Health Organizzation (WHO) the estimated number of people who require rehabilitation services is continuously increasing (1.5% of the entire world population) [1]. Unfortunately, the available solutions do not fully match their needs.

The limited availability of resources pushed the health care providers to focus on the "disease" aspect of disability. This disease-oriented approach considers disabled subjects as dependent in everyday life situations, rather than persons with a great potential for independent living. To overcome this vision, innovative rehabilitative approaches have to consider disabled people as potentially "new actors" of their everyday life, supporting them in achieving independence and satisfaction. However, the involvement in the community life requires accessibility: the possibility to participate in the physical and social aspect of life.

Accessibility doesn't mean only physical affordability, but involves the complete range of activities in which the subject is involved during his daily interaction. The everyday environment is full of social and cultural barriers for people with interaction difficulties.

Further the availability of information is usually limited for people with visual, hearing or cognitive impairments.

The evolution of technology may help in improving accessibility. A wide range of assistive tools has been developed to compensate for human functional limitations and to provide users with relative independency. However, the concurrent evolution and diffusion of technological tools in everyday life had a negative effect on the autonomy of disabled subjects. The complexity of these tools produced a wide "digital divide" between disabled people and the rest of population.

This invisible barrier suggests the introduction of alternative technological scenarios in which the user, especially if disabled, is at the centre of the technology focus. In particular, computers have to move in the background and intelligent, ambient interfaces to the foreground.

A possible answer to this need is the emergence of a new paradigm: *Ambient Intelligence* (AmI). AmI refers to a specific vision of the Information Society Technologies Advisory Group (ISTAG) of the European Community (see also Chapter 3) according to which humans will be surrounded by intelligent interfaces supported by advanced technologies distributed everywhere and mainly embedded in everyday objects such as furniture, clothes, vehicles, roads and smart materials [2].

On the practical side, AmI may be roughly described as the opposite of virtual reality: virtual reality puts people inside a computer-generated world; AmI puts the computer inside the world to help us. According to the AmI metaphor, people will live in enriched environments in which the technology is sensitive to people's needs, personalized to their requirements, anticipatory of their behavior and responsive to their presence.

The objective of this chapter is to show how AmI may support people with special requirements. Specifically, AmI may help them to live independently and to improve the access to a wide range of services and facilities [3]. Further, the chapter outlines a possible AmI scenario related to the management of cognitive disability.

15.2 Activity, disabilty and technology

According to the International Classification of Functioning, Disability and Health (ICF) of the World Health Organization [4] disability is not yet a disease but a "being condition in which people is temporarily or definitively unable in performing an activity in the correct manner and/or at a level generally considered 'normal' for the human being".

This definition does not describe disability as an individual characteristic. Instead, it is defined as a specific situation in which a person is not able to fully exploit his/her relationship with everyday contexts. This limitation could be caused by a particular physical impairment of the subject. But also it may be the result of some external constrain that compromises the full participation in a specific activity.

To make this concept clearer, an example may help. I'm in a restaurant for a formal dinner with my boss and some colleagues, but I don't know how to use the many different strange forks I have around my dish. In this situation, my lack of knowledge puts me outside, at least partially, from the social and cultural space of the "formal dinner". The result is a limitation in my agency: I don't use the forks to avoid mistakes. This example shows clearly how both physical boundaries (wall, obstacles, etc.) and social and cultural boundaries have a strong influence on the possibility of action and the quality of experience of the subject.

The introduction of activity-targeted tools could improve the quality of life in persons with special needs. As we have just seen, many constrains mediate between action intentions and the possibility of action performance. For instance, when movement capacity decreases or cognitive abilities are impaired, the everyday environment becomes hostile and even operating a coffee machine may appear an impossible achievement.

Further, the impossibility of using a specific tool becomes an explicit message of exclusion and could support a sense of inadequacy in disabled subjects.

For these reasons, technological innovation has to move from a general user-centered approach to a specific activity-centered approach. As noted by Kirsk and colleagues [5], any assistive device has to support activity in a transparent way. In particular :

> "In regard to device features, an ideal intervention will be one that is minimally intrusive, provides assistance without assuming unnecessary control, and does not demand of the user an uncharacteristic level of comfort with technological aids." (p. 201).

In particular, the focus of technology should be the improvement of the quality of the life of the subject, through an effective support to his/her activity and interaction. In this vision, if a person is able to write a paper with a pen and another person is limited in the pen use but is able to write the same paper using a computer keyboard, none of them is defined as disabled. On the contrary if both of them will be in a condition in which the tool, that allows them to write the paper, is not available in a specific moment they will be both disabled in performing the activity. This viewpoint stresses the need of developing technological tools for providing alternative affordances in performing a specific activity planning. Following this approach, the research in ergonomics is trying to identify specific guidelines for the development of tools and services supporting the activity of *any* user.

See for example the WCAG - Web Content Accessibility Guidelines [6] developed by the World Wide Web Consortium.

Following this approach, the setting up of any assistive tool - as a stair-climbing wheelchair - requires not only the development of a specific technology – for instance, a new four-wheel drive engine. The developers have to provide an alternative action plan that offers new affordances to the user. Also, they have also to consider how the tool may support the new action plan. In the specific example of a stair-climbing wheelchair, the designers have to realize how the user may use the wheelchair to climb, and how it may support the activity of the user. For instance, to climb up stairs, the subject has to back up to the first step and hold onto the stair railing. Then he has to shift his/her weight over the rear wheels, causing the chair to begin rotation of the front wheels up over the rear wheels and then down onto the first step. As the user shifts his weight backward and forward, the chair has to sense this and adjust the wheel position to keep his center of gravity under the wheels.

In conclusion, assistive technologies become autonomy tools if they help people in coping with their context in an effective and transparent way. As we will soon, AmI has a great potential for achieving this goal.

15.3 Ambient Intelligence and Rehabilitation

In Chapter Two, Riva [7] outlined a psychological framework for the concept of Ambient Intelligence (AmI), based on three concepts: **action, situation** and **presence.**

In particular the key assumptions of the framework were:

- *Any activity* is driven by a specific objective and it is structured in two different but strictly intertwined levels - *actions* and *operations* - each characterized by specific motives - *goals* and *conditions*
- *The situation* is the physical, social and cultural space (context) in which the activity is carried out. Activity is influenced by the affordances and constrains the subject perceives within the situation
- *The feeling of presence* provides to the subject a feedback about the status of its activity: the subject perceives any variation in the feeling of presence and tunes its activity accordingly. Specifically, the subject tries to overcome any breakdown in its activity and searches for engaging and rewarding activities (optimal experiences).

From this framework Riva introduced a psychological definition of AmI, based on the experience of the user: *AmI is the effective and transparent support to the activity of the subject/s through the use of information and communication technologies*.

This definition suggests that the role of AmI in rehabilitation is related to its ability to support action. Also, identifies “effectiveness” (the activity reaches its objective) and “transparency” (the activity is experienced without breakdowns) as the main characteristics of any rehabilitative AmI system. Following this vision, the most important reason for developing AmI assistive tools lies in their potential to *compensate or expand the activity of users* through new forms of human-computer interaction.

The “compensatory” approach in rehabilitation is usually divided in *person-oriented* and *environmentally oriented* interventions (see Figure 15.1).

Person-oriented interventions include the recruitment of alternate neurological systems or pathways in order to achieve a desired outcome. For instance, alternative pathways can be therapeutically induced through forced counterintuitive interventions (e.g., constraining an unaffected limb) or repetitive functional exercises [8].

Environmentally oriented interventions offer external cues to the subject in order to improve is handling of the activity [9]. As noted by Crosson and colleagues [9], environmentally oriented interventions may be "the only practical means for dealing with neurologically based deficits. Although not ideal, external modification can be effective in many circumstances" (p. 53). For instance, LoPresti, Friedman, and Hages [10] developed a palmtop that monitors the user's workspace and provides audible reminders as needed, based on the user's independent progress in the activity. Using the device, two participants with mental retardation were able to maintain levels of productivity comparable to those obtained with job coaching.

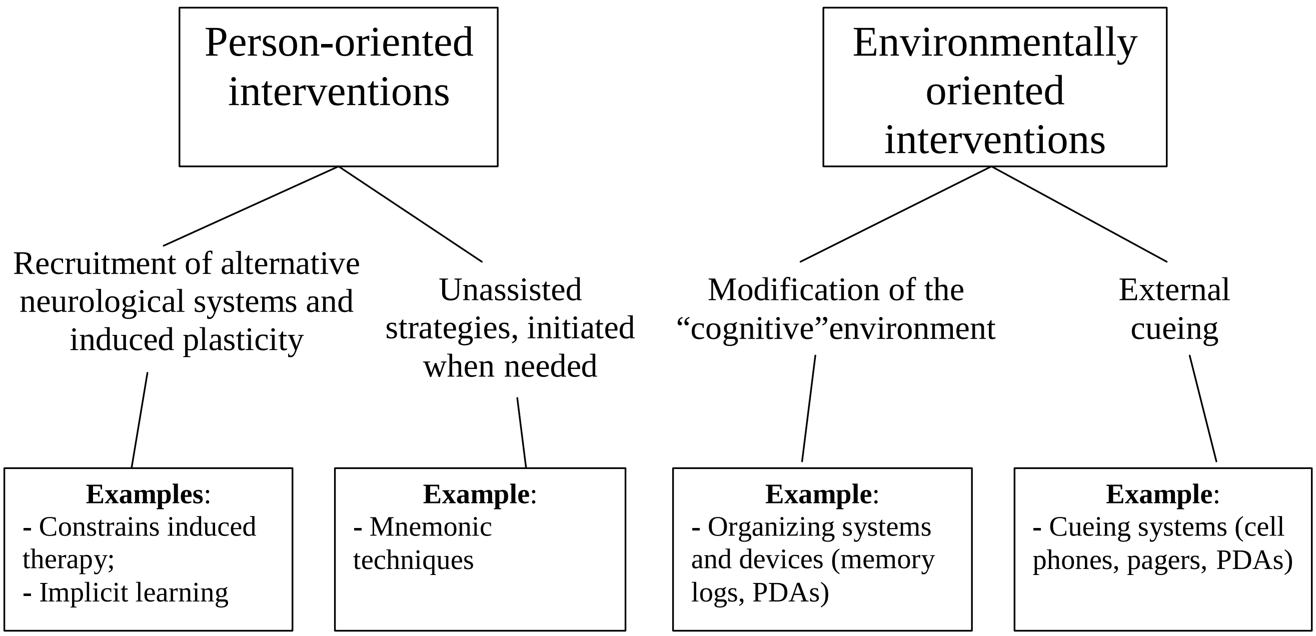

Figure 15.1 *Person-oriented* and *environmentally oriented* interventions (Adapted from [5])

AmI may offer *new and more effective environmentally oriented intervention*. First, it can provide active guidance (guidelines/suggestions) to the activity of the subject. For instance, using Intelligent Mixed Reality (IMR) it is possible to seamlessly integrate computer interfaces into the real environment [3]. If combined with mobile technologies, IMR may enhance the activity of a mobile user through the embedding of one or more objects (holograms, videos, images, texts, and/or sounds) related to his/her activity within his/her sensorial information [11].

AmI may also *adapt the complexity of a tool according to the characteristics of the user*. For example, some users may demand more or less technological sophistication based on their skills, their knowledge and the meaning given to the tool. Here an important role will be played by adaptive interfaces. An adaptive interface detects common user tasks and makes these tasks more accessible. A simple example of this interface is the list of recently-opened files in the "File" menu of a word processor. Any adaptive interface has, at some level of detail, a model of the user's behavior that is refined, and provides an interaction that fits the behavior as best as it can.

Another possibility is to use AmI *to support the use of other assistive devices*. Through "tangible user interfaces" it is possible to employ physical objects, surfaces, and spaces as tangible embodiments of digital information [12]. Following this paradigm, we can embed an active interface in any assistive device, helping the user in understanding how to use it effectively. This also *allows the provision of a feedback to the activity of the subject*.

Tangible interfaces transform the ambient (e.g., walls, desktops, ceilings, doors, windows) into an active interface between the user and its activity.

Apparently, rehabilitation may be a "killer application" for AmI. However, the use of an innovation is dependent on far more than simply offering new solutions: innovative technologies, even those that far surpass older, less effective methods, are often slow to come into general use [13].

This is not a new phenomenon. In 1834 a *London Times* editorial about the recently invented stethoscope stated:

> " That it will ever come into general use notwithstanding its value is extremely doubtful … because its hue and character are foreign and opposed to all of our habits and associations…. There is something even ludicrous in the picture of a gray physician proudly listening through a long tube applied to the patient's thorax." (McKusick, as cited in [13]).

Why does this happen? According to Rogers [14], there are a variety of characteristics of an innovation that are important in the differences in rates of adoption. Among the most important of these are the following: relative advantage, compatibility, complexity, trialability, and observability. These factors by themselves account for up to 87% of the variance in how likely a given innovation is to be adopted.

To allow an evaluation of these factors, scenarios have a key role. Scenarios are designed to encompass societal, economic as well as technology developments and form a logical framework in which use cases can be fitted. The European Commission and different research organizations encourage scenario-based approaches for pushing the research in the right way. Experts have to analyze the scenarios drawing consequences, and future research topics. The main output of these modeling efforts will consist in the ”pieces of technology” needed to provide the functionalities envisaged within the reference scenarios.

In order to clearly evaluate the AmI potential for rehabilitation, the following paragraphs will describe a possible scenario of for its use. The focus of our analysis will be *Anna*, a fictitious patient with a particular form of cognitive impairment: topographical amnesia.

15.4 A cognitive impairment situation: Anna

Anna is a 45 years old teacher that after a stroke revealed a topographical disorientation disorder. In particular she shows a topographical amnesia [15]. This disturbance impairs the memory of environmental landmarks, the physical characteristics of which are correctly perceived but not remembered. Moreover Anna is actually unable to recall the location of different spatial landmarks. Actually she has a selective impairment of the ability to find one's way in new environments but her deficit is not associated with dementia, acute state of mental confusion, visuo-perceptual disorders or global amnesia.

Anna's main problem is in learning and remembering new paths, to reach different target points during her environment explorations.

For these reasons, after a long period of hospitalization, Anna returned to her home and tried to continues her common life. She is married, but she doesn't want to strictly depend to him. Moreover she strongly wish to continue her teaching activity, even more because, except from spatial orientation disorder, she preserved the best part of her cognitive functions.

Even if Anna's general cognitive level should allow her in "re-starting" a common life, sometimes Anna feels lost in new spaces and tries to call her husband or a friend for help.

But she has not the possibility to inform them about her position within the city. She doesn't recognize buildings or significant places in order to give indications about the nearby. She is not able in mentally rehearsing a traveled path she has done. Further, she has not the ability of position herself in relation to a well known landmark. Generally, she is able in recognizing a known place. However, she doesn't know how to relate it to a specific information about the right direction she have to follow to reach a target point.

Even the use of a city map does not provide a concrete help. In fact, to use the map, Anna should be able to position herself within it and to relate that point to the part of the environment she is perceiving in that specific moment. It is a not easy task for Anna and after some time she decide to give it up.

At this point it is clear that Anna needs a support to effectively route the surroundings according to her everyday needs. Anna's rehabilitation primarily consist in achieve this apparently easy behavioral goal. At the same time, however, Anna has to cope with the anxiety problems she experiences during the exploration of new environments. Moreover the incessant feeling of being disoriented makes Anna frustrated and limits her possibility of creating social relationship with colleagues or friends.

Finally, Anna's relatives, too, become anxious about her disorientation. They try not to interfere with Anna's choices but at the same time they are anxious and scared about problems that topographical disorientation might cause her.

In this context, to help Anna in overcoming her disability, an assistive intervention has to:

1. Provide Anna with the possibility of effectively operate within the environment
2. Improve Anna's autonomy monitoring her, without significantly changing her habits
3. Support Anna's social re-integration improving her psychological sense of autonomy
4. Actively involve Anna's relatives and caregivers without turning them intrusive or giving them the opportunity of deciding for Anna's life
5. Coordinate clinicians and relatives information about Anna's rehabilitation course, creating a highly interactive place for knowledge share
6. Psychologically support Anna and her relatives during the rehabilitation process.

How AmI might copy with these needs? AmI in particular will be able to:

- Create both accessible opportunities for Anna, and provide action affordances that are aware of Anna's changes during the recovery process
- Sense her location within the environment, both outdoors and at home, relying on a wide range of sensors such as motion detectors, and other ubiquitous computing infrastructure

- Learn to decode patterns of everyday behaviors, and recognize signs of distress, disorientation, or confusion, using bio-signals monitoring, voice recognition, and behavior analysis
- Offer help to Anna through not invasive sound or visual cues
- Create a common knowledge space for health experts and Anna's relatives.

15.5 An AmI scenario

Let's look at Anna in her AmI environment. In order to have an added value in cognitive function recovery Ambient Intelligence will create a multilevel scenario around Anna's life (see Figure 15.2). In particular it has to:

- Consider different aspects of Anna's daily interaction with the "known" context such as her home and/or job life
- Manage her goals and needs within the "unknown" part of the city
- Link her with the hospital in
- Order to track the rehabilitation program.

It is for that reason that three apparently different AmI scenarios where chosen in describing Anna's life.

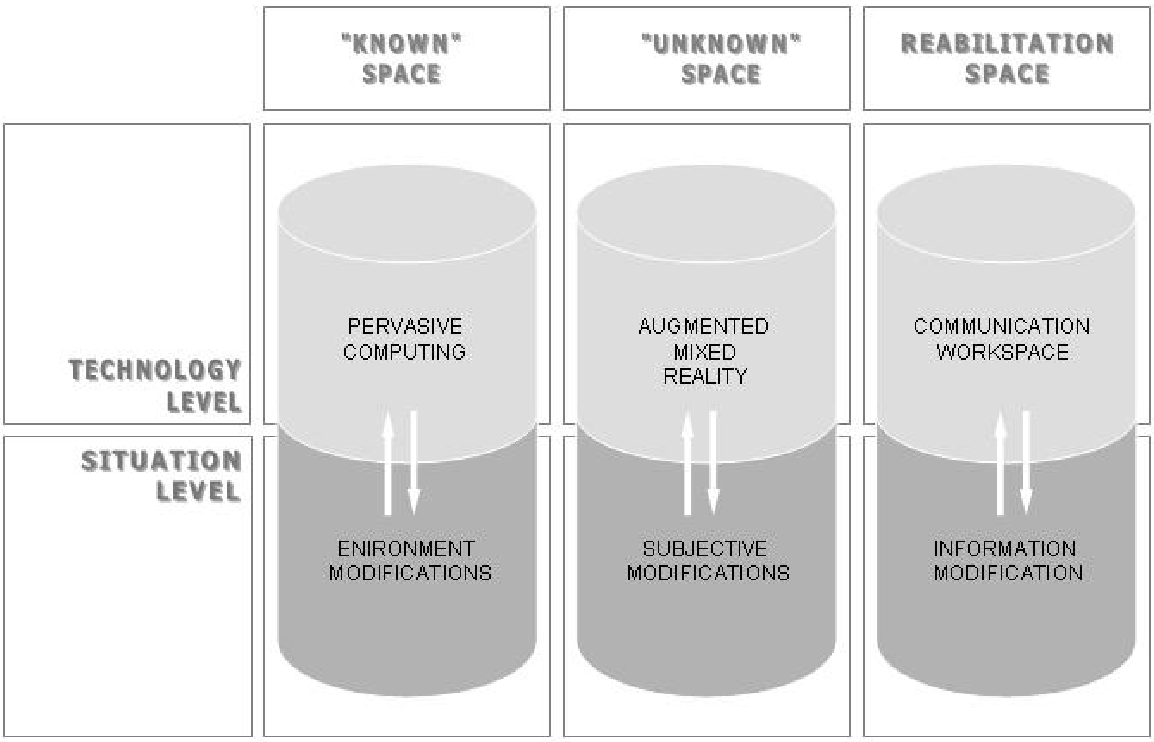

Figure 15.2 AmI scenario for spatial rehabilitation

15.5.1 Anna's "known" space

The easier part of Anna's everyday life is when she is at home. Her spatial impairments, in fact, concerns only new environments and she is able to move herself effectively at home.

Here, the critical problems is to remember the location of objects, especially if new or recently moved.

For example, if Anna is sweeping out a room and the telephone rings, she may leave the broom against the wall edge and reach the telephone on the other room. When the call ends, Anna may have some problems in remembering the location of the broom causing her a waste of time and a slight feeling of frustration.

But, if Anna lives in a AmI-based home, the situation may be very different. Anna usually needs two hour to clean her home. If, after this period, she does not correctly place the cleaning stuffs in their original location, the AmI system will monitor the environment to locate them and will provide a notice.

For Anna it is useless to have information about the position of the broom in terms of spatial directions, because she is not able to use them. So, the AmI system will provide her an alert, such as an intermittent light or a "*beep*", allowing an easy location of the object.

Such as in her home, Anna has no problems in moving at school. She has always worked at this school and continues to be able in finding target places within it. However, it is the environment in which Anna spends the majority of her time. So, it is the better place in which the spatial rehabilitation program has to be developed. For instance, it is possible to use the school as example for creating an AmI-based ecological training context.

The AmI system has the possibility to monitor and collect information about the exploration strategies used by Anna and help her in not taking a wrong way during the hardest routes.

In exploring a space people make travel choices, and actively individuate spatial aids such as landmarks that could be useful achieving specific goals [16]. In spatial behaviors, goals might be modified during the travel path. Contrariwise some environmental configurations might require path modification during exploration. In both these assumptions the user continuously modifies relevant landmarks in navigation, also giving different meanings.

So, in the school building too, there are paths that require a more detailed planning and attention. Embedded sensors might sample Anna's paths and travel preferences during her more frequent navigations and, linking this explorative information with other information (such as the direction of her view, the time she require in choosing direction in front of a crossroad, etc.) it might create appropriate aids for navigation.

15.5.2 Anna's "unknown" space

As underlined before, spatial directions and landmarks are not the same for all users and are not always the same for the same user. In order to be useful, spatial aids have to be meaningful: useful landmarks are context-based and have a specific link with the user's goals. This point is critical for supporting Anna in an unknown city place.

Anna has a local goal (reach the right place) that depends on her more general goals (recover her ability in exploring new places, improve her independency from relatives, etc). It is on this hierarchy of goals that the perception of a possible opportunity for action is based [17].

Let's imagine Anna in a tedious day: She wants to break from her actual activity and decides to go out for a walk. She doesn't have an explicit local goal: she has only a general goal of deleting the boring feeling she's experiencing. During her walk she can find different local goals (finding a shop, entering a park, etc.) that may change according to environment or context modifications. Probably she will get lost. Even more probably, she will not start her stroll because she is frightened, or more probably frustrated, for the possible consequences of her impairment.

The introduction of AmI may greatly support this process. As in "known" space, AmI can detect Anna's preferences in spatial navigation and support her in cope with unexpected occurrences. But in the "unknown" environment AmI has to be smarter: it has to facilitate Anna in navigational choices preventing her mistakes.

During Anna's walk, ubiquitous sensors within the environment continuously check her position. They are able in being aware about Anna's preferences in exploration because they are linked with a "knowledge" database that recorded a great amount of information about Anna's strategies by monitoring her within the "known" space.

For example, Anna stops at a cross light for more than 3 minutes. From the database information the AmI system knows the choice of a direction within a known environment requires less than 3 minutes. So it provides a meaningful cue to Anna.

It is not reasonable to provide a verbal indication such as "turn on the left and take the street beside you" if Anna is not able in deciding between the right/left directions. It will be more useful to Anna seeing through her glasses or on the screen of a PDA/mobile phone an egocentric based map: something like a 3-D map in which the main point of view is fixed on Anna's eyes. In this way Anna can be free to choose between alternate courses of action without experiencing disorientation or frustration.

Finally, even if Anna has the possibility of freely explore the environment and to progressively test her spatial abilities, sometimes unexpected events could come. For instance, Anna gets lost and she feels so confused that she is not able to ask for help. To help Anna, the AmI should also monitor Anna's physiological state during her exploration.

With biosensors embedded in Anna's clothes is possible to capture her basics physiological parameters, such as heart and respiration rate, temperature and involuntary muscular contractions.

Definitely, those biological parameters will change during a stressful situation. A significant change alerts the system that provides to Anna some support. According to this "embedded" aid procedure Anna has not the explicit feeling of being controlled during her daily activity. Nevertheless, it can receive a critical help during an awkward situation.

15.5.3 Anna's "rehabilitative" space

Even if Anna, supported by AmI technologies, is engaged as much as possible in a normal life, she is also involved in a rehabilitative course with health professionals, especially when she is away from the hospitalization context.

Also here an AmI system has an important role: thanks to its support, Anna has the possibility of training her remaining capacities in an ecological scenario. At the same time, the system monitors her providing help in navigation, and calibrating the spatial tasks complexity according to her progresses in everyday life. Following this vision, AmI will also provide a technological workspace in which all the information concerning the rehabilitative process will be integrated and exploited.

If we focus again on the situation of Anna, she has the possibility of being continuously monitored during her navigation. This possibility constitutes a link with health care professionals. Without interfere with her choices, rehabilitative therapists will be able to track Anna's spatial ability level and match it with other parameters, such as physiological indexes.

All these information will be collected and integrated into a virtual information space accessible to all the professionals involved in Anna's rehabilitative course. According to this information, the therapist may tune the support provided by the AmI system to Anna, in managing "known" space and in exploring "unknown" space.

As noted in the first part of the paragraph, even if these three AmI configurations were described separately it is not difficult to understand how they are strictly related. The AmI "rehabilitative" space constitutes the core scenario through which recovery take place.

However, its efficacy is linked to the information collected in the other two scenarios: "known" and "unknown" space.

15.6 Conclusions

According to the World Health Organization [4] disability is a being condition in which people is temporarily or definitively unable to perform an activity in the correct manner and/or at a level generally considered 'normal' for the human being.

Following this vision, a critical reason for developing AmI assistive tools lies in their potential to compensate or expand the activity of a disabled subject through new forms of human-computer interaction.

In fact, AmI can be defined as the effective and transparent support to the activity of the subject/s through the use of information and communication technologies. This definition also identifies "effectiveness" (the activity reaches its objective) and "transparency" (the activity is experienced without breakdowns) as the main characteristics of any rehabilitative AmI system.

In particular, AmI may offer new and more effective environmentally oriented interventions through:

- The provision of active guidance (guidelines/suggestions) to the activity of the subject
- The adaptation of the complexity of a tool according to the characteristics of the user.
- The support to the use of other assistive devices
- The provision of a feedback to the activity of the subject by tracking its course.

To clearly evaluate the potential of AmI for rehabilitation, the chapter also described a possible scenario of for its use. The focus of our analysis was Anna, a fictitious patient with a particular form of cognitive impairment: topographical amnesia.

After the analysis of the provided scenario it is possible to consider AmI as a revolutionary change in rehabilitative paradigm, especially if we agree with the idea that recovery is a continuous process that doesn't occur only in a clinical setting. In fact, AmI does not handle disability like a disease but it supports the relationship between the subject and its and context during a specific activity. With the introduction of AmI is now possible to have a safe and controlled natural context for rehabilitation.

However transforming the scenario in reality is not an easy task. In particular, it requires the development of *self-adapting interfaces* which address all the possible dimensions of variation (objectives, skills, the characteristics of involved tools, the relevant aspects of the situation, etc.).

Further, the availability of working prototypes is critical to allow therapists and patients to investigate how effectively use such a system during the rehabilitative course.

15.7 Acknowledgments

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