The Collective Experience of Empathic Data Systems

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CEEDs user-experience research plan and year 1 report

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Executive Summary

This document describes the first year of activity within WP7. A first draft of guidelines for measuring and studying the users' experience with CEEDS technology was outlined. Preliminary tests of available CEEDS components were carried out. Finally, the configuration of the space surrounding the user was explored with a neurocognitive approach and – when needed - with virtual environments.

Regarding the user's experience, a set of dimensions and methods was identified that are relevant for interfaces having the characteristics of CEEDs interface, i.e. receiving input from touchless hand/gesture movements and/or implicit physiological/brain activity. Critical aspects of the interface are its ability to:

- provide prompt and pertinent response to the users' input (responsiveness),
- be easy to learn and be used by novice users (learnability),
- be perceived as accurate (accuracy) and trustable (credibility),
- include equipment that is comfortable to wear (wearability),
- facilitate the manipulation of complex data (reduced mental workload), and
- be pleasant to use (pleasantness).

The analysis of the literature on interfaces similar to CEEDs provided several recommendations, contained in Chapter 1. For instance, natural, familiar gestures that clearly refer to the device to which they are directed should be preferred over more sophisticated and free-standing gestures, which are difficult to learn and embarrassing to perform. Credibility of the interface must be ensured by raising the right expectations in the user, providing only the kind of output that can be accurately elaborated, and adding explanations on why a certain output resulted from the user (implicit) input. The persuasive aspects implicit in the feedback should be kept under control, so that a healthy mental state is encouraged. State of the art techniques to reduce tool calibration should be implemented, and possible delays in delivering output should be dealt with by appropriate feedback.

These initial guidelines are meant to be extended in the second year with specific recommendations derived from testing the interface prototypes, and from dedicated studies on credibility and social ergonomics (preliminary accuracy test have been conducted with some wearable sensing devices of CEEDs interface).

In parallel, WP7 started investigating the nature of the spatial cognition in manipulating virtual and real objects in mediated and "natural" spaces. A set of studies was carried out based on the bisection line paradigm. The first study showed the technical feasibility and the scientific potentials to implement the fNIRS brain image technique in the study of immersive virtual reality experience. In the experiment we acquired a correct signal registration when participants were immersed in VE through a head mounted display appositely modified to be used together with the fNIRS fibers. In addition, results of our experiment showed clearly an activation of the parietal lobe and occipital lobes. Contrary to expectations, the same areas were activated both when the stimulus was presented in the peripersonal space and when it was presented in the extrapersonal space.

Most importantly, these studies explore how and when a tool can extend the peripersonal space representation to the limit of the tool handled. The peripersonal behavioral space is defined by grasping, reaching and manipulating actions while the extrapersonal behavioral space is defined by visual search and recognition of objects. The extension of the peripersonal space occurs even when a tool allows to reach a distant space that would be otherwise out of reach. The studies showed that this extension occurs even when the procedure adopts a chinrest (experiment 2) and whatever the arm position of the user (experiment 3). Moreover, in all cases the distinction is clear, abrupt and not gradual: stimuli presented at different distances in peripersonal space are perceived identically, as well as stimuli presented at different distances in extrapersonal space. We are currently investigating whether visual continuity between the part of the tool held in the participants' hand and the tip of the tool touching the extrapersonal space is necessary in order for this prosthesis to expand the peripersonal space. The results of these studies are important for the CEEDS system because of their implications for the design of interfaces that support navigation in large amount of data and 3D virtual environments. These results suggest that the virtual space upon which the user can act can be coded as close to - or even part of - the individual bodily space; this provides strong support to human-computer confluence framework and leaves room to the future work in WP7 on the modalities that facilitate the incorporation of artificial tools into effective usage practices.

Table of Contents

List of Figures

1 Document description

The present document synthesizes the activity carried out within WP7 during M1-12 in CEEDs project. During that period, two tasks were scheduled: T7.1 and T7.2.

Chapter 2 describes the results of the activity in T7.1, "Cognition of psychophysiology of user experience", which started in M6. The activity in this task led to a *first set of user experience guidelines* that will inform the prototype tests starting from the second year of the project. The user experience evaluation in CEEDs needs to focus on the specificities of the interface developed, in addition to classic effectiveness and efficiency tests. Therefore, during this first year UNIPD:

- collected relevant published work from databases such as ACM Digital Library, GoogleScholar or PsychInfo regarding interfaces similar to CEEDS (i.e. featuring navigation of complex data, massive use of signal generated by physiological/neural activities and not accessible to awareness, or touchless hand/body gesture based input modalities);
- identified the usability issues that emerged from each single study;
- grouped the usability issues into a smaller set of overarching dimensions;
- derived a set of guidelines related to each dimension, and drafted a first set of CEEDs usability guidelines, which will be refined in the next months and be completed in M30.

In addition, some *tests of existing CEEDs technologies* were carried out.

Chapter 3 describes the activity within T7.2, "Spatial cognition and actions in technologically enhanced spaces", which started in M1. This activity focused on the users' "attention" and "action" in peri-personal, inter-personal and extra-personal space and considered the effect of new interfaces on the configuration of these spaces. Three lab experiments were completed, and a fourth one is at the data analysis stage. The experiments investigate spatial cognition in 3D mediated spaces and highlight the neural and cognitive correlates of spatial cognition in virtual space, the role of body/hands in 3D natural interaction and the role of tools in modifying spatial perception and attention.

Chapter 4 describes the future work foreseen in the second year in each task.

2 Relevant dimensions of user experience with CEEDs technologies

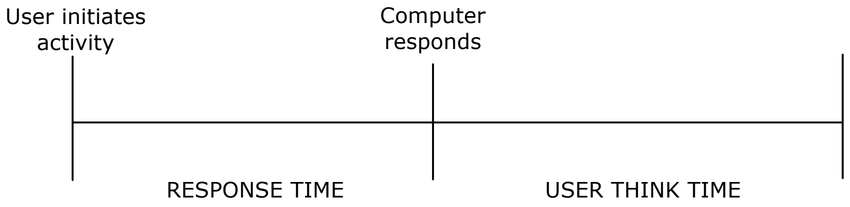
2.1 Introduction

Section 2 of this document describes the dimensions that can predictably characterize the users' experience with CEEDs technologies and are general enough to work for each application scenario. It is based on the analysis of about 70 papers on design, usability and user experience of interfaces that can be assimilated to the planned CEEDs interface. The issues emerged are grouped into nine dimensions (responsiveness, learnability, accuracy, wearability and comfort, feedback, reduced mental workload, pleasantness, acceptance, credibility).

The section ends with the description of some preparatory tests with available CEEDs components.

2.2 Responsiveness

Responsiveness consists of perceiving the system as reacting quickly to an input. Emphasis on responsiveness has characterized design for about forty years ([117] [83] [9]). In Human-Computer Interaction, responsiveness is the capability of an interface to detect the user's input and to respond to it in a short time (Fig. 1 -).



(from [119], p. 427)

Fig. 1 - ***Simple model of system response time and user think time***

2.2.1 Measuring Responsiveness: Metrics and Evaluation Methods

According to [117] the maximum latency between "event occurrence" and "system response" should be shorter than 45ms; this interval is the longest response time that the user would perceive as "no delay". When the computer cannot provide fairly immediate response, continuous feedback should be provided to the user in the form of a percent-done indicator [84]. More recently, Nielsen describes the time limits that need to be respected in order to obtain a positive user experience [90]. These limits are as follows:

- Up to 0.1 second**:** the users feel that they are directly manipulating objects in the interface.
- Up to 1.0 second**:** the users feel that they are freely navigating the command space without having to unduly wait for the computer. A delay of 0.2-1.0 seconds means that users notice the delay and thus feel the computer is "working" on the command, as opposed to having the command be a direct effect of the users' actions.
- Up to 10 seconds: this is the delay limit within which the users can keep paying attention to the task. Anything slower than 10 seconds needs a percent-done indicator as well as a clearly signposted way for the user to interrupt the operation (available at http://www.useit.com/papers/responsetime.html).

Finally, Duis and Johnson discuss four techniques to improve responsiveness despite limited or fluctuating resource availability: adaptive resource allocation; parallel problem solution; work-ahead, i.e., pre-computing solutions; X3 and non-sequential input processing [13].

Metrics for responsiveness are basically based on measurements of time spent to accomplish a task or a sequence of tasks; the method adopted to measure these metrics is mainly a kind of time-tasks analysis. Often responsiveness measurements are accompanied by accuracy metrics, since productivity does not only depend on the speed/responsiveness of the interface but also on the human error rate and the ease of recovering from these errors [117].

2.2.2 Responsiveness in “hand/body” gesture interface

Given that common gestures are normally a natural sequence of several basic signs, the processing workload required of the machine in order to recognize and understand user actions is often heavy and this is one of the main issues affecting responsiveness in this kind of system. Starting at 300ms, a gesture interface result can be sluggish, possibly provoking oscillation and causing a symptom know as “move and wait” [130].

2.2.3 Responsiveness in “Implicit Signals” based interface

The signal in implicit input technologies - such as Brain Computer Interfaces and Biosignal acquisition input devices - requires processing of a high quantity of data; this in addition to the early stage of development of this technologies, generates some latency problems. Other problem can arise when algorithms are needed to categorize the signal; Krausz, Scherer, Korisek, and Pfurtscheller state that when the algorithm computation starts immediately after a signal, the categorization occurs at least two seconds after the trigger [64]. This delay is too long for a real-time user interface; so in order to improve interface responsiveness Friedman, Leeb, Guger, Steed, Pfurtscheller and Slater provided a visual feedback immediately after the BCI data acquisition (without classification of brainwaves)[27]. Blankertz et al., in a multiplayer game with players using BCI and other players adopting traditional input devices, deliberately slowed down the players using a traditional interface until all gamers had approximately the same level of control [4]. This can be accomplished in several ways, e.g., by adding delays to keyboard inputs and/or by adding an amount of uncertainty to each control decision.

2.2.4 First Guidelines for CEEDS

- Adopt algorithms with the lowest computational load possible and try to optimize the process that delivers the output;

- Maintain responsiveness time under 45ms, never exceed 300ms;

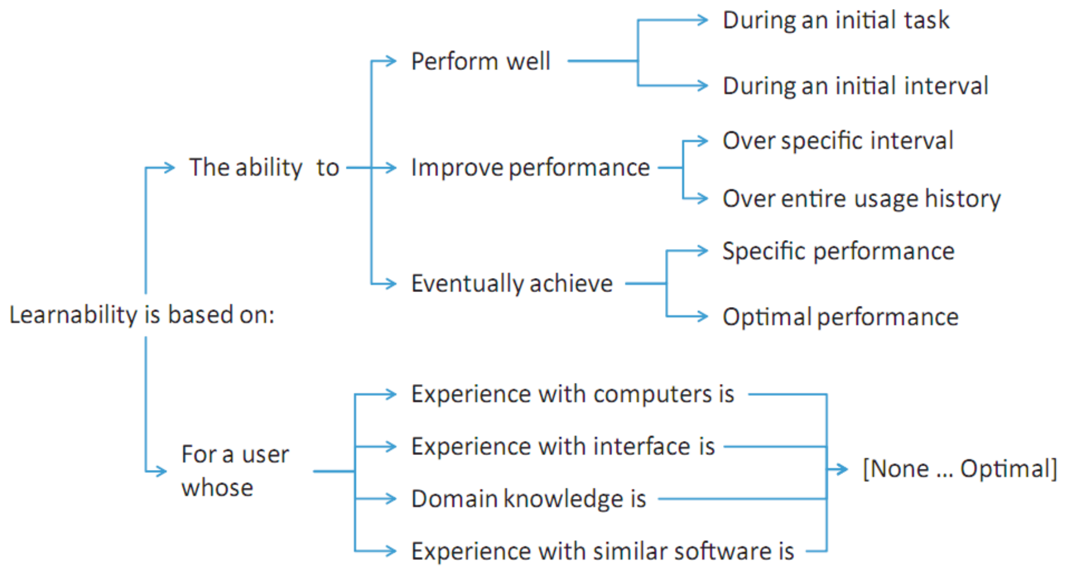
- Provide consistent feedback (e.g., progress indicator) when the system delays and let the user do something productive while the system is busy (e.g. reading instructions);

- Deliver intermediate results, before the operation is finished.

2.3 Learnability

Designing interactive system from a human-centered perspective has often to do with the ability of people to quickly learn and easily remember ([3] p.274) how to interact with a system. The term learnability had been suggested for the first time by [71] as an aspect of software usability, and was adopted during the 1980's in the usability evaluation of word processing software. In the 90's the term became very common and omnipresent in any form of usability test after being extensively used in web usability ([91][14]). The need for designing products where their control/uses are easy to remember is also enhanced by the fact that any technical documentation (i.e., manuals or instructions) is usually ignored, browsed or checked erratically, while users prefer to learn by trying things out ([112], p.275).

According to a review of 88 papers published in ACM CHI conferences and TOCHI from 1982 to 2008 [36], there is no well-accepted definition of learnability. Eight definitions are identified: generic learnability (easy to use), generic usability (easy to use), first time performance, first time performance after instructions, change in performance over time, ability to master system, ability to remember skill over time and finally a more generic adoption of the term without referring to any definition. A taxonomy was developed based on this review, (see Fig. 2 -), which includes two main categories of "learnability scope" (initial and extended learnability) and all the possible considerations about users' skills.



(from[36])

Fig. 2 - ***Taxonomy of learnability definitions***

In a recent work on videogames usability [112], main variables influencing learnability were: familiarity (knowledge of the game affects the degree to which players follow the game learning curve), users' cognitive and interactive skills, difficulty (depending on how steep the videogame learning curve is) and frustration. It is clear that different kinds of software force us to reconsider the meaning of learnability: for example, in videogames a higher difficulty could be a desired characteristic deliberately introduced by the game designers.

2.3.1 Measuring Learnability: Metrics and Evaluation Methods

Several methods are reported in the current literature of "software engineering" or "human computer interaction" to assess software and system learnability.

Learnability measures are based on several different metrics: task performance (e.g. percentage of optimally accomplished tasks), command usage (e.g. success rate of commands usage after being trained), cognitive process performance (e.g. change in chunk size over time), subjective reporting (e.g. learnability questionnaire), documentation usage (e.g. decreased help command usage over a certain time interval), specific rules metrics (e.g. numbers of rules to describe systems). For a complete list of possible metrics please refer to [36].

Both formative and summative evaluation [91] are usually adopted; the former approach aims to understand specific learnability issues, the latter approach provides an overall assessment of the system's learnability. Thinking aloud protocol ([18] [57]) is one of the most frequently adopted methods to test learnability; it provides rich qualitative data and allows first-hand insights into the thought processes associated with learnability tasks. Thinking Aloud protocol could be supported by other subjective and qualitative data collection techniques (e.g., questionnaires, focus groups, interviews and video analyses of users' interaction with the target device) as well as by more quantitative approaches (e.g. measuring users' performance). An interesting method derived from the thinking aloud protocol is the "coaching" or "question asking protocol" [60] where an expert (coach) answers any question the user has during their interaction with the interface. These methods aim to encourage users' verbalization of their thoughts and difficulties with the system. With the same purpose, "group thinking aloud" allows users to express their ideas and to verbalize their problems during a testing session involving a small group of participants.

2.3.2 Learnability in "hand/body" gestural interface

There is a lack of scientific work on users' performance as a function of the gesture vocabulary [130]. The gesture patterns used to control applications must be easy to learn and remember. An optimal gesture vocabulary can be defined as a set of gesture/posture-commands pairs that minimize the time for a given user to perform a specific task. [123] found that gesture preferences are highly individualized, providing evidence to refute the hypothesis of the universality of gestures; these authors introduced the notion of "complex consensus gesture vocabularies" in which multi-gestures are linked with single commands and multi-commands are linked with single gestures. An interesting approach to hand gesture vocabulary design using psycho-physiological and technical factors is proposed by [123] and includes human as well as technical design factors.

2.3.3 Learnability in "Implicit Signals" based interface

Learnability and Intuitiveness of implicit interfaces, such as Brain-Computer Interfaces and Physiological Computing (affective computing, neuro-adaptive interfaces), seems to play an important role in their usability, especially in applications such as assistive technologies and in videogames.

In a study on BCI videogames, [100] argue that if the mapping between a mental task (the command) and the "in-game action" is not intuitive and easy to learn, players' performance will be reduced as an effect of the time and effort spent to memorize commands and instructions. One way to define suitable mental tasks from a user perspective is to simply ask people what they would like to do to trigger a certain action and then evaluate the experience of using these mental tasks [91].

BCI interface as well as "physio-interface" can be used to enhance user's experience and add controls to features in combination with other traditional input devices (keyboard, mouse, game controller, gestures, etc.); this would make interaction more easy for example avoiding the simultaneous use of multiple keys [18]. Sometimes, as with implicit biosignals, commands cannot be directly expressed by the user and in this case learnability and intuitiveness could be an important issue; this kind of interface would fit applications that exploit its characteristics without becoming an "invisible and alternative joystick". For example, two sports games (skiing and shooting) adopt heart rate measurement as the control for specific features [86]. In the skiing game heart rate controls the skiing speed, while in the shooting game the HR in connected with the degree of vision steadiness (simulating a stress condition). Games, evaluated in a user study, showed that implicit interaction can be fun and engaging. Another example is described in [64], and consists of a musical instrument controlled by both gestural interaction and physiological parameters, such as Galvanic Skin Response (GSR) or heart rate.

2.3.4 First guidelines for CEEDS

- Gestures that are natural and intuitive are preferred: users are more likely to remember them [130];
- Avoid universal gesture alphabet, be "specific" and "situated";
- Introduce hybrid gesture vocabularies, decided by consensus with several gestures individually selected [123];
- Prioritise and design hybrid interfaces where implicit signals interaction work together with a classic interface;
- Involve users in the design of gestural alphabet and in the definition of the best implicit command;
- Supply consistent feedback to support learning steps.

2.4 Accuracy

Accuracy is a term generally adopted to describe a close "agreement between a measured quantity value and a true quantity value of what is measured (International Vocabulary of Metrology). In usability studies accuracy is an ergonomic requirement that deals with the "accuracy and the completeness with which a user achieves a specific goal" (ISO 924-11:1998), or in other words "the accuracy with which a user completes a task". This usability concept is strongly connected with the theories of human error [107] and is often considered as the result of a trade-off between execution time and performance quality. When the interface provides a high degree of accuracy, for example when recognizing a hand movement, users produce less errors and acquire more speed.

Accuracy is also strictly linked to the characteristics of the device, task and setting of use. For example while in adaptive systems it is common to evaluate the predictive accuracy, [57] in affective computing, accuracy is more related to "affect/emotion recognition" and to the accuracy of the tools in recording physical and physiological user activities [100], and in face recognition technologies accuracy is an expression of the best match of the digital model of a face with the reference person [126].

2.4.1 Measuring Accuracy: Metrics and Evaluation Methods

Usually, accuracy measures quantify the number of errors users make either during the process of completing tasks or in planning the solution to the task. An example Would be simply counting the number of errors in data entry tasks.

Spatial accuracy, typically measured in studies of input devices like gesture interfaces is usually explained as user's accuracy in pointing or in manipulating user interface objects.

Metrics for spatial accuracy include errors expressed as distance of an action from a target, orientation error in radians when rotating a virtual object and other measures of spatial precision [49].

2.4.2 Accuracy in "hand/body" gesture interface

Wachs, Kolsh, Stern and Edan identify three main criteria affecting the performance of hand gesture systems from the accuracy point of view [130]. These are detection, tracking and recognition. The first indicate when an hand (or a part of the body) is in the camera view, the second describes the capability to follow step by step a hand, the third criteria, recognition, is about "how close the hand/body's trajectories are to learned templates, based on distance metrics, and indicates the level of confusion of the given gesture with other gesture".

In a more technical approach to accuracy in gesture based interface, Hoffman, Varcholic and LaViola examine accuracy as the relation between the number of gesture in the alphabet and the amount of training samples used in training the recognition algorithm [47].

Problems in accuracy that in several situations can also affect users' cognitive workload and comfort parameters, can be generated by:

- allowing movements where arms and hands occlude the visual field;
- forcing users to maintain a body position for too long;
- allowing users to execute strange uncomfortable movements;
- too many system failures in recognizing (involuntary) gestures as a command.

2.4.3 Accuracy in "Implicit Signals" based interfaces

Accuracy is an important aspect of innovative interfaces. Van den Berg found that users stated that the most important aspect in the use of BCI in gaming is high accuracy [129]. Challenging users with conventional inputs can lead to "an unfair disadvantage". Advances in technology seems to lead to devices of higher quality and higher accuracy; for example, in task selection, [36] found that a large population can perform this kind of tasks adopting a brain controlled interface, and that a high accuracy of above 90% can be achieved when users performed a single operation (e.g. to select a single letter among many others).

Another important usability aspect of "implicit interfaces" is their "perceived accuracy" (that can be different from "objective accuracy" of an interface), which directly affects the level of acceptability of the technology. [1] showed that the acceptability of these interfaces rests on two primary factors, the intrusiveness of the sensor apparatus and the level of trust engendered by system usage. To reach a high level of trust, interaction with "physiological computers" should be intuitive and therefore, the system response should be accurate and able to match the users' expectations. The perceived accuracy in these interfaces is thus generated by the quality of the conversion from the users' physiological activity to the visible system response.

Finally, movements in free space can lose precision since there is no reference to measure them against; exploiting discrete gestures that can be easily produced in small series, such as tilting or pinching, can be a solution since their repetition helps to increase accuracy [82]

2.4.4 First guidelines for CEEDS

- Strongly consider the accuracy of biometrics measurements in different movement conditions;
- Ensure accuracy in the detection, tracking and recognition of hand/body gesture;

- Identify the ratio of correct data retrieved and the total number of documents retrieved (in navigating complex data activities);
- Ensure accuracy of signal capture devices and the match with users' expectations.

2.5 Wearability and comfort

The constant advance of digital technology leads to an increasing development of wireless, portable, ubiquitous systems and consequently to a growing claim of light, wearable, comfortable and usable equipment. In CEEDS, comfort assumes a particular role because of the adoption of wearable technologies in several application scenarios.

Knight, Baber, Schwirtz and Bristow developed an assessment tool to measure comfort, the comfort rating scale, CRS. Knigh and colleagues consider comfort as a multi-faceted construct, defined by six different dimensions (Emotion, Attachment, Harm, Perceived Change, Movement, Anxiety) and influenced by several factors both external and internal to user [64]. These authors used CRS to assess the comfort of SensVest v1.0, a shirt that records and transmits wearer's biometrical data to a base station. The authors divided wearers in different conditions (general, throwing, dynamic condition) and asked them to score the comfort they experienced on CRS. In doing so, they gathered interesting suggestions to improve SensVest v1.0; for instance, when the shirt was active, it made the user more worried than in general conditions in which no data were recorded, as predicted by a relatively low score on Anxiety scale.

The concept of "wearability", or "*dynamic*-wearability" is described by Francine Gemperle and colleagues [30] as the active relationship between human body and the solid but flexible form that interacts with it without interfering with movements. As with manufactured articles the evolution of computing tools is intrinsically linked to their historical context and the particular social climate of each era, which means chiefly miniaturization, portability and wireless spread of information. Designing wearable technologies means obviously the use of the human body as the environmental support for the process of development of the product, but the human body changes from moment to moment and this inevitably leads to many compromises. Gemperle, Kasabach, Stivoric et al. propose thirteen "rules" that can be adopted as guidelines to frame the design process of such products [30]. The guidelines are listed from the simple to the more complex, understanding that a trade-off exists among them. The guidelines regard:

- Placement on the body
- Language formation (defining the shape)
- Human movement
- Human perception of space (proxemics)
- Diversity of body size (sizing)
- Attachment and fixing forms to the body
- Containment (considering what's inside the form)
- Spreading of the weight across the body
- Physical Accessibility to the form
- Sensory interaction (active or passive input)
- Thermal characteristic
- Aesthetics
- Effect of the long-term use on body and mind

2.5.1 Measuring wearability: metrics and evaluation method

Comfort and wearability assessment adopt both quantitative and qualitative measurements methods. The first approach consists of recording and measuring users' movements, their speed, force and pressure, and specific characteristics of the device (e.g. weights, temperature). Martins, Sommerer, Mignonneau and Correia highlight that comfort is needed for ubiquitous applications in view of the long exposure times that normally characterize this technology [78]. In their work, authors asked users to perform tasks (e.g. holding and manipulating objects) while wearing a bracer called "Gauntlet"; this wearable wireless device was able to record pressure and force, to give a haptic feedback and to analyze users' speed with an accelerometer module. These measurements were used to assess the comfort and the wearability of the Gauntlet that, once donned, felt comfortable.

Chae, Hong, Cho, Han, and Lee analyzed smart clothes on different usage scenarios [10]. Qualitative methods as brainstorming, structured interview, video and voice recording, script extraction, individual preference for scenarios and record of purchase intentions were adopted to evaluate usability and wearability of smart clothing.

2.5.2 Wearability in "hand-body" gestural interface

All wearable devices deal with hand and body gesture; it is important to highlight that to be appreciated by users, a wearable computer adopted for gestural interface (e.g. data glove) must take into account the dynamic quality of the human being as well as his/her peculiar needs.

Stain, Ferrero, Hetfield, Quinn, and Krichever stressed the importance of treating in detail the wearability of a wearable gesture interface, that must be safe, comfortable and as portable as possible [122]. Cables must be minimized and ease of cleaning and setting need to be optimized.

Wearable technology becomes a useful support to embody several other wireless devices and sensors. For example, a data glove used to recognize hand movements, can also embody a GSR sensor, a finger pulse oximeter or a vibrotactile effector to feedback to the users. However, on some occasions and in some specific scenarios, wearable gesture interfaces such as markers, gloves, or long sleeves could be avoided, according to the concept "come as you are". One can obtain good results without requiring users to dress a device, for instance with artificial vision systems and algorithms or with devices embodied in everyday life object can be adopted [130].

2.5.3 Wearability in "implicit signals" based interface

Advanced wireless biometric sensors exploit the possibilities offered by a tissue support, especially to be comfortably set over the human skin without asking users to install any invasive electrode. This approach was adopted by the *smart-shirt* (a t-shirt able to register biometric data) by [97] and [10] and proved successful after an evaluation of usability and wearability of smart clothing.

2.5.4 First guidelines for CEEDS

- Refer to and adopt the above listed guidelines and/or the comfort rating scale, CRS;
- If "cap mounted eye-tracker system" is used, it should subjected to a wearability/comfort test.

2.6 Feedback

Feedback can be defined as a reaction to a behavior that has the potential to influence the original behavior. In HCI studies the feedback is the information that an interactive technology sends back to users and that results from the user's input to the system ([6][99][118]). In other words, when a user does something, the interface responds, so that the user understands how his/her action is interpreted by the system. For example, when the user moves the mouse, the pointer moves on the screen letting him/her understanding what happened.

Feedback is also a fundamental concept in Donald Norman's "seven stages of action" model [93]; feedback supplied by an object allows users to perceive the state of the world, to interpret it and to evaluate what happened after his/her actions on the object. Without responsive and relevant feedback, users question whether their actions were recognized and understood correctly. It is then important to provide users with perceivable, consistent, and meaningful feedback.

Several other definitions of feedback can be found in the HCI literature and each refers to a particular theoretical perspective and tradition but the basic concept of *loop* is central in all of them. Some models consider also the different polarity of feedback: positive feedback supports change in the same direction, negative feedback in the opposite direction and homeostatic sustains the equilibrium [121].

2.6.1 Measuring feedback efficacy: metrics and evaluation method

Several kinds of usability metrics and methods (quantitative and qualitative) can be adopted. Metrics include subjective judgments on a Likert scale of the perceived efficacy of a feedback as well as objective measurements of the time spent by users to react to feedback. An eye-tracker based methodology can be used to test visual feedback relevance. Intuitively, feedback efficacy assessment is intrinsically linked to the sense involved. For instance the importance of tactile feedback for minimally invasive surgery has been highlighted by [13] on a telepresence system driving a surgical robot.

2.6.2 Feedback in "hand-body" gestural interface

In scenarios where hand or body driven interfaces are used in conjunction with 3D environments/objects, feedback becomes a central issue. In hand/body recognition technologies, the most obvious kind of feedback is the vibro-tactile one, but it should not preclude the possibility of including a visual feedback element or sending an acoustic signal to the user [93]. With regard to tactile feedback, it is important to mention the work by [30] for their interesting optimization of a wearable tactile display. Zimmerman, Lanier, Blanchard, Bryson and Harvill [138] explored how tactile feedback added realism to a virtual world.

2.6.3 Feedback in "implicit signals" based interface

Feedback in implicit interaction systems can clearly change the perception that users have of their experience with such a "strange" interface. A series of works show that feedback plays an essential role in improving BCI users' skill ([37][38][4][135][87][87]). However, feedback can also degrade users' performance due to insufficient attention to other aspects of the interface or because of the presence of frustration caused by incorrect/not understandable feedback. People sometimes become overwhelmed by controlling a technical device with their thoughts, especially during their first attempts at using BCI-based interfaces [101]. Sometimes, incorrect execution of the mental task/command can be the reason for a failure; in these cases, training users with "neuro-feedback", a biofeedback system that displays real-time EEG and illustrates/explains to users their brain activity, can help to improve performance [51].

2.6.4 First guidelines for CEEDS

- Always provide users with adequate feedback, ensuring its punctuality, consistency, intuitiveness, and perceptibility.
- Feedback from 3D touch-less interaction (see CEEDs's Commercial Scenario) should be carefully considered and provided. The possibility of providing vibro-tactile, acoustic or multimodal feedback should be explored.
- Feedback of implicit interactions (e.g. CEEDs's Neuroscience Scenario) should be carefully considered (visual, vibro-tactile, acoustic or multimodal feedback).
- Given its novelty, CEEDs interface could have usability issues still unknown in the literature; adequate natural feedback should be ensured.
- Users often need specific training to recognize feedback of implicit signal based applications/interfaces (e.g., BCI systems).

2.7 Reduced mental workload

Mental Workload is a psychological term indicating the amount of mental effort perceived by a person involved in a specific task [42]. The original concept comes from the cognitive ergonomics model outlined by the Human Information Processing (HIP) paradigm. The human cognitive system is considered as an information processing system of limited capability. The limited amount of cognitive resources forces the user to invest all his/her effort on executing a difficult task. Depleted of all the available cognitive resources, performance in that specific task will not improve, but will remain stable or worsen. Norman and Bobrow [93] define that specific task 'resource limited'. Then, mental workload is a measure of the resources used by the information processing system to accomplish a particular task [96]. Mental workload is also multidimensional construct that reflects the individual attentive involvement and mental effort [134].

System design, as much as software design, has to take into consideration the user's mental workload, since it directly influences the effects of work on the user as well as the development of the user's abilities and skills. General design guidelines, which are however to be strictly connected with the nature of the task, equipment, environment and work organization, can be the following:

- Organizing correct training for the interactive system;
- Optimizing, instead of reducing;
- Avoiding over-load as well as under-load;
- Taking into account qualitative differences in mental workload required by different systems;
- Investigating the quality and intensity of the mental workload as well as its duration and distribution over time.

More specifically, to reduce mental fatigue and monotony and to increase satisfaction and vigilance, designers are recommended to [85]:

- disambiguate the task goals and offer consistent information;
- consider the dimensionality and dynamics of control movements;
- fix compatibility problems, and reduce time pressure;
- reduce or avoid repetitiveness and monotonous environmental conditions;
- avoid structurally similar tasks and low signal detectability.

2.7.1 Measuring mental workload: metrics and evaluation methods

Mental workload and performance strongly depend on the task, individual strategies as well as individual differences. Several measurement methods exist to quantify mental workload: subjective measurements, in which the user at the end of the task provides the feedback through questionnaires or interviews; behavioral measurements, in which the quantification is provided by task indices of performance (number of errors, reaction times); physiological measurements, performed with heart rate and respiratory frequencies, evoked potentials, eye movements and pupil dilatations [52]. Different studies suggest that workload can be measured using the dual-task paradigm: users complete a task interrupted at different times by a signal (usually a tone), to which they have to respond as quickly as possible. The amount of time necessary to respond to the signal is considered to be the amount of mental workload used to complete the main task [22].

O'Donnell and Eggemeier suggest five criteria for the selection of a mental workload measure [96]: sensitivity, diagnosticity, primary task intrusion, implementation requirements and operator's acceptance. IEEE Standard 845-1999 provides other important criteria: acceptability (agreement among experts in the field), accuracy (minimal potential for error), applicability, bias, precision and reliability.

A system that regulates notifications using the measures of the user's mental workload was presented by [11]. To measure mental workload Heart Rate Variability signals and electroencephalogram were used. The system, named Physiologically Attentive User Interface (PAUI), uses mental workload measurements in order to register four different user's states: at rest, moving, thinking and busy. The PAUI was implemented in a mobile phone to automatically regulate the arrival of notifications. PAUI's activity to measure or to regulate notifications could be managed completely by the user. An evaluation showed that PAUI appropriately selected the notification level in 83% of cases.

2.7.2 Mental workload in "hand-body" gestural interface

According to [130] "having to recall gesture trajectories, finger configuration and associated action is likely to add to user's mental load". Natural gestures, if well contextualized and afforded by the graphic environment can minimise this problem.

2.7.3 Mental workload in "implicit signals" based interface

Mental workload in implicit technologies can be directly evaluated by the system. [137] adopted BCI and/or other physiological input devices to identify the user's mental workload and, consequently, to influence the digital environment. In [92], the mental workload level was used as a trigger to change the state of the avatar in a multiplayer game. As a result, users found this kind of interaction with the interface engaging and intuitive.

On the other hand, it is important to reduce any risks to the user's health connected to stress level, increased blood pressure, hyperventilation, especially when the users are successfully engaged in the task [19]. Activation is a natural response to an exciting and engaging computer game. For this reason, applications that encourage users to self-regulate their psycho-physiological state should emphasize "healthy" mental states (see [81] for an investigation on videogames).

2.7.4 First guidelines for CEEDS

- use natural gestures;
- check for the users' conditions during the usage of the system (stress level, increased blood pressure, hyperventilation);
- design the feedback so that careful that it encourages a healthy mental state.

2.8 Pleasantness

Pleasantness is a dimension of satisfaction that only relates to the aesthetic satisfaction felt by the user during the usage of the tool, regardless of the effectiveness of this tool. This excludes other aspects that can positively affect the experience of using a tool: the absence of annoying events (e.g., breakdowns, inconvenience of use, after-effects), also called "goodness" of a tool [43], as well as the way in which the technology fulfills expectations and supports the activity. Pleasantness is connected to aesthetics and to affectivity. In a study on the factors underlying web aesthetics with exploratory and confirmatory factor analysis, [71] two main dimensions were identified: "classic aesthetics" and "expressive aesthetics". The former resides in applying rules of order and clarity in design (e.g. [126]) and is especially important when displaying complex information. The latter consists of the designer's ability to break conventions and show creativity. Regarding affective usability, attractiveness has great impact on usability [59], therefore taking it into account can alone improve the ratings of an application and the user's satisfaction with it [95].

2.8.1 Measuring pleasantness: Metrics and evaluation methods

Pleasantness is typically a subjective dimension investigated by directly asking the user. The Software Usability Measurement Inventory [60] measures if an interface has any superfluous element that risks confounding the users and overloading the cognitive system. Users rate a product according a certain dimension on a differential semantic [43], or 10-point scale [127]. Rafaeli and Vilnai-Yavetz, [104] interviewed experts in aesthetics and coded their statements. A different approach was adopted by [139], who collected information about the aesthetic value of a product with an implicit, projective technique based on choosing the clothing style of the ideal user of the evaluated product. This is considered to offer a general impression of the perceived aesthetic quality of the product to the designer. The resulting manikin is then assessed on a differential semantic scale, with self-assessment manikin answer scales, where each point on the scale is symbolically illustrated by a manikin, with personality scales as well as with direct questions about the product.

2.8.2 Pleasantness in "hand/body" gestural interface

Complex gestures do not work well as input modalities although they might seem fancy after appearing in movies and fiction: very familiar gestures are preferred (e.g. [21] on input modalities on large screens), especially if the technology application is designed to be used by novice users who do not have time to develop a familiarity with peculiar usage practices. This will increase user satisfaction on the user's first experience with the system, when the user tries out movement that s/he already knows to see how the interface reacts (e.g. [49]). Gestures should not to lead to physical fatigue [89] except in applications where working out is the goal.

2.8.3 Pleasantness in "Implicit Signals" based interface

In everyday life applications, the time taken to calibrate and to train the user [4], as is the case with BCI applications, might discourage people to approach an interface based on reading physiological parameters or on recording brain activity. In this case, state-of-the-art solutions should be adopted to reduce the time required to calibrate the system. Another obstacle can be that for some users a system based on implicit brain signals are not accurately detected and the application does not work with them. To prevent delusion, users must be alerted that the process does not fit them [4].

2.8.4 First guidelines for CEEDS

- Attractiveness might not be pursued at the expense of usability; very familiar gestures are to be preferred as input modality even though they do not seem fancy (e.g. [21]);
- Even the first approach with the system must be pleasant: therefore the interface should capitalize on movement that the user already knows;
- Include gestures that do not exhaust the users physically [89], [109] unless this is the primary goal of the application;
- Prevent delusion by raising the right expectations in the ability of the machine to detect users' implicit signals, including the possibility that for some people the system might not work well [4];
- Reduce the technical time needed to calibrate the tool, which might reduce the positivity of the experience and the attractiveness of the interface [4].

2.9 Acceptance

Acceptance relates to the user's willingness to adopt a certain tool. Although it is sometimes considered synonymous with satisfaction with a certain device, acceptance is related here to the actual adoption (or even the adoption intention, e.g., [45]) of a certain technology. The relevance of this concept is especially high when the device is to be rejected by the user, e.g. a system sending notifications to the users at home [45]. Organizational studies and social informatics have also highlighted that acceptance is affected not only by the effectiveness and satisfaction experienced after using the tool, but by a series of individual, and social expectations and by symbolic and political constraints [1], which can facilitate or prevent the full adoption of a tool by individuals or by groups [62]. To favor acceptance of a technology the basic suggestion is to involve the target users in their design [7], so that any possible resistance against adopting it can emerge early in the design process. A specific type of acceptance is social acceptability, which has to do with the perceived effect that using a certain technology will have on other people [106][107].

2.9.1 Measuring acceptance: Metrics and evaluation methods

Acceptance can be quantified by measuring the actual usage of a certain tool, especially when this measure can be automatically collected as with websites. Social acceptability of a set of gestures has been measured with ranking expressed on a worksheet and semi-structured group interviews [108] to groups of people familiarizing themselves with the device prototypes. The prototypes used were mock-ups: they did not respond to the actual gestural command except by confirming the correctness of the gesture execution with a green light. The same authors also used a web survey to test the appropriateness of a certain gesture to location and audience and an in-field trial of mock-ups [109]. The survey included a video of the gesture and a list of locations and audiences among which to choose the preferred one for that gesture. A set of in-field trials simulated the actual, repeated usage of the gesture-based interface (a mobile phone), each one followed by a semi-structured interview of the reasons why they liked a certain gesture or not.

2.9.2 Acceptance of "hand/body" gestural interface

An aspect that can prevent acceptance of gestural interfaces is the possibility that the necessary gesturing and bodily movements are embarrassing to be performed in public. Thus prototypes should be tested for their social acceptability early on [108], as well as the location and likely audiences where they are to be used [109]. Consequently, it is recommendable to use familiar gestures whose meaning and purpose is already acquired and fits the application context. In addition, device based gestures that clearly show the relationship of the gesture to the device interface are preferable to free gestures that can be misunderstood with communication acts or those that are simply considered bizarre. [109].

2.9.3 Acceptance of “Implicit Signals” based interface

A technology using implicit signals can make the user suspicious on the use of information whose existence is unknown to him/her. This is especially true if the personal data collected is sensitive (e.g. medical). Provisions to avoid this suspicion and to effectively protect the users’ privacy are included in CEEDS ethical guidelines.

In addition, some application scenarios might be considered difficult to be accepted: users might agree to release their personal data for research purposes (see 2.11 in this document) but not for commercial purposes. Again, respecting the users’ rights and transparency about the provisions made to protect his/her privacy is a good way to obtain his/her trust.

2.9.4 First guidelines for CEEDS

- Test early prototypes for their social acceptability, also considering the location and audience to which they are addressed [108] [109];
- Use familiar gestures whose meaning and purpose are already acquired and fit the application context;
- Use gestures that are clearly directed to the interface or involve the use of a device [109];
- Avoid users’ suspicion of and lack of trust in the system by disclosing the nature of the information extracted, and its exploitation. Apply the specific recommendations contained in CEEDs ethical guidelines (D10.2).

2.10 Credibility

This dimension refers to the extent to which the user perceives a technology and its content as credible and trustworthy [23]. It is likely that all aspects of a technology are potentially scanned for cues to make a decision about its credibility. Social psychologists maintain that an object is judged as credible after processing its characteristics either peripherally/heuristically or centrally/systematically. When there are not enough resources to process an object thoroughly, users rely on heuristics [119]. A distinction between different factors affecting credibility was made by [23] with respect to websites: credibility based on the experience of the user with that product (“earned”), on shared assumptions about the product (“presumed”), on a superficial inspection of the product (“surface”) or on third parties judgment about the product (“reputed”).

2.10.1 Measuring credibilty: Metrics and evaluation methods

Credibility in a message source can be measured with questionnaires testing the extent to which various factors concur [24].

2.10.2 Credibility of “hand/body” gestural interface

There are no specific guidelines, except for the general requisite that the input be recorded and responded by the application appropriately and timely: lack of accuracy in functioning would decrease the credibility of the system ([23] [130]).

2.10.3 Credibility of "Implicit Signals" based interface

Credibility must be pursued since it can be a vehicle to obtain trust, which can be a problematic achievement in a technology capturing personal implicit data. Common recommendations are showing the expertise of the source, declaring the scientific nature of the project, avoiding breakdowns in the system functioning or providing accurate information increasing the credibility ([23] [130]). Also providing the reasons behind the way in which a certain output is provided in the form of a simplified explanation can increase its credibility [71]. The more clear the connection between the users' signal and the output, the higher will be the learning value of this information [63].

2.10.4 First guidelines for CEEDS

- Care for accuracy: input must be recorded and responded to by the application appropriately and timely; breakdowns in the system functioning should be avoided (see also 2.6); the information should be stored and its navigation must be checked for correctness;
- Show the expertise of the source, declare the scientific nature of the project ([23] [130]);
- Provide simplified explanations of the way in which the output is provided [71].

A specific task on credibility will be conducted in the CEEDs project (T7.3). Therefore more specific recommendations will be outlined as part of that activity starting from the second year of the project.

2.11 Preliminary tests of CEEDS's technical components

Smartex Wearable Wellness System (WSS) is a wearable fully integrated system able to acquire several physiological parameters from the human body: heart rate, respiration, posture, and movement. The Smartex system is particular useful for CEEDs purposes because it can simultaneously provide different kind of signals without causing any discomfort to the user compared to traditional devices; it also allows the user to move naturally in several environments (e.g., running, swimming) where conventional monitoring is difficult [119][82].

The system is composed of a vest, available for men or for women, which can be worn under normal clothes. The vest contains two ECG electrodes (lead I) and a strain gauge mounted on it. The same strain gauge is also available on a band. The strain gauge detects a breathing signal and the electrodes detect cardiovascular parameters. Data can be stored internally on a memory card and/or transmitted via Bluetooth to a PC. The software also permits data visualization in plots and, using an API written in c#, to write applications to collect and analyze data online.

ECG and respiration are monitored via sensors that are fully integrated into the fabric structure, made of yarn; posture and movement are controlled by a 3-D axis accelerometer placed on the motherboard of the electronic device (SEW3, by CSEM). The SEW system integrates algorithms that pre-process raw data and return measures of several physiological parameters:

- a full electrocardiogram
- heart rate
- R-R peaks
- breathing
- breathing rate
- analysis of movement level
- type of activity (running, walking, lying, etc.)
- energy expenditure

We started from this device the testing activity within CEEDs. We tested both the accuracy of SMARTEX heart rate measures compared to traditional (i.e., non-wearable) devices for physiological signals detection and the user acceptance in different scenarios.

In a first test we explored accuracy and wearability of Smartex Wearable Wellness System in four different movement conditions. The step counter included in the Smartex Wearable Wellness System was also considered; although its prior goal is to support signal filtering from artifacts, we considered its output as a possible pedometer and compared it with a dedicated software developed by us to count the steps on a Nintendo Balance Board. The reliability of the software was validated manually. Six participants, selected at random, were asked to walk on the balance board following a random Beat-per-Minutes fixed metronome (varying from 40 to 200 BPM). The tasks were video-recorded and steps were counted offline by using video-analysis software Noldus Observer XT. The software developed for the extraction of pacing from the Balance Board Device was written in C# language using wiimotelib C# library which derives a signal from the balance board connected via Bluetooth to a PC. The balance board consists of four digital pressure sensors located near the four corners of the device and acts basically as a digital balance. The algorithm used to detect steps identifies when one of the two front sensors reaches a threshold of 40 Kg with increasing slope, in which it is assumed that the person stands on one leg, and therefore moves a single step.

In a second test we explored the characteristics of Beddit, a sensor that can be adjusted in beds or sofas and recognizes physiological signals. Below we describe the two tests.

TEST 1] Eleven male university students with an average age of 24 years (SD = 1.1), were recruited for the study. Every participant signed an informed consent, wore the SMARTEX band and a BFD2000 pulsoximeter. Participants were asked to complete four different tasks:

- lying on a sofa (low stress) for 240 seconds;
- standing (low-moderate stress) still for 240 seconds;
- walking (moderate stress) on a balance board following the rhythm of a metronome set at 60 BPM;
- running (high stress) on a balance board following the rhythm of a metronome set at 168 BPM.

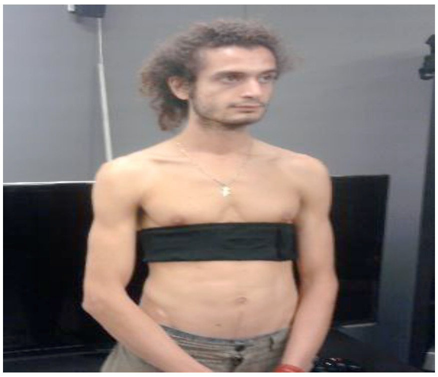


Fig. 3 - ***A participant wearing the SMARTEX band***

During each task, the heart rate recorded by SMARTEX and BFD2000 was synchronized and collected every 10 seconds through ad hoc software developed by us. For the last two tasks, which imply some body movement, number of steps was also recorded. In order to measure the discrepancy between the two instruments, the relative error was calculated for each pair of values, i.e., the value returned by SMARTEX and the simultaneous value returned by BFD2000. The formula: e=(a-b)/b*100 was used, where "a" is SMARTEX value, "b" is BFD2000 value and "e" the error. The result is shown in Fig. 4 -

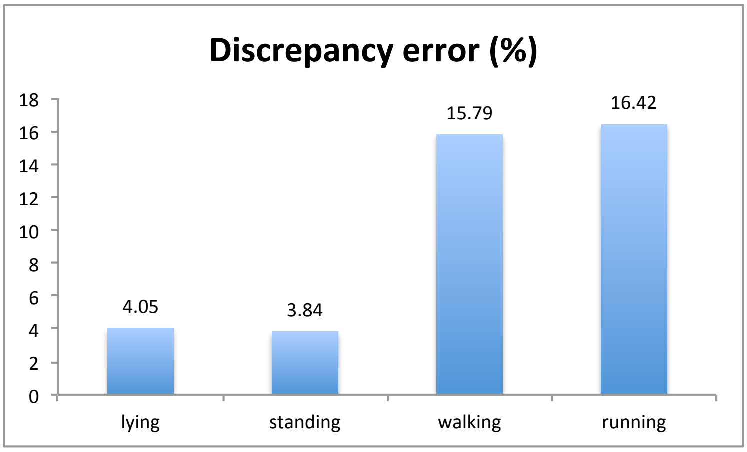


Fig. 4 - ***SMARTEX vs BFD2000: Average discrepancy per participant in the four tasks***

The SMARTEX data distribution and the Biofeedback 2000 data distribution were more similar in the tasks in which participants' movements are absent or slow.

Regarding the step counter, steps were measured every 10 seconds. Only in task 4 did a t-test show a significant difference (p<0,05) in half of the cases (data from task 3 could not be analyzed due to a high failure rate from the device).

TEST 2] In a second preliminary work we tested the Beddit system (Fig. 5 -), which adopts a pad of variable dimensions with a ballistocardiography (BCG) able to detect heart rate. The device can detect the signal also through a mattress or a layer of clothing and could be adopted in scenarios where people stay on a comfortable chair, on a bed or wherever it would not be possible/convenient to ask the user to wear a sensor.

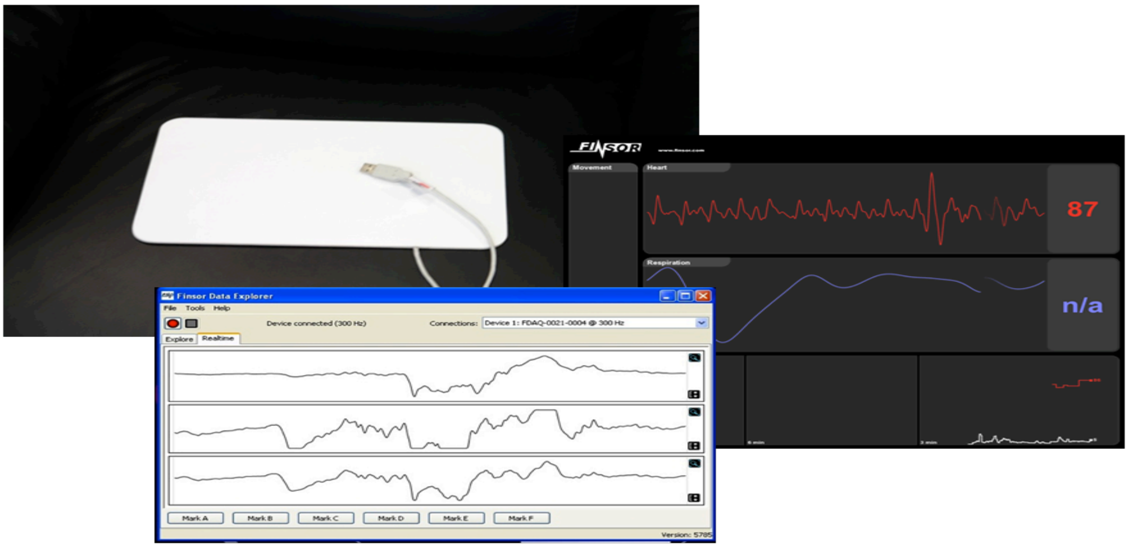


Fig. 5 - ***Beddit Ballistocardiographic device and related software***

Two pieces of software were developed using Java language; one extracted the measurements from the Beddit device and computed the mean value every 5 seconds, the other software extracted the measurements every 5 seconds from SMARTEX.

Participants' heart rate was measured in two different conditions: lying on a sofa and sitting on it. In the first case the participant was sitting on an armchair, wearing the Smartex WWS and the Beddit technology was placed under their bottom. In the second condition the participant was asked to lie in the supine position on a sofa, wearing the Smartex WWS. The Beddit pad was placed under their chest. Participants were asked to stay calm and relaxed.

21 students were recruited for this experiment. They were all men, aged 24 years on average (SD = 3.7). Three participants had to be eliminated during the analyses because no measure was recorded during the tasks.

Results (Fig. 6 -) showed that the two technologies differ in providing heart rate measures for less than 2% in both conditions.

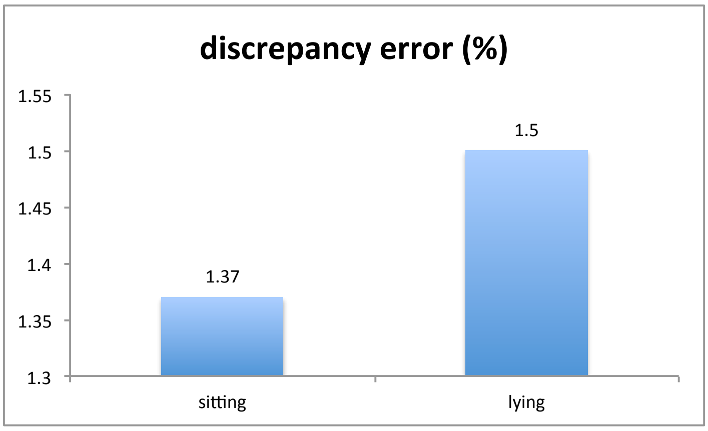


Fig. 6 - ***SMARTEX vs Beddit: Average discrepancy in the two conditions***

An exploratory 12-item questionnaire was also administered to the participants after the Beddit test, to investigate SMARTEX acceptance and usability (mainly wearability). Participants, who had already worn the band during the test, were asked to wear the vest. Then they filled in the questionnaire.

The questionnaire started with a short description of SMARTEX technology. Then the respondent was asked to imagine 4 different scenarios, one at a time, involving a specific application of SMARTEX technology: commercial, home medical care, physical training and research. The respondent was asked about the likelihood and reason for wearing SMARTEX in each scenario. Finally an item inquired about the amount of money participants were likely to spend on such a device. All items but the last one were answered by expressing the agreement with the assessments on a five-point Likert scale (5= I totally agree).

The results are reported below. Acceptance is shown when scores are low, apart from negatively formulated items.

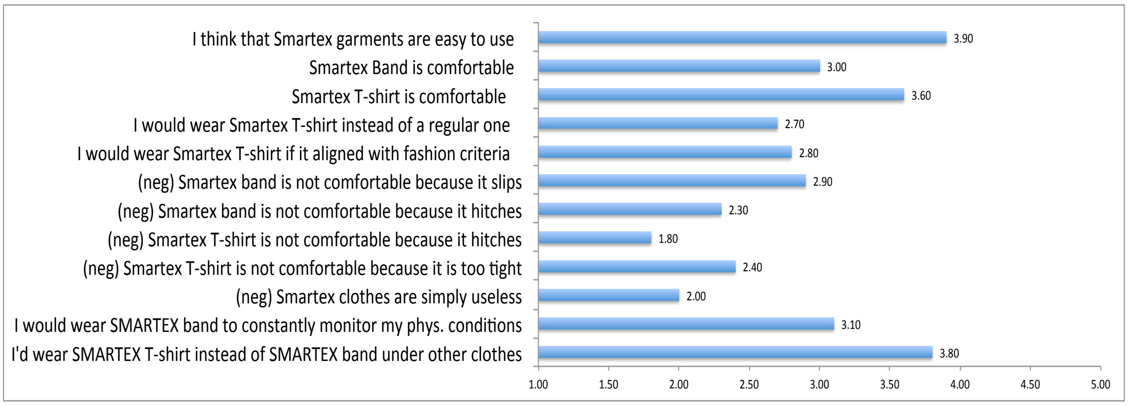


Fig. 7 - ***Average answers to the usability items in the questionnaire.***

Although only exploratory and somehow decontextualized, the answers show that SMARTEX is perceived as an easy-to-use technology that does not give particular discomfort to the wearer (Fig. 7 -). Preference was given to the vest garment compared with the band.

The answers to the questions related to specific scenarios are listed in Fig. 8 - Fig. 9 - Fig. 10 - Fig. 11 - below. Being a preparatory test, the results should be read while keeping in mind that participants were inquired about imaginary scenarios they were not experiencing and about which they might not have any familiarity.

Scenario 1: commercial

“Imagine to wear SMARTEX clothes in your daily life. As you enter a shop, SMARTEX can connect with the store and suggest your preferences based on your physiological parameters.”

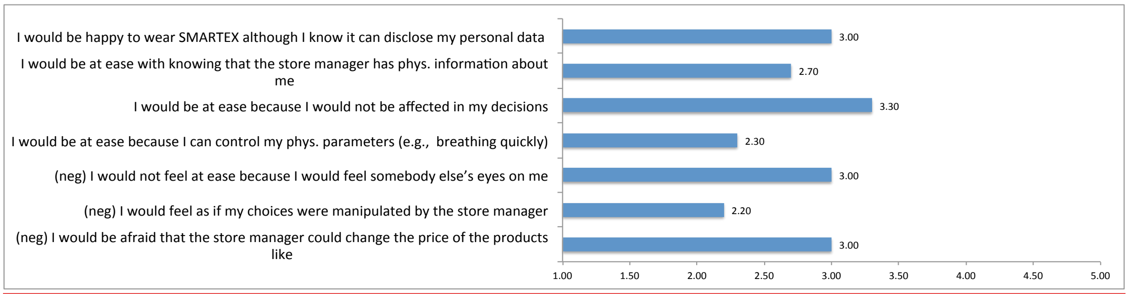


Fig. 8 - ***Answers related to scenario 1 (commercial)***

Scenario 2: Now imagine that you are at home. SMARTEX can constantly monitor you by talking to your pc and can alert you and your physician immediately if any physiological parameter changes dangerously

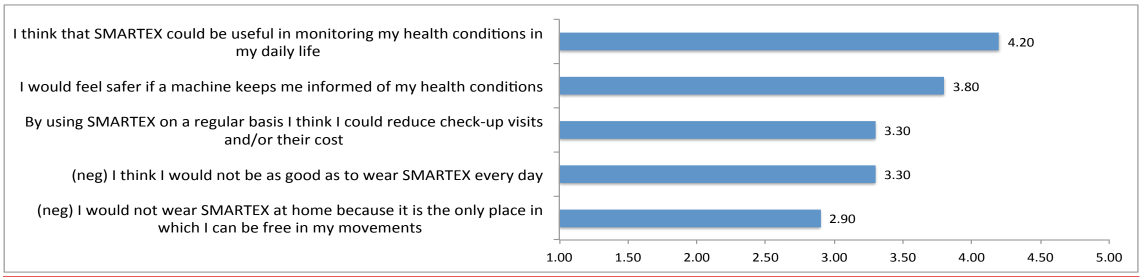


Fig. 9 - ***Answers related to scenario 2 (home medical care)***

Scenario 3: Now imagine that you are working out. SMARTEX can collect physiological measures and store them in your pc or smart phone to visualize them later.

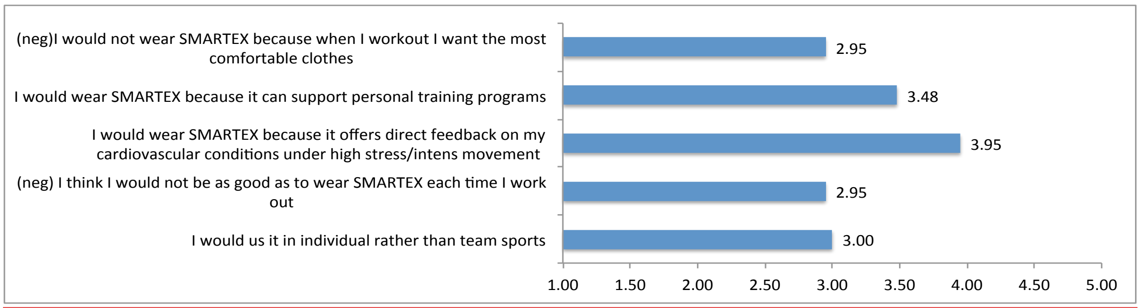


Fig. 10 - ***Answers to scenario 3 (sport)***

Scenario 4: Now imagine you are in an experimental setting. You are wearing SMARTEX clothes while the researcher has instructed you to execute a task. SMARTEX can help the researcher by giving him/her some physical parameters, of which you are not even aware of.

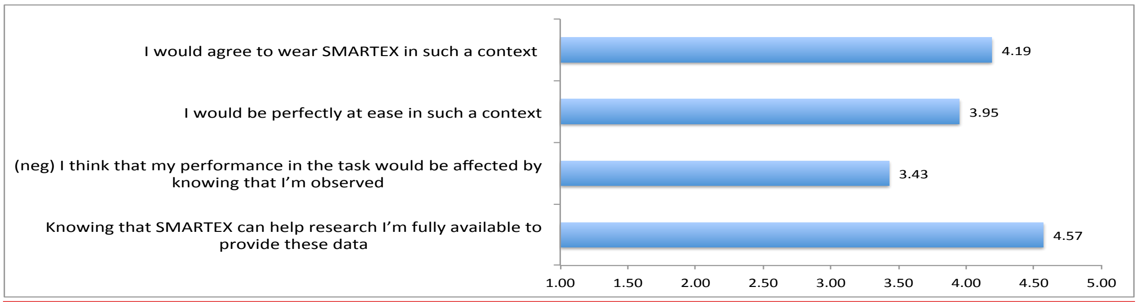


Fig. 11 - ***Answers to scenario 4 (research)***

People do not know if they are able to use SMARTEX every day, but they largely agree about its usefulness. When asked how much they would you spend on such an item, they answered on average 95 euros (SD = 110).

Finally, there seemed to be some user suspicions because of the possible violations to privacy (dissemination of personal data), especially in the commercial scenario where the score is quite low (but never negative). When users where asked to express their agreement to wear Smartex, the answers collected in the different scenarios were higher in the research scenario and lower in the commercial scenario.

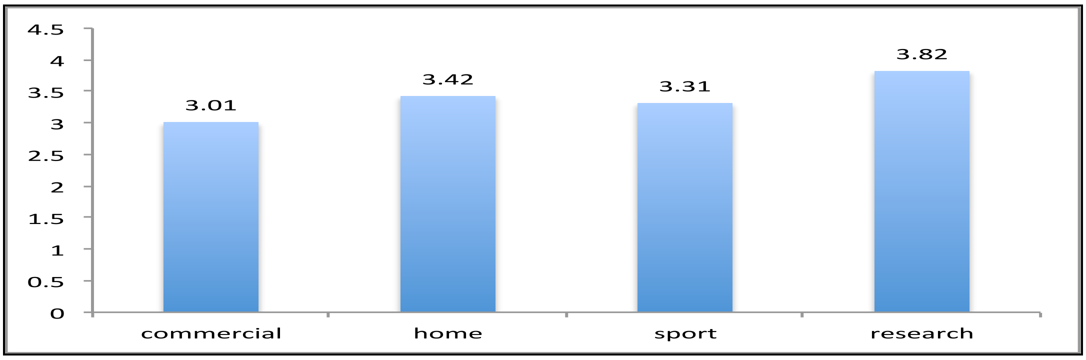


Fig. 12 - ***Average agreement to wear SMARTEX in each scenario***

Work on preliminary testing of CEEDS components will continue during the next year with the goal to test other input/output interface (eye tracking, dataglove with vibrotactile feedback, etc). Acquiring this knowledge supports the work in WP8, orients the scenario design and details some of the technical applications.

2.11.1 Conclusions from preparatory tests

The tests conducted suggest that:

- acceptance risks may be lower for commercial scenarios; therefore, applications need to address participants' concern about exploitation of data and privacy rules, providing users with a clear idea of whom will be benefited.
- accuracy of heart rate measures can be critical when the participant performs large movements (walking or running); therefore the usage of the interface should not involve these kinds of movements when heart rate (and possibly other physiological) data are inputted, or movement artefacts will compromise data interpretation.

3 Spatial cognition and actions in technologically enhanced spaces

3.1 Introduction

3.1.1 Goals

Virtual representations – such as those supported by "visual environments" like the XIM in CEEDs - can improve the users' interaction with complex amounts of data. Task 7.2 explores the interaction with objects in mediated/virtual spaces and investigates the process through which such space is defined.

First, we will introduce the concept of near and far space from a neurocognitive and neuropsychological perspective, illustrating the literature on peripersonal/extrapersonal space, spatial attention, neglect and pseudoneglect in animals and human beings. Second we will introduce the research work conducted during this first year which comprise four experiments aiming to advance our knowledge of the way in which we use our brain, our cognitive system and our body to recognize and to act in near and far spaces. Based on the neuropsychological paradigms of line bisection we could investigate user's spatial cognition (mainly visuospatial attention) in near and far space, when using (or not using) different tools, which are more or less able to extend the body/brain capabilities.

In synthesis, with this experiment series we pursued two aims:

- To investigate spatial cognition in 3D mediated spaces and highlight the neuro-physiological correlates of spatial cognition in virtual space, the role of body/hands in 3D natural interaction and the role of tools in modifying spatial perception and attention.

- To test new technical and methodological solutions for doing research on human factors in confluent systems.

3.1.2 Scientific background: the neurocognitive dimensions of the space around us

Moving our body throughout the natural environment involves the brain constantly monitoring body position and movements in relation to near objects. The brain has to compute a neural representation of our body, the 'body schema', and of the space surrounding our body, the 'peripersonal space'. (Head and Holmes [44] divide the body schema into two separate schemas: the first, the postural schema, is represented by the body position and movement, and principally arises from kinaesthetic and proprioceptive afferent impulses; the second schema arises from skin afferent impulses that inform the body about the tactile stimulus position. Body schema also involves visual and auditory information.) Peripersonal space is defined as the space immediately surrounding our body [110]; objects within peripersonal space can be manipulated. Objects beyond this space, the 'extrapersonal space', cannot be reached unless the user moves toward them [101] Then, the brain elaborates peripersonal space objects representation differently from the way in which it elaborates objects located in the extrapersonal one. The former is more complex and involves more sensory information modalities than the latter. This difference is supported by the observation that, after a brain damage to the right hemisphere, some patients show behavioural deficits in objects perception within the peripersonal space, for example in finding the true centre drawn on a sheet of paper, but show less difficulties when they are asked to find the true centre of line with a laser pointer when presented in the extrapersonal space [40]. The multisensory representation of peripersonal space is plastic: when humans and animals see themselves in a mirror or on a monitor, or when they look to artificial body parts, their peripersonal space representation is altered creating a new perceptual visual configuration of the body with respect to the surrounding environment. Those situations produce conflicts between different senses: in a mirror, on a monitor or when looking at artificial body parts, we see our body appearing in a certain position, while we proprioceptively feel that it is in another position ([32][33][76][77][8][98]). Inanimate objects can also extend our body limits and has important implications for how humans perceive peripersonal space; for instance, inanimate objects, like tennis rackets or bicycles, could be incorporated in what Head and Holmes [44] call ‘body schema’. In turn, the comprehension of how our brain represents body and peripersonal/extrapersonal space has important implications for patients with attention deficits, like neglect and extinction. This understanding could also help to develop tactile virtual reality technologies [46], prostheses for amputees [105][106] [113] and navigational supports for those who suffer from visual deficits [48].

The neural representation of peripersonal space is constructed within a network of cortical and sub-cortical areas that interact with each other. The representation of the space surrounding the body and individual body parts that can be reached by the hands needs the brain to elaborate the arms’ position in the space. This representation can be produced through various different reference systems, for example centred on the body or centred on the eye. The term reference system is used to define the centre of a coordinate system that represents the objects and their relations [10]. For example, if we imagine that we are sitting in a kitchen while watching a coffee cup over the table, its position can be described with different reference system: relative to our eyes the cup is straight in front of us; relative to our left arm, instead, the cup is on the right; cup position could also be described with a reference system that depends on the external world, for example, the position relative to the table. Then, a retinotopic reference system will take every retinoic fovea as centre and will represent visual objects relative to this origin point. In a reference system centred on the head, instead, objects will be represented independently from the eye movements, and in a reference system centred on the body, objects will be represented independently from the head and eyes movements. Reference systems centred on both the body or body parts are important in the representation of peripersonal space. A reference system centred on the body, and representing topographically the body surface, exists in the primary somatosensory cortex and in other brain areas (secondary somatosensory cortex, putamen, premotory cortex, primary motor cortex). Visual signs received relative to the body parts position could be addressed to the zones interested in this somatotopic representation to transmit the visual space around the individual body parts. It is possible that the brain uses the most appropriate system to compute information: for visual signs it uses a retinotopic system; for the eyes movements it uses an eye-centered system; last, for auditory signs and head movements a system centered on the head [10]. For the visuotactile peripersonal space and for the control and representation of the body position and movements, the most appropriate reference system seems to be the one centered on individual body parts. Several brain areas were discovered that code multisensory spatial maps with a reference system centered on individual body parts, like putamen, area 7b , and the intraparietal ventral cortex (VIP) [34][35].

The human peripersonal space was studied and analyzed through experiments both with brain damaged patients and with normal persons [67], [77], [94]. The goal was to discover if the same principles documented for animals, could be applied to humans. The findings on humans demonstrate that the visuotactile spatial interactions centered on the hand change relative to the position of the hand in the space, and confirm that visuotactile peripersonal space is represented according to a coordinate system centered on body parts, as shown before through the studies on single neurons in the monkey’s premotor and posterior parietal cortex [29]. Definitely, deficits discovered in neuropsychological patients seems to reflect the same multisensory integration principles found on monkey premotor cortex single neurons [29][32][38][41][66][68][69][70][80][97][111]. Peripersonal space representation is centred on the body or body parts, confined within the space immediately surrounding the body (with a 20-40 cm extension from the monkey skin surface and 70 cm for humans) and involves the information integration from multiple sensorial modalities (somatosensory, proprioceptive, visual and auditory).

Welch et al. [133] demonstrated that an active control of the virtual environment by the users, compared to a passive one, enhances the sense of presence. Technology actually represents an invisible extension of our body and the adaption of our body to it is made possible by our natural brain plasticity. In terms of space segmentation, peripersonal and extrapersonal space, telepresence technologies and virtual reality interactions could represent an attempt to overstep the limits of this space segmentation. Biological artifacts, like artificial hands or common tools, could represent body extensions and are of high relevance in the telepresence and virtual reality field. Understanding the conditions that underlie this integration has implications in the design of virtual environments, teleoperative systems and in the body representation modalities throughout those mediated spaces.

3.2 Experiment 1 - Neural correlates of peripersonal and extrapersonal space: an fNIRS study

Neuropsychological and behavioral studies have shown that different cognitive mechanisms are involved in coding peripersonal (within reach) and extrapersonal (beyond reach) space. A valuable method in investigating this dissociation consists in using the line bisection task in healthy participants. Recently, the line bisection task was simulated using immersive Virtual Reality (VR)[27]. The main goal of the present study is to investigate brain activity with the functional Near Infrared Spectroscopy (fNIRS) brain image technique [26], while performing a (line bisection) task in an immersive Virtual Environment (VE). This research represents one of the first attempts to investigate the neural correlates of immersive VR experience with fNIRS. According to the results of a PET investigation of line bisection [132], parietal lobe is expected to be highly activated in bisection within peripersonal space while parieto-occipital lobe is expected to be highly activated in bisection within extrapersonal space.

3.2.1 Objectives

The goal was to find a valuable solution for a correct signal acquisition with fNIRS during an immersive VR task. More specifically, the study aimed:

- to implement fNIRS technique during 3D experiences;
- to acquire a correct signal registration when immersed in VE;
- to verify which brain areas are activated when performing a line bisection task in peripersonal and extrapersonal space.

3.2.2 Tools

Participants

Eight right-handed males with normal or corrected-to-normal vision took part in the experiment (M = 27.6 years, S.D. = ±2.3 years, range = 24-36) after providing their informed consent. None of them reported a prior history of neurological or psychiatric disorders, and none was under medication at the time of testing.

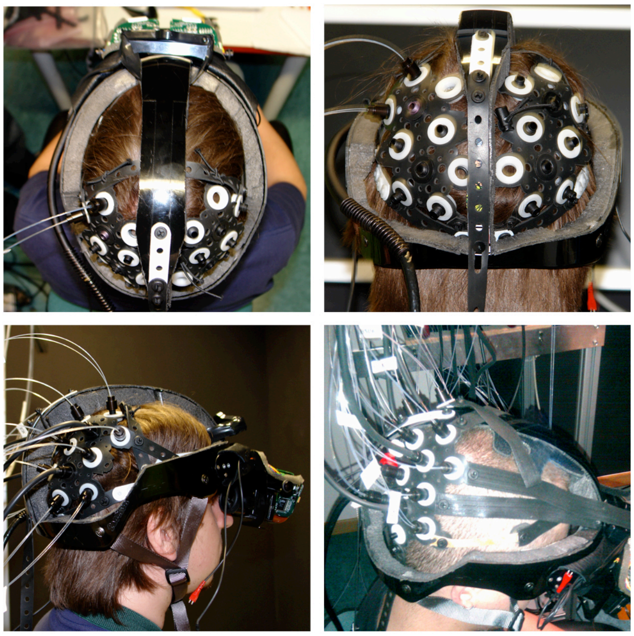


Fig. 13 - ***Views of the virtual reality helmet adapted to host fNIRS fibers.***

Apparatus and Stimuli

Participants saw the virtual environment through an adaptation of a V8 Research HMD (Head Mounted Display). V8 Research HMD LCDs were taken from the original helmet and attached to a bike helmet that was modified in order to reach brain areas from the fNIRS optical fibers (see Fig. 13 -). A Velcro belt was attached at the back of the helmet in order to counterbalance the effect of the LCDs' weight in front of the helmet. This belt was subsequently secured to the participants back through a thoracic belt. An Intersense tracker was mounted above the LCDs, in order to allow the participants to be completely immersed into the environment (see Fig. 13 -). The virtual environment was created using 3DStudio Max 8.0 for the development of three-dimensional objects and Virtools 3.5 for the interaction with them. A virtual room was created with a "wooden" table in the centre. Above and aligned with the table's centre, was a white panel (50 x 50 cm) for displaying horizontal lines. In the panel's centre there was a bracket; on the left of the panel there was a telephone, while on the right some books (see Fig. 14 -). There were two viewer-line distances: 60 cm and 120 cm. Line lengths were 4 and 8 cm at the distance of 60 cm, and 8 and 16 cm at the distance of 120 cm (subtending a visual angle of 3.82° and 7.54° for each line pair 4-8 and 8-16 respectively). In front of the table there was a mobile chair with wheels that served for the participant, as he was instructed that, once he was seated, he could move along the two distances through that chair. Virtual lines were planes (i.e., a type of 3D object primitive used in computer graphics) 2-mm thick. To guarantee high precision in the response acquisition each centimetre of each line was subdivided in 4 segments, resulting in 0,25 mm for each segment. To decrease normal aliasing provoked by three-dimensional lines, line textures of the same dimensions were superimposed above virtual lines. To simulate the laser pointer, a Nintendo Wiimote was used. The Wiimote operates as a normal mouse throughout the software GlovePie (http://glovepie.org/). In the virtual environment the Wiimote moved a 2.5 mm red dot as a simulation of the same one represented by a real laser pointer. The virtual red dot was represented by a 3D cone whose tip could collide with the lines, giving the point of contact over them (i.e., the bisection point). The A button on the WiiMote served to memorize the response (the last point of contact over the line) and to switch to another line and/or distance. The virtual environment was perceived stereoscopically as two points of view. That is, two cameras outdistanced by 2 cm were created as a simulation of the left and right eyes: the left camera for the left LCD and the right camera for the right LCD. The task was divided in two blocks: the experimental block and the control block. The experimental block consisted of 72 stimuli in which the participant had to bisect the lines. The control block consisted of 36 stimuli in which only the right extremity of the lines had to be reached. Lines and distances presentation was randomized. The order of blocks was counterbalanced across participants.

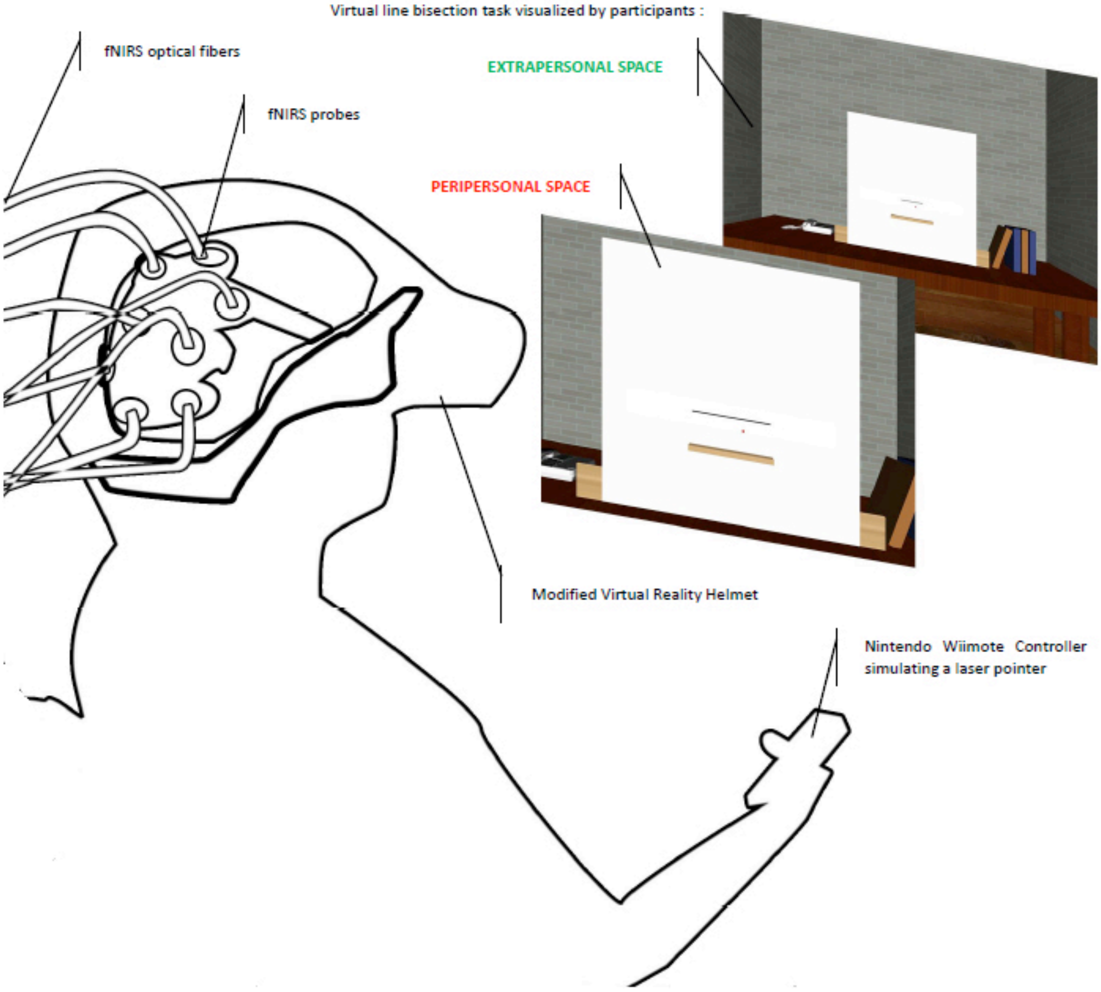


Fig. 14 - ***Sketch of the experimental setting.***

3.2.3 Procedure

After filling in the informed consent, each participant read the instructions to complete the experimental task. Then the participant was invited to seat in a comfortable chair placed inside a sound-attenuated and dimly lit room, where the virtual reality helmet and the NIRS optical fibers were placed on his/her head. Before starting the experiment the participant was instructed to remain as steady as possible during the experiment and to avoid repetitive movements. The participants performed a training task in which 16 lines were presented (8 for the experimental block and 8 for the control block). The overall duration of the experiment was 20'.

3.2.4 Data

The recording optical unit was a multi-channel frequency-domain NIR spectrometer (ISS Imagent™, Champaign, Illinois), equipped with 32 laser diodes (16 emitting light at 690 nm, and 16 at 830 nm) modulated at 110.0MHz. The diode-emitted light was conveyed to the participant's head by multimode core glass optical fibers (heretofore, sources; OFS Furukawa LOWOH series fibers, 0.37 of numerical aperture) with a length of 250 cm and a core diameter of 400 μm. Light that scattered through the brain tissue was carried by detector optical fiber bundles (diameter 3 mm) to 4 photo-multiplier tubes (PMTs; R928 Hamamatsu Photonics). The PMTs were modulated at 110.005 MHz, generating a 5.0 KHz heterodyning (cross-correlation) frequency. To separate the light as a function of source location, the sources time-shared the 4 parallel PMTs via an electronic multiplexing device. Only two sources (one per hemisphere) were synchronously (t=4 ms) active (i.e., emitting light), such that the resulting sampling frequency was f=15.0625 Hz, due to the 64 ms sampling period required to cycle through the 16 multiplexed channels. To stabilize the optical signal, a dual-period averaging was performed, resulting in a final sampling period of 128 ms ($f=10^3/128=7.8125$ Hz). Following detection and consequent amplification by the PMTs, the optical signal was converted into alternating current (AC), direct current (DC), and phase (Φ) signal for each source-detector channel, considering separately each light wavelength. These values were then converted into estimates of absorption coefficient variations (Δμα) using the differential-pathlength factor (DPF) method. Temporal variations (Δ) in the cerebral oxy-hemoglobin (ΔHbO) and deoxy-hemoglobin (ΔHbR) concentrations were calculated based on the values of Δμα at the two wavelengths (Franceschini et al., 2000; Sevick et al., 1991).

3.2.5 Results

Individual hemodynamic responses were baseline-corrected on a trial-by-trial basis by subtracting the mean intensity of the optical signal recorded in the interval 2 s – 0 from onset from the overall hemodynamic activity (12 s; Schroeter et al., 2002). For each sampling period, artifact rejection thresholds were chosen as the mean response intensity at that timepoint ±3 SDs. Trials that contained at least one value exceeding the values of the threshold function were discarded from further analysis. Subsequently, the mean ΔHbO and ΔHbR signal intensities during the vascular response were calculated for each participant and condition. As an estimation of cerebral blood volume, we calculated the concentration of ΔHbT (sum of ΔHbO and ΔHbR). The analysis performed on the data recorded in the trials using the individual optical maps aimed at verifying the channels showing a significant activation increase relative to the baseline. Results clearly show an activation of the parietal lobe and parieto-occipital lobe when lines are bisected. On the contrary, no dissociation between peripersonal and extrapersonal space was found, probably due to the virtual nature of the two spaces and to the experimental task presented (Fig. 15 -).

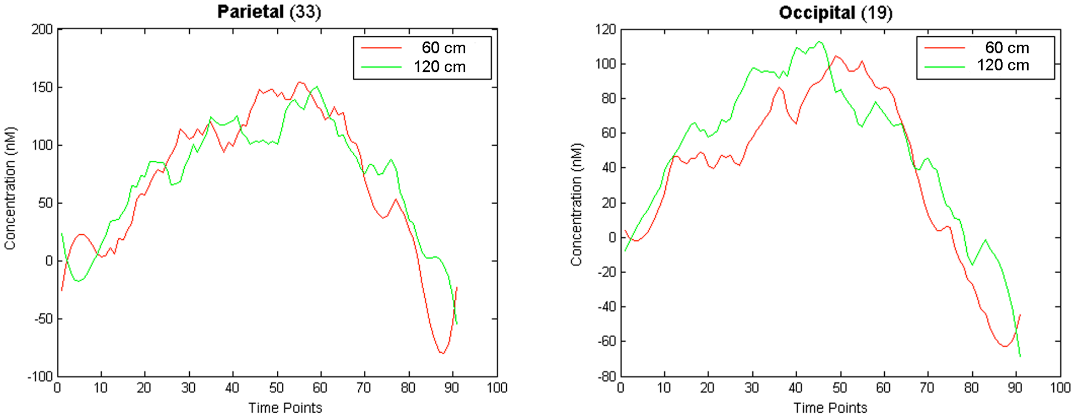


Fig. 15 - ***Activation of parietal and occipital areas during line bisection.***

3.2.6 Discussion

The use of fNIRS has considerable benefits for neuroscience studies. The procedure is noninvasive and does not constrain the participant inside huge machineries such as those for positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). It allows a natural position compared to the horizontal position assumed within the PET or fMRI. Implementation of fNIRS systems in the analysis of the cerebral functions that subtend VR experiences represents an important goal. The present study is one of the first attempts to explore brain activation during an immersive virtual reality experience using fNIRS. Previous studies have implemented VR but only in a non-immersive desktop setting. Combe et al. [12], for example, have studied the neural correlates of depth perception estimation in a 3D environment, and its effects on the participants’ emotional state. Previous studies have implemented flight-simulators [125], drive-simulators [72], or war video game-like simulations [54].

Results of our experiment showed clearly an activation of the parietal lobe and occipital lobes both when the lines were bisected at 60 cm and at 120 cm. These areas are implicated in visuomotor tasks. The inability to find dissociation in neural activation for the two distances presented, as for the study of [132], could be ascribed to the virtual components or to other methodological differences with previous work. Anyway, the aim of our exploratory investigation was to examine the possibility to implement the fNIRS brain image technique in the study of immersive virtual reality experience and the result seems to confirm this possibility. Using a virtual line bisection task a cerebral activation was found and described by the fNIRS analysis. Definitely, further investigation is needed to confirm to which extent results can be generalized. A major problem was represented by the adaptation of the helmet on each participant. As the helmet prototype was not adjustable and each participant has a different head circumference, we had to use Velcro components to better fix the fNIRS patch both to head and to the helmet, and to add several pieces of rubber fit correctly and comfortably the helmet to the participant. Moreover, in this solution only blood oxygenation level–dependent (BOLD) in parietal and occipital brain areas can be measured, because for the other ones there was no space to place NIRS probe. The implementation of an adjustable helmet could probably solve most of these problems. Another solution could be the adoption of stereoscopic and auto-stereoscopic 3D displays.

3.3 Methodological bias in the study of peri/extrapersonal space

3.3.1 Experiment 2 - The role of the body position

Body position can alter how healthy humans perceive the surrounding space and the space beyond the arm reaching distance. Based on the results obtained [27][71], in this experiment we aimed at verifying if the feeling of having the body blocked or free to move during an attention task has implications on how the perceptual transition from peripersonal to extrapersonal space is modulated. The experiment studied if the presence or absence of a chinrest has implications in a real line bisection task performed in peripersonal space and extrapersonal space. When using a laser pointer (i.e., a device that does not expand the peripersonal space), we hypothesized that the presence of the chinrest [27] would lead to an abrupt shift in the bisection error from the left to the right of the true centre of the lines (pseudoneglect) in the transition from peripersonal to extrapersonal space. The absence of the chinrest [71] would lead to a gradual shift. When using wood sticks (i.e., a device that expands the peripersonal space), we hypothesized no influence from the implementation or not of the chinrest, and a leftward bias of the true centre of the lines for all the distances.

3.3.1.1 Objectives

- to verify if having the body blocked ('chinrest' condition) leads to an abrupt shift in a line bisection task performed in peripersonal and extrapersonal space;
- to verify if having the body free to move ('no chinrest' condition) leads to a gradual shift in a line bisection task performed in peripersonal and extrapersonal space.

3.3.1.2 Methods

Participants

Eighteen participants with normal or corrected-to-normal vision took part in the experiment (9 males and 9 females; M = 22.83 years, S.D. = ±2.7 years, range = 19–29 years). All participants gave their informed consent to participate in the study. Results from the Edinburgh Handedness Inventory (Oldfield, 1971), showed a majority of right-handed participants (M = 57.33 , S.D. = ±32.4).

Apparatus and stimuli

Apparatus and stimuli were the same used for the first experiment in [29]. There were two viewing distances for peripersonal space (30 and 60 cm) and two viewing distances for extrapersonal space (90 and 120 cm). Lines measured 2, 4, 8, 16 and 32 cm (height: 1 mm). Each line was centred on a white sheet of paper (width: 33 cm; height: 24 cm). Each sheet of paper was positioned in the centre of a 50 by 50 cm white panel. Participants used four wooden sticks (length: 49.2, 78.6, 104.3, and 121.8 cm) to perform line bisection at the four viewing distances (30, 60, 90, and 120 cm, respectively). In order to indicate the midpoint of each line, sticks had a point at the endpoint opposite the grasped one. The laser pointer was attached on the head of a tripod (height: 10 cm) in order to avoid the effects of natural handshaking. The tripod was located in front of the chin rest. The laser pointer projected a red point (diameter: 1 mm) to indicate the midpoint of the line.

3.3.1.3 Procedure

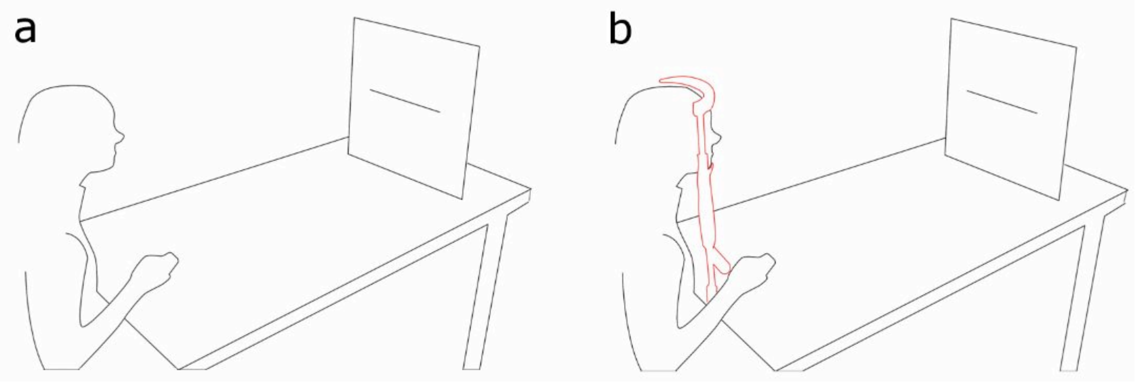


Fig. 16 - ***The main experimental blocks: a) without the chinrest, b) with the chinrest.***

After filling in the informed consent form and the Edinburgh Handedness Inventory [103], participants were invited to sit in front of a table (length: 180 cm; width: 60 cm). There were two main blocks: in one block participants performed line bisection without the chinrest, in order to keep the body free to move (see Fig. 16 - a); in the second block participants performed line bisection using a chinrest in order to keep the body blocked (see Fig. 16 - b). Within each main block there were other two sub-blocks: in one sub-block participants performed line bisection with the laser pointer; in the second sub-block participants performed line bisection with the wood sticks. On each trial, the participant was asked to indicate the midpoint of a single line that was displayed at one of four viewing distances (i.e., 30, 60, 90, or 120 cm). There was no time limit to perform the task. Before the beginning of the experiment, there was a practice block (i.e., 5 trials using the stick and 5 trials using the laser pointer). Each experimental sub-block included 40 trials for a total of 80 trials. Each main block included 80 trials for a total of 160 trials. Order of stimuli and order of viewing distances were randomised. Order of blocks (no chinrest vs. chinrest and stick vs. laser pointer) was counterbalanced among participants. On half of the trials participants performed bisection starting from the right endpoint of the line, while the other half performed bisection starting from the left endpoint of the line. Participants handled and moved the stick or the laser pointer with their dominant hand. Whenever the participant indicated the midpoint of the line, the experimenter marked it on the sheet and the next trial started.

3.3.1.4 Data

There were three independent variables (i.e., chinrest [two levels: no chinrest, chinrest], device [two levels: stick, laser pointer] and viewing distance [four levels: 30, 60, 90, 120 cm]). The dependent variable was the mean difference (as error percentage) between the observed midpoint (i.e., the midpoint indicated by the participant) and the true midpoint of the line. Positive values of the dependent variable indicate shifts to the right of the true midpoint, whereas negative values indicate shifts to the left of the true midpoint.

3.3.1.5 Results

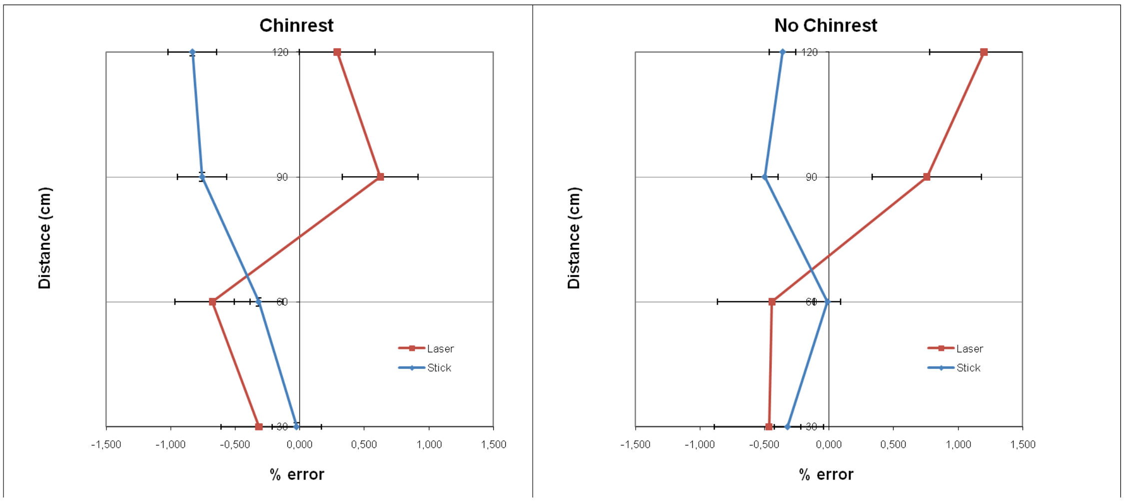


Fig. 17 - ***Mean percentage error in each chinrest condition, by device, and at each four distances . Negative values show a bias to the left of the midpoint, positive values show a bias to the right of the midpoint.***

A three-way analysis of variance (ANOVA) for repeated measures was conducted with Chinrest (no chinrest vs. chinrest), Device (laser vs. sticks) and Distance (i.e., 60, 30, 90, 120 cm) as factors. No main effect of Chinrest was present. There was a significant main effect of Device F(1,14) = 5.23, p = 0.038, indicating, in the 'chinrest' condition, a mean bias to the left of the midpoint when the stick was used (M = -0.423 % error) and when the laser pointer was used (M = -0.023 mm % error). In the 'no chinrest' condition, results show a mean bias to the left of the midpoint when the stick was used (M = -0.273 % error) and a mean bias to the right when the laser pointer was used (M = 0.252 % error). The main effect of Distance was also significant, F(3, 42) = 3.34, p = 0.028, showing a left to right shift when the laser pointer was used, during the transition from near to far space ('chinrest': 60 cm = -0.66 vs. 90 cm = 0.48; 'no chinrest': 60 cm = -0.31 vs. 90 cm = 0.71). The interaction Device by Distance was significant, F(3, 42) = 9.52, p = 0.000. Paired comparisons revealed a significant difference between 60 and 90 cm, for the laser pointer, in the 'chinrest' condition t(17) = -5.11, p = .000 and in the 'no chinrest' condition t(17) = -2.72, p = .014, whereas this difference was not significant for the sticks (see Fig. 17 - and Fig. 18 -).

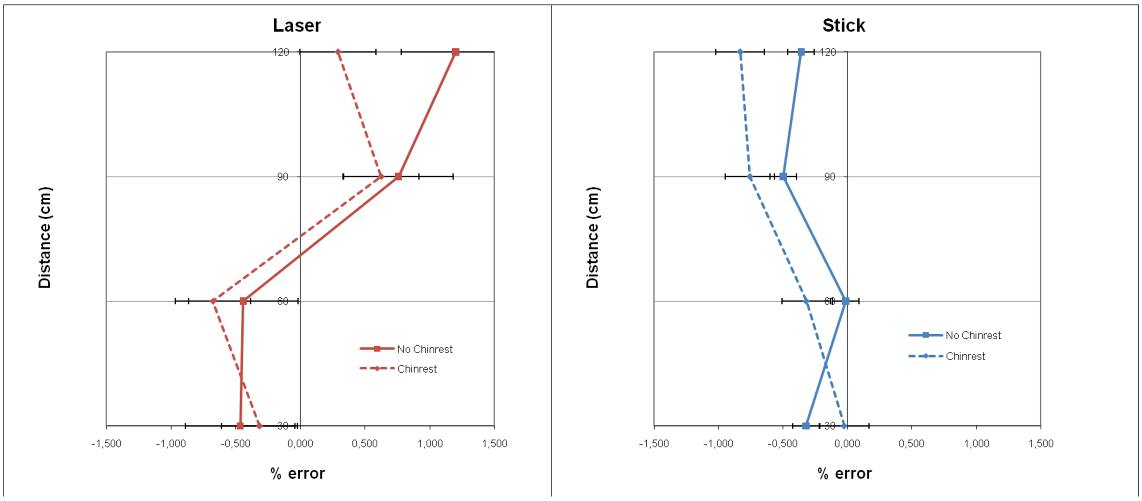


Fig. 18 - ***Mean percentage error with the two device types, by chinrest condition and at each four distance. Negative values show a bias to the left of the midpoint, positive values show a bias to the right of the midpoint.***

3.3.1.6 Discussion

When participants perform the line bisection task with or without the chinrest, a shift from the left to the right of the midpoint of the line when using a laser pointer (i.e., a device that does not expand the peripersonal space), is present only for the 60 vs. 90 cm distances. In contrast, no significant differences are present for the 30 vs. 60 cm distances and for 90 vs. 120 distances. These results indicate that an abrupt, not gradual, perceptual change occurs when healthy humans perform an attention task within peripersonal and extrapersonal space. Having the body blocked or free to move has no implication in how the two different spaces are perceived. Moreover, when using a tool (i.e., a device that expands the peripersonal space), whether or not the chinrest is used has no implications too; a constant shift to the left of the midpoint was present in peripersonal space (30 and 60 cm) also observed in the expanded peripersonal space (90 and 120 cm). The tool extends peripersonal space representation to the limit of the tool handled.

3.3.2 Experiment 3 - The role of the arm position

Arm position can alter how healthy humans perceive the surrounding space and the space beyond the arm reaching distance. Based on the results obtained in the previous study, chinrest vs. no chinrest, in this experiment we aimed at verifying if having the arm bent or stretched during an attention task, has implication on how the perceived peripersonal and extrapersonal space are modulated. The experiment explored if stretching or bending arm while using a tool has implications in a real line bisection task performed in peripersonal space and extrapersonal space. We hypothesized that in the 'stretched arm' condition the error on the left of the true centre is greater than in the bent arm condition.

3.3.2.1 Objectives

- to verify if bending or stretching the arm has implications on a line bisection task performed in peripersonal and extrapersonal space.

3.3.2.2 Methods

Participants

Thirty participants with normal or corrected-to-normal vision took part in the experiment (15 males and 15 females; M = 22.83 years, S.D. = ±2.45 years, range = 20–29 years). All participants gave their informed consent to participate in the study. Results from the Edinburgh Handedness Inventory (Oldfield, 1971), showed a majority of right-handed participants (M = 56.68 , S.D. = ±43.43).

Apparatus and stimuli

Apparatus and stimuli were the same used for the first experiment in Gamberini et al. (2008). There were two viewing distances for peripersonal space (30 and 60 cm) and two viewing distances for extrapersonal space (90 and 120 cm). Lines measured 2, 4, 8, 16 and 32 cm (height: 1 mm). Each line was centred on a white sheet of paper (width: 33 cm; height: 24 cm). Each sheet of paper was positioned in the centre of a 50 by 50 cm white panel. For the 'bent' arm condition, participants used four wooden sticks (length: 49.2, 78.6, 104.3, and 121.8 cm) to perform line bisection at the four viewing distances (30, 60, 90, and 120 cm, respectively). For the 'stretched' arm condition, participants used two wooden sticks (length: 30 and 60 cm) to perform line bisection at the four viewing distances (30, 60 and 90 cm with the first one, and 120 cm, with the second one). In order to indicate the midpoint of each line, sticks had a point at the endpoint opposite the grasped one.

3.3.2.3 Procedure

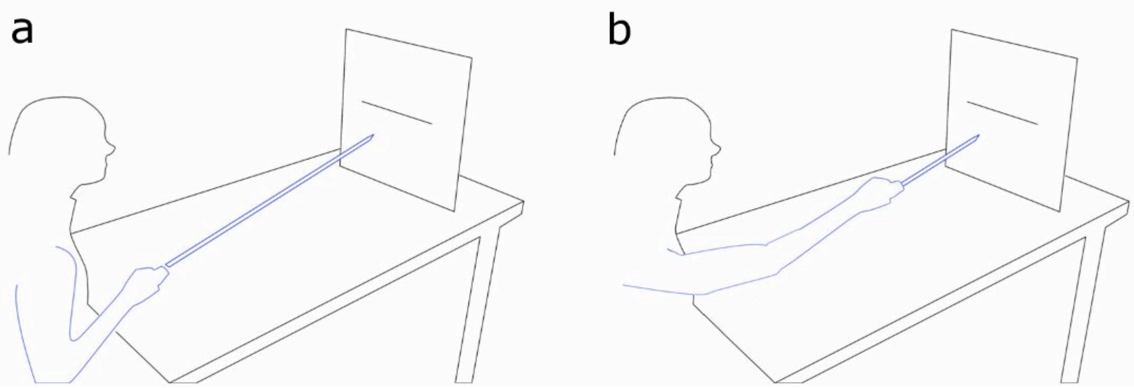


Fig. 19 - ***The main experimental blocks: a) with bent arm, b) with stretched arm.***

After the completion of the informed consent module and the Edinburgh Handedness Inventory [103], participants were invited to sit in front of a table (length: 62 cm; width: 100 cm) and to position their head in a chinrest, in order to guarantee that the distance between the participant's eyes and the displayed line was maintained constant. There were two main blocks: in one block participants performed line bisection using the wood sticks with the arm bent (see Fig. 19 - a); in the second block participants performed line bisection using the wood sticks with the arm stretched (see Fig. 19 - b). On each trial, the participant was asked to indicate the midpoint of a single line that was displayed at one of four viewing distances (i.e., 30, 60, 90, or 120 cm). There was no time limit to perform the task. Before the beginning of the experiment, there was a practice block (i.e., 5 trials using the stick and 5 trials using the laser pointer). Each experimental block comprised 40 trials for a total of 80 trials. Order of stimuli and order of viewing distances were randomised. Order of blocks (bended vs. stretched) was counterbalanced among participants. For one half of the trials participants performed bisection starting from the right endpoint of the line, while the other half performed bisection starting from the left endpoint of the line. Participants handled and moved the stick with their dominant hand. Whenever the participant indicated the midpoint of the line, the experimenter marked it on the sheet and the next trial started.

3.3.2.4 Data

There were two independent variables (i.e., arm [two levels: bent, stretched]). The dependent variable was the mean difference (as error percentage) between the observed midpoint (i.e., the midpoint indicated by the participant) and the true midpoint of the line. Positive values of the dependent variable indicate shifts to the right of the true midpoint, whereas negative values indicate shifts to the left of the true midpoint.

3.3.2.5 Results

A two-way analysis of variance (ANOVA) for repeated measures was conducted with Arm (bended vs. stretched) and Distance (i.e., 60, 30, 90, 120 cm) as factors. There was a significant main effect of Arm F(1,26) = 16.25, p = 0.000, indicating a mean bias to the left of the midpoint in the 'bent' condition (M = -0.555 % error) and in the 'stretched' condition (M = -0.172 % error). No main effect of Distance was present. The interaction Device by Distance was not significant. Paired comparisons revealed a significant difference between 'bent' vs. 'stretched' conditions at 30 cm, t(29) = -2.63, p = .013, and at 120 cm, t(17) = -2.58, p = .015 (see Fig. 20 -).

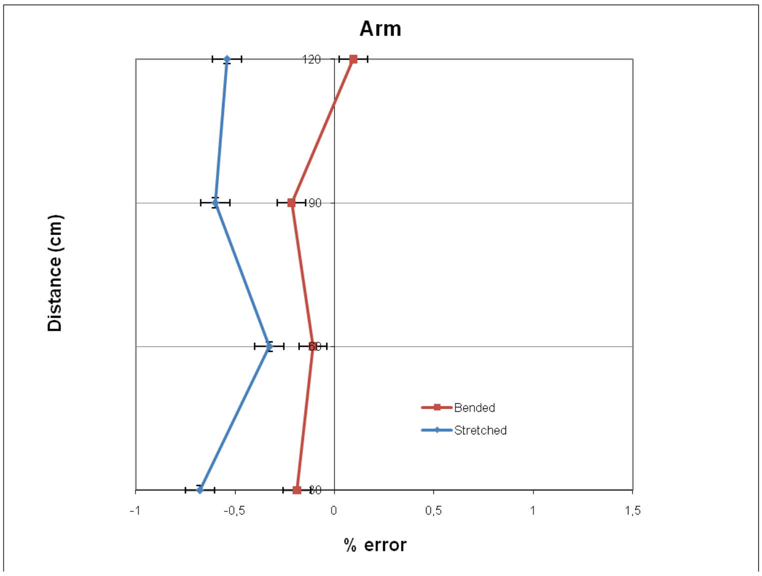


Fig. 20 - ***Mean percentage error at the distances of line presentation in the two arm conditions. Negative values mean a bias to the left of the midpoint, positive values mean a bias to the right of the midpoint.***

3.3.2.6 Discussion

Results clearly showed that the arm position modulated space perception when performing an attention task. The tool (stick) extends the peripersonal space representation to the limit of the tool handled, both when the arm is bent and when the arm is stretched, with a constant bias to the left of the midpoint of the line along all the distances. When the arm is stretched, a greater leftward bias in the very near space (30 cm) and in the very far space (120 cm) is observed.

3.4 New approaches in the study of peripersonal space

3.4.1 Experiment 4: An investigation on virtual peripersonal space

Previous studies have implemented different tools in real environments trying to expand the peripersonal space, as it is believed that the different ways in which those tools are manipulated (to touch or to move the objects) lead to the phenomenon of peripersonal space expansion. A device, like a laser pointer, that only indicates a space region does not have this ability. The essential feature to induce peripersonal space expansion seems to be the ability to actively manipulate the space. As observed by [29], a fundamental feature to modulate peripersonal space expansion also seems to be a visual continuity from the hand to the space region manipulated. To test this hypothesis we implemented a virtual line bisection task in which the tools to bisect the lines, some virtual wood sticks, could be either totally visible or partially visible (only the end of the wood stick). If the visual continuity represents the essential feature to expand the peripersonal space, we expect a bias to the left of the midpoint for all the distances using the totally visible tool, and instead a shift from the left to right of the midpoint in the transition from peripersonal to extrapersonal space when using the partially visible tool. If the essential feature to induce peripersonal space expansion is the ability to actively manipulate the space, then we expect a bias to the left of the midpoint for all the distances using both tools.

3.4.2 Objectives

- to understand which aspect of the tool manipulation is responsible for the peripersonal space expansion.

3.4.3 Tools

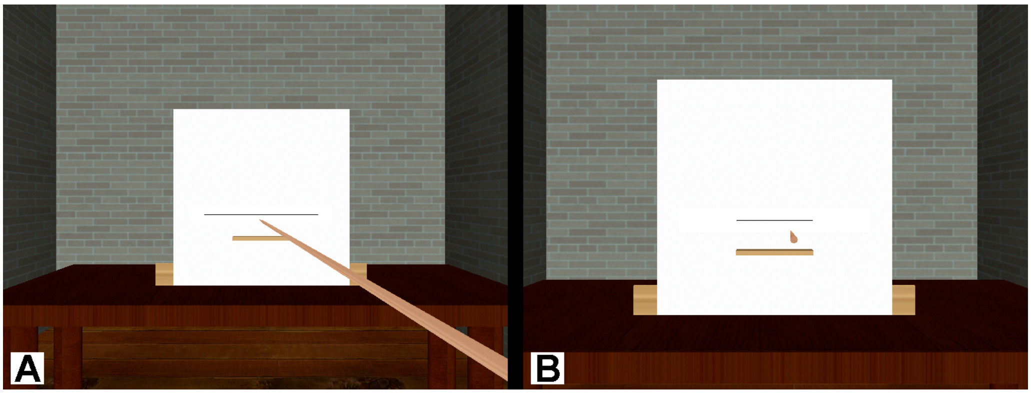


Fig. 21 - ***The two virtual sticks used: a) visible, b) invisible.***

Participants

24 students of the University of Padua, Department of Psychology, participated in the experiment, 12 men, 12 women (Mean age = 23,20 ; S. D. =±3.2). All participants were right handed, as reported by the Edinburgh Handedness Inventory, with normal or corrected to normal vision. 10 participants were short-sighted and 6 were astigmatic, with vision corrected to normal.

Apparatus and Stimuli

The virtual environment was created with 3DS Max 8.0 software, while for the interaction with it Virtools 3.5 was used. The virtual environment was a 3x5x2 m room with a 180x60 cm wood table on the centre and a chair in front of it. On the wood table a 50x50 cm vertical white panel was positioned upon which lines were presented. The environment could be explored only by moving and rotating the head. The shift of the point of view along the distances was computerized. There were 4 different lines presentation distances: 30, 60 cm, peripersonal space, and 90, 120 cm, extrapersonal space. There were 5 lines that differed in length: 2, 4, 8, 16, 32 cm. Line bisection was made possible through the manipulation of 2 different tools: the first tool was a virtual wood stick whose entire shape (totally visible) could be seen (see Fig. 21 - a); the second tool was a virtual wood stick whose only the upper extremity could be seen (partially visible) (see Fig. 21 - b). Each virtual wood stick length was modified automatically by the software according to the line distance presentation. The manipulation of the tool was made possible through the use of a WiiMote controller, a wireless controller able to detect hand movements, synchronizing them with the virtual wood sticks movements. The signal emitted by the controller was detected by an infrared Sensor Bar positioned in front of the controller at 50 cm, and then transferred to the computer via Bluetooth. The virtual environment was visualized by participants through a Virtual V8 Head Mounted Display (HMD), 800x600 resolution, upon which an Intersense tracker was mounted for the head movements detection (see Fig. 22 -).

3.4.4 Procedure

Once in the experiment room, participants were invited to sit in front of a monitor. After having completed the informed consent and the Edinburgh Handedness Inventory, participants read the instruction for the experiment. Instructions were also repeated orally by the experimenter, making sure that the experiment was clearly understood. The participants' wrist was blocked on the armchair support with an elastic rubber strap, in order to prevent excessive arm movements and to ensure that the WiiMote controller was guided mainly by the wrist movement. A first training session with 8 lines presented in front of the monitor was performed. The same training was repeated with the participants wearing the HMD. Then, the experiment started and the experimenter sat on the right side of the participant watching the task on the monitor. Participants could bisect the lines moving the virtual wood stick toward the lines centre, through the manipulation of the WiiMote controller. Once they were sure of the position selected they pressed with the thumb the A button on the WiiMote controller to save the response (with a precision of 0,25 mm). After a few seconds the next line was presented and the virtual wood stick was automatically re-located to the initial position. This procedure was repeated until the end of the experiment. Each participant completed 2 main blocks of 40 lines, one with the 'totally visible' tool and one with the 'partially visible' tool. Each of the 5 lines was presented once for all 4 distances of presentation, for a total of 20 observations. This subset of lines was repeated twice each block varying the starting position of the tools that could be on the right or left lower portion of the white panel. Order of distances and lines presentation was randomized. Order of tools and starting position was counterbalanced across participants. Each participant performed each experimental condition, for a completely within subject experimental design. Independent variables were represented by the tool used (2 levels, 'totally visible' and 'partially visible'), and by the distances of presentation (4 levels: 30, 60 cm, peripersonal space, and 90, 120 cm extrapersonal space). The dependent variable was represented by the position indicated by the participants as the centre for each line. It was calculated by subtracting the numeric value of the position indicated and the numeric value of the true centre of the lines. Negative values represent a leftward error compared to the line centre, while positive values represent a rightward error.

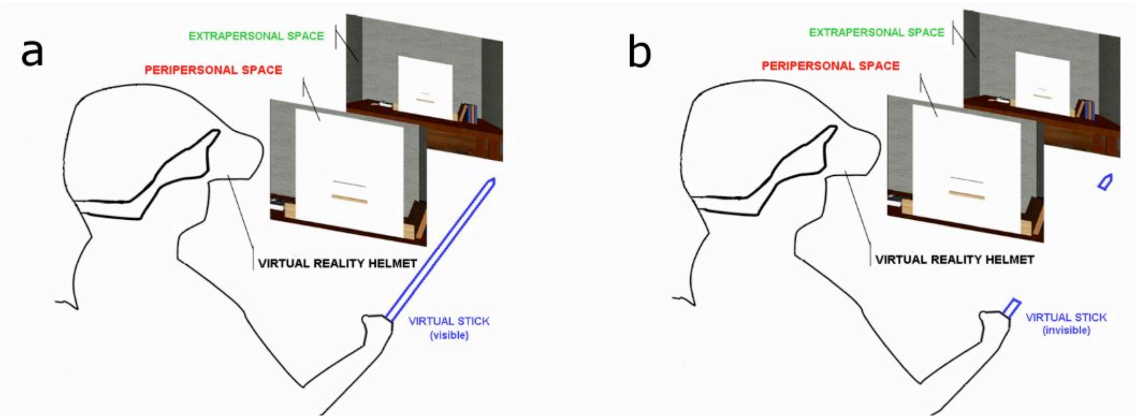


Fig. 22 - ***The experimental setting with the two virtual sticks: a) visible, b) invisible.***

Data have been collected and are under analysis (M12)

4 Future work

4.1 T7.1

The research on user experience (leader: UNIPD) in the second year will include:

> *1. Definition and adoption of a self-reported tool to collect the extent of users' experience of confluence with CEEDs along the dimensions identified in section 2.1 to 2.10 above.*
>
> The tool will be organized into a set of statements, negatively or positively formulated, and regarding the experience with CEEDs interface, with a Likert response scale from 1 to 6. Existing tools will be adapted to CEEDs specific features, and brand new items will be added to cover novel aspects of human-computer confluent interfaces.
>
> *2. Design and adoption of a list of tasks to test the effectiveness and efficiency of the general CEEDs functions with attention to the different scenarios*
>
> Tasks will involve individual or group of users and will be video-recorded. Success in completing the task, and occurrence of errors and breakdowns (as in [56]) in the user's actions with the interface will be evaluated. Task sessions will be repeated in order to check learnability and other relevant parameters. Accompanying documents (e.g.. instructions, training, consent form) will be acquired from partners, when available, and adapted.
>
> 3. *Creation of a checklist to verify the fulfilment of the privacy requirements as they are outlined in D10.2.* The checklist will be for experts, who will have to check the requirements that have been fulfilled and describe those that are considered unsatisfactorily addressed.

As soon as CEEDs prototypes are available, the test environment and procedure will be designed and the evaluation will be carried out with the research tools described in the lines above.

In addition, *the design guidelines will be improved*. The final version of the guidelines is expected to be delivered in M30 and it will be based on the test results as well as on initial work in T7.3 and 7.4 and will include design as well usability and user experience evaluation suggestions.

4.2 T7.2

During the second year of project, the fourth study with line bisection paradigm will be completed and new studies with different kinds of mediated spaces will be carried out (leader: UNIPD). A new experiment will investigate what happens to users' performance during a bisection task executed in a very far extra-personal space (i.e. a space that extends the standard distance normally adopted in recent literature). This experiment can be realized thanks to the adoption of an immersive VE that permits users to act in far spaces.

Then a new series of experiments will be planned that will bring T7.2 studies to a more applicative context, i.e., the CEEDS scenarios. Touchless interfaces based on hand/body gesture recognition (i.e., the tools adopted in CEEDS commercial scenario, WP8) will be explored and investigated in their capability to support visuo-spatial attention and users' action in near and far spaces. In particular, we will focus on possible forms of natural interaction that are suitable for navigating large amounts of data in 3D environments.

Part of this work will concern the evaluation of different kinds of sensorial feedback provided to the users after their actions: in particular, attention will be focused on the vibro-tactile feedback developed in WP2.

4.3 T7.3

This task (leader: UNIPD) relates to the credibility of confluent systems, which is a pre-condition to their acceptance. Exploratory research on factors contributing to CEEDs interface credibility will be carried out and will be related to specific scenarios, where credibility can be more or less at risk.

As an initial step, focus groups with target users will be carried out, showing visual material (e.g, scenarios, mockups etc.) related to the applications, so that participants can envisage the situation and handle concrete examples of the objects about which they are asked to express opinions. In parallel, the literature will be monitored for new studies that integrate the literature analysis already carried out in the first year.

4.4 Task 7.4

This task (leader: UNIPD) addresses the social dimension of ergonomics, which is particularly relevant to CEEDs. While the aspects related to social acceptability of the interface/input modality are dealt with in T7.1 and 7.3, the aspects related to interaction of several users with the same interface are addressed in this task.

The activity will include literature review on usability issues in large shared displays plus initial studies on existing devices, focusing on issues related to workspace juxtaposition/sharing, co-reference, familiarization. The final results will converge into the guidelines delivered at M30.

4.5 Task 7.5

This task focuses on improving information retrieval adequacy through Relevance Feedback (RF). CERTH, who is the partner leading this task, started working in the relevance feedback task at the end of the first year. CERTH developed an implicit response relevance feedback model to enhance the search process. CERTH will continue working on an evaluation of the model, applied to extracting affective tags for the query objects from eye gaze and facial expressions.

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