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Spatial cognition in Virtual Environments

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Introduction

Some of the most problematic issues in experimental psychology are the control of the variables and the repeatability of the results. Indeed, all the disciplines which rely on the scientific method have to face these problems, but experimental psychology in particular has to take into account several issues that are not occurring in other sciences like mathematics or physics, as for example the main theoretical problem in psychology, which is that the object of investigation coincides with the investigation tool itself. Psychological research investigates cognitive processes in humans by performing different kinds of experiments, ranging from controlled laboratory true experiments (involving the manipulation of independent variables and controls for confounding variables) to field research (involving deliberate manipulation of independent variables in natural uncontrolled environments) to naturalistic/quasi experimental method (involving observation and analysis of independent variables changed by natural incidence) to, finally, the use of “artificial environments”: something which is supposed to be in the middle between laboratory experiments and naturalistic observation. This last methodology binds together the naturalistic effect of a realistic situation and the possibility to pre-define, create and totally control almost all the variables (including the environmental ones), allowing a completely controlled (and safe) setting, which is not always possible in natural environments or in laboratory settings. Moreover, the creation of an artificial environment with certain features and characteristics, offers the possibility to replicate the same experiment in different conditions, only by sharing a scenario or its source-codes with other groups or collaborators.

This is the reason why the use of Virtual Environments (VEs) in cognitive research has increased its popularity during the past decades and nowadays is actively employed in a variety of experiments aimed to investigate human behavior and cognition in situations which would be otherwise impossible to recreate in a natural environment or would not offer the same possibility of manipulation of the involved variables.

Moreover, Virtual Reality (VR) is widely used not only in research, but also in rehabilitation and in professional trainings or e-learning, showing all the possible practical applications of this innovative tool.

Unfortunately, this methodology is still far from being validated and theoretical discussions are open between scholars about the reliability of such a tool. The lack of proprioceptive feedback, which should bind the actual body position of the person to the movements seen in the environment, the use of unimodal sensory information (mainly visual), and the imprecise image resolution of the presented scenarios, are some of the most discussed issues which make the use of VEs in research still controversial. While it is openly recognized that using a computer program is easier and faster than trying to reproduce a certain situation in the real world, it is still not clear if (and in which cases) the gap between the virtual experience and the real one might cause a discrepancy in the results obtained by means of VEs with respect to the ones obtained in Real Environments (REs), or if the differences that occur are negligible.

Related to this fact, after reviewing most of the recent material on the issue “Virtual Environments in cognitive cognition”, it soon appeared clear to me that at least two opposite attitudes are present in literature towards the use of VR in research on cognitive processes: one trend is mainly focused on highlighting that VEs and REs follow different perceptive rules, especially considering the acquisition of basic spatial knowledge, such as depth perception, evaluation of distances and so on (for example, Ärmbruster et al., 2008). The other trend produces a series of results which show basically a similarity in the performances obtained in Real and Virtual scenarios in cognitive tasks, especially the spatial ones or the ones including interaction within the environment. Quite a number of studies referring to the usefulness of Virtual Trainings (VTs; see for example, Seidel & Chatelier, 1997), represented by the concept of “transfer” of abilities learned in the VE to the real world’s tasks, claim in fact that the human brain can give more or less the same answers in the two different kind of environments: some work (for example, Waller, 2000) even produced proof that measures of spatial knowledge collected in a VE maze were highly predictive of subsequent performance in a similar real-world maze, suggesting therefore that VEs can be useful for training people about real-world spaces. Some authors (Farrel et al., 2003), even though not disproving VEs usefulness in spatial learning or acquisition, conclude that actually available VE technologies do not provide better route learning than studying a map.

So, where is the truth? Are they different or similar? But, most importantly, if they work on different perceptual basis, as for example has been proven in evaluation of distances, where there is a clear tendency to underestimate in virtual scenarios (with or without stereoscopy), in opposition to the well established tendency to overestimate in real ones (Gilinsky 1951; Loomis et al. 1996; Loomis et al., 2003), how can we then explain the claimed similarity of cognitive spatial processes using artificial environments, assuming that all these studies obtained scientifically correct results?

Since Kant’s philosophical distinction between “Sensibility” and “Understanging” processes of human mind, we know that, theoretically, there is a distinction between the so-called “low-level” basic cognition, which include all the perceptual-related processes, and the “higher-level” cognitive processes, such as spatial navigation, wayfinding, landmark recognition, spatial memory and so on (Chalmers et al., 1991; Dietrich, 200). The first class of processes should work differently in virtual and real environments, since they follow a data-driven, bottom-up direction of processing, and in an artificial scenario are simulated by machines. The high-level processes, which rely on different neuronal networks and brain areas and have a deeper influence from the so-called “top-down” processing, are more “global” processes, and probably they work quite fine even in computer-generated worlds.

This basic distinction, which I will address more deeply later in this chapter, could explain, according to the hypotheses of the present work, the effective/non effective results that scholars obtain using this technology for their research purposes.

The general hypothesis proposed in this dissertation is that, although the clear and proven diversity of virtual and real environments especially regarding the information processed by the human perceptual system, this difference does not prevent the cognitive system to be able to adapt to the new rules and perceptual cues of the new environment and use them in a good way. The “good way”, since we know that brain follows the most “economic” rule, should be the easiest one, i.e. the most similar to the one that works in the REs. So, at higher levels, one might behave in the virtual world *like if* it was the world he/she is used to. So, investigating some higher spatial processes within VEs, we should be able to have a good measure of human behavior in the physical world, even though, at lower levels, we might not.

In order to help finding some intrinsic limits of VEs and technologies for their visualization, suggesting which ones can be used to consistently prove research hypotheses in experimental settings, the present work addresses some fundamental questions about the use of VEs in research on the cognitive processing of spatial information. It represents also an attempt to fill some gaps about open questions such as: “is the space and the depth of a VE represented in the user’s brain in a sufficiently correct way? Or, if not, is he/she still able to perform correct actions interacting within the scenario?”, or “is stereoscopy a good way to allow a realistic perception of depth in a VE?”, but also more general issues like “is the way of navigating in an environment, and the strategy used to find a way in an artificial maze different from the way of navigating in a simple PC screen-presented 3D environment?”.

These questions refer either to the low- or high-levels of spatial processing. Since it is supposed that, without a correct processing of the spatial information, a successive “top-down” use of this knowledge to perform action within the environment would not be possible, we can say that the two levels of processing are intimately correlated, so a deeper investigation of their relation represent something really useful for a more correct use of this technology.

Structure of this dissertation

The structure of this work is aimed to follow in some ways the VR concept intrinsic scheme: from its development as an “externalization of the computer-represented world” and its roots in the informatics field and the deep role that computer science had in the historical development of cognitive psychology, to the actual “state of art”, enriched by the results and outcomes of the present study.

In the first Chapter, I will first offer a brief historical review (paragraph 1.1), exploring the strict connection between theories and models in cognitive psychology and technology in the last 50 years, such as cybernetic, connectionism, architectures of mind, artificial intelligence and so on, to focus then on the development of VR as one of the most recent innovation in the field of “visualization technologies”, in paragraph 1.2. Here I will try first of all to delineate a univocal and unambiguous definition of this complex tool and concept, and in second instance to point out the characteristics and features that make this technology likely to become a relevant tool in science and research, although still on its way of development.

In paragraph 1.3 I will discuss which are the experimental (and also practical) uses of VR in the field of psychology, focusing in particular on research in spatial cognition (paragraph 1.3.3), but suggesting that the findings in this field could be strictly related and deeply relevant for a correct practical usage of the VR as a tool in other applicative fields, such as rehabilitation and clinical psychology (paragraph 1.3.1), professionals training and learning (paragraph 1.3.2). I will then discuss the importance of the linkage between computer science and experimental psychology, showing how different kinds of technologies help scholars in their work (paragraph 1.3.4). Related to this, the question about why VR is useful in cognitive psychology research is then discussed, presenting both advantages and disadvantages of VEs; the chapter ends with the questions and problems that are still open on this issue. The Paragraph 1.3.5 focuses on the technical features of VSs, like the presence of the absence of stereoscopy, the dimension and shape of the screen, the screen refresh-rate, and so on, pointing out also the different levels of immersivity that every VS is capable to offer. All these features are intended to reproduce somehow our “cognitive features” and way of functioning, so they have a central importance in this topic. I will focus especially on the so-called “immersive Virtual Environments” (iVEs), and discuss the importance of a good quality of movement reproduction. The multisensorial experience that VR is able to offer to a user is therefore exposed and the two main concepts of “immersivity” and “sense of presence” are explained. Finally, I address the functioning and technical details of VR (such as stereoscopy, for example, as opposed to a simple “pictorial” depth representation in “normal” 3D environments).

In chapter 2 I will offer a preview and explanation of the contents discussed in the following chapters 3 and 4, which will be focused on the methodological aspects of the research: after offering an introduction and an overview of the background and motivation of all the experiments, I expose, in Paragraph 2.2, the functioning and the main features of the VSs offered by the Fraunhofer Institute, trying to give a technical definition and description of the ones used in experiments of this project.

On the basis of these premises, in chapter 3 I present the first level of investigation of my study, starting from a definition of distances perception as a basic process for spatial perception and representation. In the following Paragraphs I will, first of all, discuss the “preliminary study”, which allowed me to define my work hypotheses (3.1.), and then I will describe in detail the 3 experiments (paragraphs 3.2, 3.3 and 3.4) aimed to evaluate different aspects of the issue, each of them with the detailed description of experimental paradigm, results, discussion and conclusions. Following the same scheme in Chapter 4, I present the experiments on the second level of investigation (high-level spatial processes): the first experiment (Experiment 4) investigates the effect of a semi-immersive VE in a spatial and visuospatial planning and navigation task, giving new insights on the importance of using a 360° display in researches about spatial navigation in VEs, and the second (Experiment 5) is a technical investigation to evaluate the best and more ecologic way of interact inside these kind of iVEs, focused mainly on the interaction device (a joypad alone or combined with a tracking).

Finally, in the Conclusions, I summarize the results obtained with the experiments and I discuss how collaboration and interdisciplinarity are nowadays necessary for the improvement of technology products. Furthermore, I will mention the possible development of more precise paradigms for the investigations and evaluation of other important aspects of VEs that could be addressed in the future within other follow-up studies and/or the creation of new applications. I will then show some practical examples of applications and possible development of the VR technology, which can be forecasted in the future.

1. A general overview on Virtual Reality

1.1 The birth of Information Era

One of the most important factors contributing to the birth and the development of cognitive psychology is without any doubt the development of computer technology (Santrock, 2003). Cognitive psychology did not only benefit from the development of computers themselves, but also from the theories and models behind the new technologies and machineries; and in turn, it even stirred further growth of computer technology, too. For example, Artificial Intelligence (AI) was developed also thanks to the rise of cognitive psychology, in the attempt to create a technological innovation for machines allowing them to perform intelligent functions, such as diagnosing medical illnesses, prescribing treatments, examining equipment failure, evaluating loan applicants, and advising students on college courses (Santrock, 2003). And this is also what is currently happening in the field of Virtual Reality (VR).

The “history” of the modern computers, robotics, AI and VR officially starts on Valentine’s day of 1946, day in which the ENIAC (Electronic Numerical Integrator and Computer) started its activity in the Moore School building at the University of Pennsylvania houses. It was a huge machine with twenty banks of flashing lights indicating the results of its computations, which were obtained surely faster if compared with the same task performed on a hand calculator of that time. By showing that electronic computing circuitry could actually work, ENIAC paved the way for the modern computing industry that stands as its great legacy. This is the reason why historians consider that the hushed moment when ENIAC's vacuum tubes first began to glow constituted the birth of the Information Age.

Actually, before ENIAC existed, already in 1839, Charles Babbage designed and developed the first true mechanical digital computer, which he described as a “difference engine”, for solving mathematical problems including simple differential equations. He was assisted in his work by a mathematician, Ada Countess Lovelace, daughter of Lord Byron, and together established many principles of computer operation that have been rediscovered with newer machines a full century later. By the early 1930s, physicists started to use radiation counters, which employed vacuum tubes as the ENIAC did more than 10 years after. In the later 1930s and early '40s, at least three separate efforts to use electronic circuitry to address the problem of computation were made by John Atanasoff, British Intelligence, and IBM. Between 1937 and 1941, John Atanasoff set out to design a specialized machine that could solve a complex system of linear equations. In the late 1930s IBM began to work with Wallace Eckert of Columbia University to explore how their equipment could be used in various scientific applications. It became clear that an electronic multiplier would greatly speed up the kinds of computations being employed by Eckert. IBM had collaborated with him in designing such a system. British Intelligence's Colossus, a special-purpose large-scale electronic machine developed to decode secret messages, performed only the logical, as opposed to arithmetical, operations necessary to defeat the famous German code machine Enigma. It was built at Bletchly Park around 1942.

What made the first prototypes jump forward in the development of computers was the new “stored program” concept (that is, the ability to store a program in its own memory), which definitely ENIAC lacked, to which contributed John Mauchly and J. Presper Eckert of the Moore School, in collaboration with John von Neumann and others. The first machine to operate with this particular design (that means, with indexed memory and random access memory) was the EDSAC computer built in 1949 at the University of Cambridge by Maurice Wilkes. Neither ENIAC nor its successor, the EDVAC, had indexed memory and random access memory, which, some might argue going beyond stored program capability, are essential ingredients of modern computer design.

Von Neumann and Herman Goldstine at the Institute of Advanced Studies and a team of researchers at the University of Manchester did the most to develop and formalize early computer architectures. Conditional branching (the "IF" statement in a BASIC or FORTRAN program) was not part of the ENIAC original design.

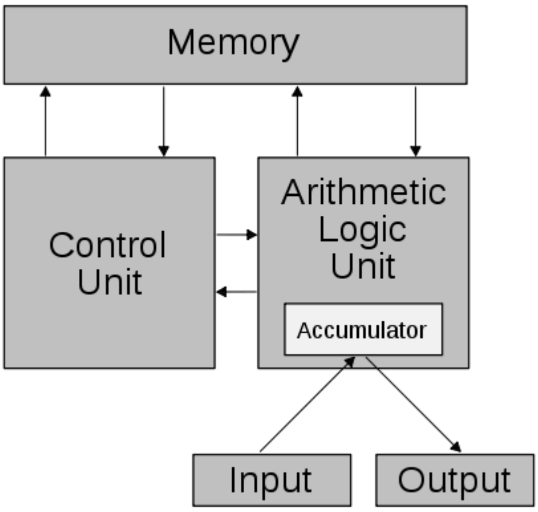

Fig. 1: Scheme of the architecture of a computer according to von Neumann. The control unit and the arithmetic logic unit form the main components of the CPU (Central Processing Unit). From von Neumann (1940).

In the late 1940s, the first modern computer by John von Neumann showed that machines could perform logical operations. Von Neumann is one of the scholars who made it possible the jump in the “Information Age”: his design of a computer architecture (see Fig. 1), is the first attempt to define the main components, and their respective relations, of the so-called “stored-program computers”, a sequential (hierarchic) architecture representing an advance with respect to the “program-controlled computers”, like ENIAC.

Contemporary to the development of these new machines, which founded the basis of the modern “computers”, in the late 1940s, MIT scientist Norbert Wiener founded the field of cybernetics (from the Greek “*kybernetes*”, that means “helmsman” or “governor”) to explore the sociological impact of the communication between human and machine. His research is critical to an understanding of the impact of virtual reality in cognitive psychology, because Wiener opened the door to the study of the relationship between the human and the technology, defining the resulting symbiosis as “cyberborg” (cybernetic organism; Wiener, 1987). Wiener describes an increasingly technological society reliant on machines, and he explains how the nature of those interactions affects the quality of life. The work started by Wiener lead some groups of scientists directly to the development of machines which could interact with the human in the same “working system”, and his studies offered the basis of the modern field of robotic and VR application as we know them. The design of VR technologies that extend our reach, for example, such as tele-robotic devices (the control of robots at distance), is informed by Wiener's research in cybernetics and his concern with the nature of sending messages and the reciprocal feedback inherent in those systems.

The successive formalization of a convincing way to quantify the transferred information amongst these systems, operated by Shannon by means of his famous “Information theory” (1948), made it possible to complete the process and promote the definitive jump into the modern era. His theory, describing how to find fundamental limits on signal processing operations such as compressing data and on reliably storing and communicating data, and moreover his definition of entropy as an information measure, finds applications in many areas, from natural language processing to networks and communication (Lachman et al., 1979). But, what is more interesting for the topic of this research, the applications of fundamental topics of information theory include lossless data compression (like ZIP files), lossy data compression (for example MP3s and JPGs), and channel coding (like the ones used for DSL lines, for example). So, its impact has been crucial not only for many important technologies which supported the development of informatics, like the invention of the compact disc, the feasibility of mobile phones, the development of the Internet, and even the study of linguistics and of human perception, just to name few, but also it has been the starting point of graphics and visualization standards, thing that leaded to the development of the actual knowledge about everyday more compelling image rendering and visual representation in VR and the creation of Virtual Environments (VEs).

But what made it possible for the cognitive psychology field to be born is the active application of all this knowledge to the human brain. In the 1950s, following von Neumann's suggestions, in fact, some speculations started to be proposed by scholars that computers actually reflect the way the mind works. Herbert Simon, (1969) was the first to compare the human mind to computer processing systems (Santrock, 2003), postulating the famous parallelisms between the human and the computer: the brain would be a computer's hardware, and the mind would be the software which makes it work: mental processes are "analogous" to software applications; sensory and perceptual systems, "act like" input channels; muscular efferent system gives the output of the internal states; memory storage has the "same features" of disk storage; the process of memory retrieval could be assimilated to a printer or screen display, and so on. Although Simon's analogy is compelling, many psychologists complained that it was too simplistic. In fact, as some scholars pointed out, first of all neurons communicate with each other electrochemically, while computer wire connections use only electricity, they are plastic and can change, while wire connections are permanent, but they can also die and be lost forever (like in case of degenerative diseases), electronic wires can be removed and substituted without changing the state of the machine; so the human brains and computers function on different basis. Moreover, without human input, computers cannot work, while it is possible for a human to work without the help of a computer. Besides this, an important difference between computers and humans is that the lasts make frequent errors, and are unable (with some extraordinary exceptions) to calculate extremely complicated equations only by using imagination. Computers, in turn, completely lack of imagination, which is a typical human feature, and moreover, while human brain is told to be "aware of itself", which means, allows the person to have self-consciousness, this is impossible for a computer. The other criticism to Simon's analogy, which is the fact that the human brain can learn, generalize and understand relationships, actually lead to a new, self-standing field of research, also known as connectionism, trying to build some special machineries, called "Neural networks", which, basing upon human nervous system's way of functioning, aim to make a machine learn, generalize, build rules and, basically, be autonomous and improvable. Neural networks are simplified models of the brain composed of large numbers of units (the analogs of neurons) together with weights that measure the strength of connections between the units, which are supposed to model the effects of the synapses linking one neuron to another (see Stanford Encyclopedia of Philosophy). Cognitive psychologists started to be interested in connectionism because it provided an alternative to the classical theory of the mind: the widely held view that the mind is something akin to a digital computer processing a symbolic language, as suggested by Simon.

Despite the limitations of Simon's analogy, it stimulated further growth of cognitive psychology. The analogy sparked the interest of some cognitive psychologists to generate insights into how the mind processes information based on how computers work. It also pushed some other cognitive psychologists to investigate how the mind is further distinguished from computer software applications.

In the 80s, for example, theories like the "Modular mind" from Fodor (1983), or the definition of "Architectures of mind" from Johnson-Laird (1983), tried to evolve the inception launched by Simon and develop more precise analogies, which could work operatively to the goal of a better definition of a Model of the Human Mind. The theories on mind based on vertical or horizontal architectures were based on different evidences, and were in a first moment in strong opposition: the horizontal view (functional processes operating in parallel) refers to cognitive processes which interact and are expressed by faculties such as memory, imagination, judgement, and perception, and are not domain specific and largely formed and develop in the humans according to the empirical experience. The vertical ones (hierarchical modules) claimed that the mental faculties are strongly differentiated on the basis of domain specificity. They are genetically determined, and at the neuroanatomical level, are associated with distinct neurological structures; the difference of these vertical structures from the horizontal ones is that the layers are computationally autonomous.

These different views of mental architecture, in turn, made it possible the development of fields like AI and Neural Networks, which are two different ways of creating "expert systems": the first is based on sequential and hierarchical structures (thanks to an improvement of the normal calculator's structure; according to Johnson-Laird, this would be a "vertical" architecture of mind), the seconds relies on diffused activity in parallel, where only (but not always) the main structure is initially defined and then self-organize themselves according to the presented inputs; this last organization, in the frame of the "architectures of mind", would be an "horizontal" one (Johnson-Laird, 1983).

This theoretical discussion about "vertical" or "horizontal" architectures of mind, stimulated not only a vivid debate between scholars and theorists, but allowed a big improvement of our knowledge of each single cognitive process, which later have been "recomposed" in a "unitary" and dynamic picture, giving birth to more global and complete theories on functioning of mind.

Anyway, regardless the undeniable boost that informatics gave to the science of mind, the very first "conceptual jump" in the way of considering the interaction with computers and technology in general and which supported the successive development of VR, was successively completed when the computer passed from the status of “calculator” to the status of “Personal Computer” (PC), becoming an object of “popular” usage. The last decades of the 1900, in fact, have assisted to the extremely fast development of the computer as a tool in almost every domain of human activity, and this was possible mainly thanks to the introduction of human-friendly graphic interfaces: computers were finally easy to use and to learn for everyone, and not anymore destined only to “nerdy” informatics and computer science experts, mathematicians or researchers. In this frame, for example, one of the most recognized successful user-interface paradigm is the Xerox Parc “desktop” metaphor, which became first popular among the computer users thanks to the Macintosh produced computers (Gobbetti & Scateni, 1998). From a certain point of view, we could already consider these graphical user interfaces which allowed the desktop metaphor to increase the interactivity and productivity with computers, as a form of VE “*in nuce*”, since this new “environment” was for the first time able to give a palpable, concrete illusion for the user to manipulate a real surface, with physical objects positioned on the top a desk, even if these “objects” were just pictorial representation of files (Gobbetti & Scateni, 1998).

However, it became soon clear that there were certain limitations in interacting with such “bidimensional” environments, especially considering that we usually have to deal and interact within a three dimensional world. These limitations were not only due to a lack of correlation between the manipulations and their effects and, of course, a high degree of cognitive separation between the users and the models they were editing (Conner et al., 1992), which became evident especially in the cases when the users had to deal with complex spatial information, such as 3D modeling and animation, motion control, or surface modeling, where the only possible interaction by means of the mouse made it extremely difficult for the users to perform their work with simple intuitive actions. But, also, the limitation was related to the feedback the user received about the structure of the three-dimensional world, because it was conveyed by a fixed visual image, and the only way to get a correct representation of a space in its complexity and reciprocal relationships between the objects, was to provide the application with multiple views with different depth information. And this, of course, increased the cognitive charge of the user, which had to actively combine the separate views into a coherent mental model, which forced the users to concentrate more on the way to obtain a certain goal instead of being concentrated on the task itself.

The origins of VR can be maybe traced already in the mid 60s, with the publication of the “The Ultimate Display” by Sutherland (1965).

In his seminar paper this author introduced the key concepts of what we believe now to be one of the most important and necessary features of VEs, that is the possibility of “immersion” in a simulated world, with the complete sensory input and output, which are the basis of current virtual reality research (Gobbetti & Scateni, 1998). Already in the early 1965, he sets the challenge for informatics and engineers:

> *“The screen is a window through which one sees a virtual world. The challenge is to make that world look real, act real, sound real, feel real”* (Sutherland, 1965).

At this point, it was clear that new devices had to be designed, which could rely on improved configurations and user interface metaphors able to allow users to work directly in three dimensions. For this reason, the research on the so-called “Virtual Reality”, started to receive more and more inputs. The initiative took evidence from the fact that human beings are naturally well equipped to interact with the world they live in, and therefore we should be able also to make users interact with virtual worlds in the same way they interact with real worlds, making all the tasks which require an interaction with an artificial machine more natural and reducing the time needed for training people on “how to use the device”.

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Fig. 2: Advertisement for Heilig's Sensorama, from Scott Fisher's Telepresence (URL: http://www.telepresenceoptions.com/2008/09/theory_and_research_in_hci_mor/)

Actually, even before Sutherland’s formalization of the problem, the first workstation for VR applications had already been released in the early 1960’s and it was named the “Sensorama Simulator” (Heilig, M., Patent online, 1962; see Fig. 2). The setup included stereo sound, integrated with the full 3D camera views. The viewer could ride a motorcycle watching a video showed on the screen while sensing the wind, simulated by a fan (Aleotti 2006). This was the first attempt to make the user live a simulated multisensorial experience.

Only around the 1970’s researchers realized the possibility of using computer-generated images instead of analog images taken by cameras, because in this way almost everything could have been created without the need to find it in the reality. In the same period NASA began an extensive research about using this technologies for training astronauts to space flights, and later, even moon landings, and this gave the input and the material for the new studies to be born. The successive convergence of technologies that have made Virtual Reality possible have come about in the last fifteen years. With the successive development of technologies in the last ten years, which saw the birth of Liquid Crystal Displays (LCD), the creation of high performance image generation systems, High Quality and Definition videos (HQ and HD videos), along with the development of tracking and sensory glove systems there have been incredible advancements which are absolutely crucial to the VR paradigm (Aleotti 2006).

Fig. 3: Scott Fisher wears the VIEW system.

A step forward the integration of men and machines has been done in the late 1980s at the NASA-Ames Research Center in northern California by the artist and scientist Scott Fisher, whose work aimed to render virtual worlds even more closely coupled to our sensory mechanisms: he oversaw the creation of the VIEW system (Virtual Interactive Environment Workstation; see Fig. 3), the first virtual reality (VR) system that integrated the head-mounted display, data-glove (sensing device worn as a glove), voice recognition, and three-dimensional (3D) audio, which enabled the listener to experience the location and movement of specific sounds more realistically than the two-dimensional stereo field of left to right. As a result of this research, Fisher established the field of “telepresence”, in which one could virtually transport oneself to another place, real or imaginary, experiencing remote spaces and controlling objects at a distance. According to Fisher, Virtual Reality’s potential was now as limitless as reality itself.

In the early 1990s, Daniel Sandin, along with his colleagues Thomas De Fanti and Carolina Cruz-Neira, developed the CAVE System (Cave Automatic Virtual Environment) to project interactive, computer-generated 3D imagery and audio into a physical space defined by multiple projection screens and a surround-sound system. The immersive nature of CAVE was intended as an allusion to Plato's Cave, evoking the shadowy presence of the representation of reality.

The potential of VR systems seemed immediately a more intuitive metaphor for an effective human-machine interaction, because it made it possible for the user to exploit his existing cognitive and motor skills for interacting with the world in a range of sensory modalities that he/she already uses in the real world. As I will try to explain in the next chapter, VR aims to give misleading inputs to the cognitive system, relying on the fact that we know how perception works. This makes it possible to suggest to the human brain that there is something “out there”, which is actually only a set of artificial information produced by a machine and processed by the brain “like if” it came from a natural source. Technically, the information that is processed, is “really” there, because it exists: but it is just a sequence of binary code processed by a machine in a way that “makes sense” for the human brain. The boundaries between the human and the machine became more and more subtle.

1.2. What is “Virtual Reality”?

The term “Virtual Reality” (VR) evokes many different ideas in collective imagery, mainly related to computers and technology, and often limited to videogames and entertainment.

In fact, looking for definitions of “Virtual Reality”, one can find incredibly different perspectives to look at it, like for example the one that sees VR as a new form of reality that people can though share with others, transposed in the virtual world of the *internet*, for example.

This extremely conceptual definition of VR is for example well described by Reynolds (2005) in his “Four World Theory”; he distinguish between: a) online realities whose essence lies in playing together (“*ludic worlds*”), based on rules set by the maker of the game, and those who do not like the given world may leave at any time (in the MMORPG, for example, like World of Warcraft or Lineage); and b) “less traditional games” or “alternate lives”, which are communities mimicking the social order of the real world (social or civic worlds; for example, IMVU, Habbo Hotel, Second Life), where the users have a greater influence and independence on the rules of the worlds and can perform activities that are technically possible also in the real world. “Civic worlds” are the closest copies of the “geographical”, real world (Reynolds, 2005). The VR, in his description, is seen as the possibility to live an *alternate reality*, which is not the actual one, but follows the same rules of the real one: some people use technology to create and live a completely new life, dedicating most of the time of their real life to get something that they failed to obtain in the real society and living out their “alter ego” on the net, sometimes leading to deviant behaviors and loss of contact with the reality. These are what some authors called “Virtual Realities” (VRs), and they are defined as a *“graphically developed, virtual online social space created in a 3D environment”* (Williams, 2006).

Nevertheless, while it is clear that VR has been initially developed as an applicative and sometimes entertaining tool, and it became known to the masses as an “exclusive” way of enjoying realistic videogames or to live out a new life on the internet, now the concept has been extended to medic field and even to research. Regarding this last point, a long discussion aroused about the validity of the results obtained in Virtual Environments (VEs), because the central question is: is the VE exactly like the Real Environment, thus eliciting the same cognitive processes in the user that a real experimental setting would elicit? As we will see also later, the answer is still open, but I personally agree, and the results of my work suggest exactly this, to accept VEs as a satisfying consistent tool to assess high-level cognitive processes (for example, learning, language, memory or spatial cognition, to some extent), but not the low-level ones (such as visual perception, spatial representation, visual attention and so on). Consequently to this, as some authors underline, VR can be considered something "different" from a real environment, but still very useful for taking the possibility to verify some research hypotheses in an extremely controlled and ecological way (see for example, Elneel et al., 2008; Mühlberger et al., 2007).

In the attempt to find out a clear definition of "what VR really is", I will show some of the most interesting perspectives, but keeping my focus on the most "operative and practical" one, which defines the use of VR as a technology developed to "deceive" human sensorial perception and "suggests" scenarios which are either replicas of real environments or are absolutely new ones, created with the purpose to verify some hypotheses or for training particular abilities. In my doctoral work, therefore, I will not consider the VR as a "conceptual" way of living an artificial online life (like the first definition that I presented), but as a "technical and practical" implementation of a new technology.

From a *practical* point of view, actually, there is not a single and clear definition of VR, which could help us defining when a computer generated set of images could be considered a "VR Environment" or "Virtual Scenario" (Keshner, 2004).

In fact, even considering the issue in a pure "technical" way, there are different kinds of VR, and different technologies able to reproduce different VEs, each one with different features and "affordances" (see Paragraph 1.3.4 and 2.2 for a description of the different existing VR technologies and Visualization Systems currently used in research). The lack of univocal features of VR opens a series of theoretical questions about "what could be considered VR", which becomes a methodological issue when it comes to the acceptance of results obtained with different machineries or with particular scenarios.

From a *theoretical* point of view in fact, the concept has actually deeper roots, which can lead us even to the earliest artistic expressions of mankind. As Randall Packer points out in his "Multimedia: From Wagner to Virtual Reality" (Randall Packer, 2001), in fact, we could even consider the early paleolitic art as a cultural background for our modern concept of Virtual Reality.

> *"The recreation of both the external world of nature and the inner world of magic in the immersive space and controlled atmospheric conditions of the underground cavern was an early attempt at artistic expression for the purpose of the preservation of culture. Here, in the prehistoric caves, the human concept of virtual reality began with the multisensory, totalizing experience that engaged*

> *sight, sound, smell, and touch—the first conscious virtualization of the physical world".*

We can go even further, considering the earlier human architectural's attempts to recreate natural environments in closed, artificial environments, in which the visitor has the feeling to be completely immersed in a simulated, realistic small world which offers multisensorial affordances for the complete representation of an environment, like for example Gothic Cathedral of Notre Dame in Chartres, France.

> *"Everything in this extraordinary building evokes some abstract meanings offering suggestions coming from multimodal sensorial stimuli, from the magnificent rose windows and stained glass, resonant chambers, vaulted ceilings, and sacred labyrinth, to the pictures and statues which tell stories from the bible, the sanctuary transposed the virtues of the church by transporting the individual through the experience of immersion, like in a "different", but realistic, virtual world"* (Randall Packer, 2001).

Besides figurative art, architecture and even music (as Randall shows in his extensive historical review on VR), also cinematography can be considered a sort of simulation of human consciousness. This attempt, obtained by engaging the full range of the viewer's sensory mechanisms, is illustrated by the cinematographer Morton Heilig's claim in the 1950s that the cinema of the future—a medium already transformed by such innovations as the panoramic perspective of Cinerama—would *"no longer be a "visual art", but an art of consciousness; a simulation so lifelike that it gives the spectator the sensation of being physically in the scene"* (p. 250). Morton Heilig is the same inventor of the "Sensorama simulator", mentioned in the previous paragraph, and he's considered one of the pioneers of what we consider VR in its most evolved concept.

The experience of "being physically there" has been a paramount quest in the development of virtual reality. And if we consider the last movies that have been proposed in the cinemas, like "Avatar" (movie's webpage: http://www.avatarmovie.com/) or Alice in wonderland (movie's webpage: http://www.disney.it/Film/alice/), we have an idea of how true this assertion is. "Avatar", in particular, being the very first official 3D movie, had an incredible impact on the viewers, which experimented and reported something that probably no other movie ever caused on the viewers: as we can read from a report from CNN (http://edition.cnn.com/2010/SHOWBIZ/Movies/01/11/avatar.movie.blues/), a large number of people who saw that movie fell in a very deep depressive state starting from the day after they saw the movie in the cinema. The explanation for this disease is that the realistic way of seeing that movie in 3D made some of the most susceptible viewers feel deeply involved in the perceived situations and, even if they perfectly knew, at a conscious level, that this was "just a movie", still the realism and "immersiveness" that the movie was able to generate, deeply influenced them at implicit levels, making the differences between the greedy humans still leaving on the hearth and the lovely and peaceful aliens of the planet "Pandora" even more evident and leaving in the viewers a truly depressive state of mind as if this experience touched them deep in their feelings. The importance of immersion and "sense of presence" will be discussed in more detail later in the next paragraphs, as they are some of the crucial points to define VR as a technology.

From a functional point of view, some authors remark the representational features, capabilities and possibilities of VR systems: as far as we know, a textual representation can give an indirect description of the real world (Gibson, 1971), and images can undoubtedly offer a *more* direct representation of it; but Virtual Reality (VR) gives us an *even more direct* representation (Johnson, 1998). This is obviously still not a good, practical and operative definition of what VR is. In a more practical attempt to define it, Beall and Jin affirm in their paper on immersive Virtual Environments (iVEs; Beall & Jin,2008), that VEs are *"synthetic sensory information that leads to perceptions of environments and their contents as if they were not synthetic"* (see also Blascovich, et al., 2002).

So, as the technology of VR became more and more used and employed in engineering and research, finally an interesting and operative definition of VR, is the one proposed by Burdea & Coiffet (presented first in Burdea's work of 1994, and then in their updated manual of 2003), which states that:

> *"Virtual reality is a high-end human-computer interface allowing user interaction with simulated environments in real time and through multiple sensorial channels. Such sensorial communication with the simulation is done through vision, sound, touch, even smell and taste."*

This definition of VR is the most popular amongst engineers, because the authors explain the virtual experience with the paradigm of the three "I"s: Interaction,

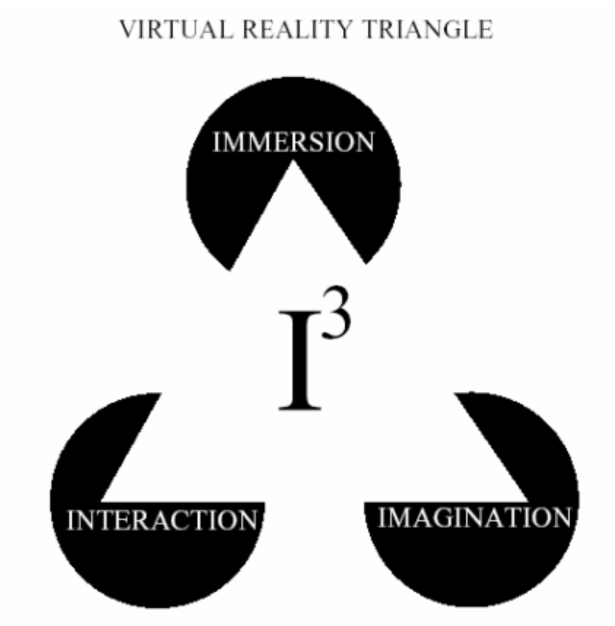

Fig. 4: the 3 "I"s from Burdea & Coiffet (2003).

Immersion and Imagination (see Fig. 4). The first two “I”s are, according to them, completely related to technology, and can always be improved to give the best experience in a Visualization System. The last one, the Imagination, is a feature pertaining to the user and his capability of “imagine” that the things that he/she’s experiencing are really “there”, but it is directly influenced by the other two. It is, in other world, similar (and strongly related) to the famous concept of the “sense of presence” that will be discussed later in this chapter. In a certain way, the third “I” is also related to the human possibility to imagine and realize infinite scenarios and situations and complex situations to propose to the users. I will talk deeply about the use of this definition in the implementation of VR technologies in the following paragraphs.

Moving back to the main problem of an operative definition of VR that can be useful in cognitive psychology research, if we decide to follow the definition of Burdea & Coiffet, an important distinction between “Virtual Reality” and “Virtual Representation” is therefore necessary. In fact, in order to be considered an artificial “reality”, it has to offer all the three “I”s at the same time. This means that without interaction, there is no VR. In order to feel “present” in a world, a user should be able to modify this world with his presence and actions, not only to perceive it with one of his/her senses. He/she should be free to interact, to move and explore, to perform actions and observe their consequences, which should be compelling enough to make him/her feel completely involved in such an artificial world. For example, according to this definition, a very well done videogame would be considered VR, because the gamer is continuously exploring the artificial world, navigating in it, behaving as the main character, interacting with the characters of the game and, in the case of Multiplayer Massive Online Role Playing Games (MMORPG), also with other real players, all of them accomplishing their missions and interpreting a part. It is a recognized fact that some of these games create in the player such a dependency that sometimes he/she keeps on thinking about the game even in the real life, and it sometimes is very difficult to interrupt or divert the attention of such extreme players while they are playing (Spence & Feng, 2010). So, we can see that, besides the great level of interaction offered to the user, the capacity of immersiveness of these games is indubitable, and without any doubt also the imagination that they are able to stimulate in the player is in some cases extremely high.

In fact, this is something different from what usually scholars who use VEs for research purposes consider that “VR” is: there is a tendency to define “Virtual Reality” whatever 3D environment that is realistic enough to be considered a tridimensional, artificial reproduction (or creation) of an environment. The famous “desktop VR”, for example, that we will discuss more in detail later, is typically the representation of a tridimensional environment presented on the screen of a PC. It is the most used kind of VS for displaying

VEs in research laboratories, for a series of motivations that we will discuss in detail in the next chapters, but most of all for reasons of space and costs. The result is that usually scholars use the label “VR” instead of the more precise and limited “Virtual Environment”, including in the “VR” concept also the more or less passive view of an artificial 3D representation, like in some studies about spatial memory, spatial attention or distance estimations (for example, Plumert et al, 2005; Mohler et al., 2006), where the subject passively perceives a scenario and give an answer, but cannot interact with it. To a certain extent also the preliminary study and experiments 1, 2, e and 3 on evaluation of distances of the present research do not allow an active exploration of the environment, although in this case the exploration of the environment is not completely “passive” because the subjects could move the mouse to “look around”, simulating the movement of the head.

Concluding, whatever “Virtual Reality” means, it is clear that it refers to the capacity to *simulate* something that is not real, but it “looks like” and “feels like” real, giving the possibility of actively interact with this “something” and perform a spontaneous and natural-like exploration of it. It is something that creates the illusion, in the human brain, that something is “there, in the real world”, even if it is not necessarily existingany other place than in the wires and chips of a well-programmed computer and, maybe, in the brain of the person who imagined it first.

1.3. Usage of VR in cognitive sciences

As already mentioned in the introduction and briefly discussed in the previous paragraph, Virtual Reality is currently used for a variety of purposes, from entertainment to commercial ones. In the cognitive psychology field, in particular, we can distinguish at least (but the usefulness of VR can be exploited in many other fields) three main directions in which VR is largely used: a) rehabilitation (either in dynamic psychology or clinical neuropsychology), b) training of cognitive abilities or promotion of learning and c) research. This last area, for the purposes of this work, deserves a deeper discussion than the other two, therefore I will introduce only briefly the most important and interesting outcomes that the studies in the other two areas (rehabilitation and trainings) bring to research purposes in general. In fact, if it is true that rehabilitation and Virtual Trainings are “applicative” fields of VR as a tool, it is also true that some studies performed to assess the validity of rehabilitation tools or the validation of training-scenarios allowed, in turn, a better and more precise knowledge of how cognitive processes work in VEs.

1.3.1 Rehabilitation

In literature there are a large number of works showing the attempt to rehabilitate patients with clinical or neurological disorder using Virtual Environments or scenarios: for example, in desensitization training for patient with phobias (North et al., 1997, 1998; Bullinger et al., 1998), to reduce anxious states or stress, psychiatric pathologies or phobic behaviours (Gregg & Tarrier, 2007; review), in treating children with autism (Strickland, 1997) or severe and critical burnings (Das et al., 2005), or people with learning deficits (Mowafy & Pollack, 1995, Cromby et al., 1996, Brown et al., 1998) or physical difficulties (Wilson et al., 1996, Stanton et al., 1998), for example after chemotherapy (Schneider & Hood, 2007).

Both *restorative* and *functional* cognitive rehabilitation approaches (Rizzo et al., 2001) rely on the advances made in research in the fields of cognitive science and cognitive psychology. Advances within this field are not only influenced by the concept of “plasticity” of the human brain, which is capable of considerable reorganization even following damage and injury (Sohlberg & Mateer, 2001), but also by the technological development of the last years, with increasingly complex technologies available in the scientific panorama (Szentágotai et al., 2011). Despite the notable progresses made by psychotherapy during the last decades, research also systematically points to a segment of patients who are non-responsive to “typical” interventions, prompting professionals to advocate for improving the efficacy of treatments and for exploring and developing new efficient and cost-effective intervention strategies (David et al., 2008). To fulfil these purposes, Virtual reality (VR) seemed therefore a very promising tool in the area of psychological intervention (Rizzo & Kim, 2005).

The possibility of3D interaction within VEs offered by the VR systems is what generates presence. “Presence” (we will discuss this concept later in this chapter) refers to the interpretation of the virtual environment as if it was real (Lee, 2004; Price & Anderson, 2006), and is the main factor that can validate and, at the same time, make it possible rehabilitation programs by means of VEs. Although the individual is conscious of his or her experience being produced by the technology, in fact, perception to a certain extent overlooks this aspect and makes the subject interpret the environment as if no technologies were involved (Krijn et al., 2004).

VR basically brings “the outside world” into the clinician’s office, and allows an higher level of control and the appropriate tailoring of the therapeutic process to the individual needs of the client, making a valuable addition to all components of the therapeutic process.

Also in neurorehabilitation, VR technologies begin to be employed to rehabilitate patients with brain damage or to help improved performances and facilitate functional reorganization (Pugnetti et al., 1995, Rizzo and Buckwalter, 1997, Christiansen et al., 1998, Davies et al., 1998, Pugnetti et al., 1998, Brooks et al., 1999, Rose et al., 1999, Rose et al., 2005; Subramanian et al., 2007) and there are some exploratory work also on patients with gait and balance problems (Nyberg et al., 2006; Oddsson et al., 2007) and tunnel vision (Apfelbaum et al., 2007).

It looks like the use of this new technology is useful mainly for the treatment of children and young people, as the extensive employment of VEs for paediatric neurorehabilitation proves (not only for the therapy of ADHD and autism, but also for the rehabilitation after cerebral palsy, as shown in a review by Wang & Reid, 2010). Motor abilities of children and adolescents with hemiparetic cerebral palsy has been proven to improve more than with normal rehabilitation (Li et al., 2009) and there are even works which prove an effective functional anatomical reorganization of the impaired areas with fMRI scanning (You et al., 2005) and finding neuroanatomical correlates of VR experience (Pugnetti et al, 1998). The rationale for the application of VR in this field mainly rests on the available evidence that a functional rearrangement of the injured motor cortex can be induced with the mediation of the mirror neurons system (Eng et al, 2007; Holden, 2005; Rose et al, 2005) or through the subject’s motor imagery and learning (Gaggioli et al, 2006). Intensive training (repetition of motor tasks) facilitating the rearrangement of cortical function and reinforcement of the motivation of the patients by means of feedback information about the ongoing improvement are necessary for motor learning to be possible after brain damage. All these conditions are easily made available in VR-mediated neurorehabilitation paradigms. Moreover VR allows online or offline feedback, which have been extensively investigated with a general agreement that it improves re-learning of lost functions (Bilodeau & Bilodeau, 1962; Gentile, 1972; Khan & Franks, 2000; Newell & Carlton, 1987; Winstein, 1991; Young & Schmidt, 1992; Woldag & Hummelsheim, 2002). The expectation is that VR-mediated rehabilitation should improve the approach efficacy and the outcome by making tasks easier, less demanding and less tedious or distractive, and more informative for the subject. Interactive VR environments are flexible and customizable for different therapeutic purposes; individual treatments can be personalized in order to facilitate movement retraining, to force the user to focus on the task key elements, and to facilitate transfer of motor patterns learned in VR environments to the real world.

Even if the enthusiasm about this new tool in rehabilitation is spreading and a great number of works show that it is a reliable tool in that field, some authors (like for example, Crosbie et al., 2007) warn the scientific community about the blind acceptance of such a technology, after performing a strict evaluation of published studies using VR in rehabilitation, and finding that not all of these researches are well assessed or consistent (they used the American Academy for Cerebral Palsy and Developmental Medicine, AACPDM, grading system and made some randomized control on trials presented in randomly chosen studies present in literature). These authors conclude that VR is a potentially exciting and safe tool for stroke rehabilitation but its evidence base is too limited by design and power issues to permit a definitive assessment of its value. Thus, while the findings of their review are generally positive, the level of evidence is still weak in terms of research quality and obliges to consider the issue with a certain caution. Another review of the literature on stroke rehabilitation was made by Henderson et al. (2007) with the same purpose, and it points out that the current evidence on the effectiveness of using VR in the rehabilitation of the upper limbs in patients with stroke is still limited but sufficiently encouraging to justify additional clinical trials in this population.

Remarkably, VEs are starting to be used to build what at the present is known as “Brain-Computer Interfaces” (BCIs), which allow the direct interaction with a machine connected to an EEG-set on a person’s head only translating the electrical activity of the brain into signals, controlling external devices linked to the computer (Kübler et al., 2001). In the very first phases of development of these special interfaces, the programs translating the cerebral activity were very simple, but since then, great advances have been done in informatics since the birth of this methodology, and by now everyday more authors decided to couple the BCI concept with VEs (Yan et al., 2008; for a review, see Marathe et al., 2008). This technology can be used in some, limited cases, as rehabilitation-programs, but most of the time it represent the only way to establish a communication with certain patients, who are unable to move, or to talk, or to use their hands to write on a computer. The extreme case is the “Locked-in” syndrome, or cerebromedullospinal disconnection, where the patient is perfectly able to process the incoming information (from the various sensorial channels), but cannot produce any output, since the efferent system is disconnected at the level of the basilar artery in the pons, located in the brainstem. The only efferent fibres not passing from the pons, are the oculomotorial ones, that is why the only form of communicating that these patient have are some small blinks or eye-movements. Giving to these patients the possibility to communicate with less efforts and more clarity with the world by interacting with a computer is for sure not “rehabilitation”, but it is still a decisive improvement of their condition.

1.3.2 Trainings and learning

A field in which VR is gaining popularity is without any doubt the one that regards learning. From virtual learning to virtual classes, from social learning to transformed social interaction (TSI, Beall & Jin, 2008), a lot of things are changing in the classical way of learning that sees the kids sitting in the class, reading books and writing on papers. In particular, Beall & Jin, (2008) demonstrate with their work how breaking the social physics of traditional learning environments can increase learning in VEs. But this is not the only application of the “virtual learning”: VRE are used also as a learning tool for professionals, to provide a safe environment where they can train and acquire skills and techniques necessary to their work, but without the risk of irreparable errors or dangerous situations. This happens for example for surgeons’ trainings (see for reviews: McCloy & Stone, 2001; Standen & Brown, 2005), reducing in this way dangerous consequences of eventually human errors during training.

Not only medical staff can take advantage of these trainings: in fact, also those professionals who must be trained to face very complicated and risky situations, where their skills on decision taking and problem solving are needed to resolve sudden emergencies benefit of this kind of training programs: for example, plane and helicopter pilots are often trained with Virtual Reality (VR) to acquire their flying competences (Proctor et al., 2004, Proctor et al., 2007a,b), but even aircraft inspectors are now starting to be trained in VR scenarios to exercise their strategies to visually detect discrepancies in observed airplanes and other aircrafts in order to find technical and mechanical problems due to human mistakes at a glance, that is very important for safety in air transportation system (Sadasivan et al., 2005).

The central concept allowing these trainings to be declared “effective” is not only the validation as a tool, but also the concept of “transfer” of the learned skills in the real life. It is not enough, in fact, to learn “how to...” in the VE to claim that a certain training was successful: the learned skills must be proven to be acquired also in the real-life tasks. Numerous validation experiments on “Virtual Trainings” show that the success rate of this way of employing VEs is quite high (Seidel & Chatelier, 1997; Torkington et al., 2001; Wallet et al., 2009, for example). Actually, some authors (Farrel et al, 2003) compared a VE training and a map-study for a route learning task, showing that from one side there is a better transfer of learned routes after an active VE training than after a passive VE training, but after a series of 3 experiment, the authors conclude also that the VE technology proposed by them, even if allows a good transfer in the real life, does not provide a better route learning than studying a map. From contrasting results like these, of course derives the necessity to investigate more deeply the actual benefit of using VEs for training people’s spatial skills.

VR employment in research is also frequent in social and behavioural psychology, as the development of Collaborative Virtual Environments (CVEs) shows.

The possibility to use, some classic paradigms which have been forbidden by ethical committees because too dangerous, like the Milgram obedience paradigm, took advantage of the possibility to test people’s behaviour in a completely safe VR, like Slater et al. (2006) show in their research.

Reeves and Nass (2000), in their studies on human–computer interaction, reported many instances of reactions to mediated stimuli that mimic what would be expected in human interactions (e.g., gender stereotypes) showing that, for some subjects, mediated stimuli are as real as the original stimuli, in terms of their unconscious responses to them.

The mimicry argument has been addressed also in other studies (Bailenson & Yee, 2005; Bailenson et al., 2007) in which they created some “digital chameleons” interacting with subjects. Lately, a great branch of social and learning studies benefiting of VEs have been focused on the development of some “learning helpers”, called embodied agents, which are animated agents, often graphically represented as human faces, or sometimes with the whole, or a part of, the body, and even as small and cute animals. They are supposed to support the cognitive processes of the user by giving advices, establishing a relationship between the user and the interface, explaining rules and instructions, but also just to relax and make the user feel comfortable. Some researchers found huge positive improvements in Human-Computer Interaction (in terms of performance, anxiety-reduction and acquired knowledge) by adding an embodied agent capable to show affections and being able to talk, use facial expressions and respond with conversational phrases coherently to the user’s actions (de Rosis et al., 2001; Beun et al., 2003; Rickenberg & Reeves, 2000).

1.3.3 Research

Finally, in research field incredible efforts have been done to validate, improve and better understand the proper use of this technology, too. As usual, there is quite a distinction between the “applied” purposes of the researches (studies on usability, human-computer interaction, and so on) and the “basic” research which aims to investigate human cognitive processes and behaviors by means of Virtual Environments appositely built to expose the human subjects to a desired setting for the experiments, with the desired set of variables and stimuli.

Just to make some examples, VR applications have been used for the investigation of components of cognitive processes, included executive functions (Elkind et al., 2001; Morganti 2004), memory (Matheis et al., 2007), spatial abilities (Parsons et al., 2004; Wolbers et al., 2004 Iachini & Ruggeri, 2006), attention processes (Parsons et al., 2007) and learning (Waller, 2000; Chen et al., 2003).

The more investigated cognitive aspect is probably the one of spatial cognition (Tlauka & Wilson 1996; Albert et al., 1998; Richardson et al., 1999; Albert et al., 1999). As we will see also in the Chapter 3, the research on spatial processes has almost completely transferred the old labs’s setting in the new artificial environments, benefiting of the possibility to completely recreate some environments (including the representation of existing ones) without having to build them in the reality or bringing the subjects to these places. According to Rizzo et al. (2002), *“Virtual environment technology may provide unique assets for targeting spatial abilities with its capacity for creating, presenting, and manipulating dynamic 3D objects and environments in a consistent manner and for the precise measurement of human interactive performance with these stimuli”*.

Not only VEs can be employed to easily perform spatial experiments and tasks, but also the benefits that cognitive modeling can enjoy from the direct interpretation of results in these fields are huge: for example, Zhang (2008) used VEs researches' findings to propose a multiscale progressive model which describes the relationship between spatial knowledge and spatial tasks in navigation.

As always happens in sciences, all research fields are strictly interconnected, since in order to be correctly used, a tool must first be scientifically evaluated and, from the other side, the use that people do and the way they interact with the tool itself is a necessary information that the investigator has to know before using a certain tool or to build the tool itself. A validation of the VR as a research tool can come also indirectly, for example observing the results of rehabilitation programs and training of specific abilities, such as the most famous application of VR in trainings, that is the laparoscopic technology's virtual simulation for surgeons (see Sutherland et al., 2006 for a review). And also studies in the applied research field can give an indirect but useful information about how people interact, uses, perceives and behaves in VR. By means of all the information coming from these different areas of scientific psychology, every result can be ascribed to the fundamental question, which is still to be clearly defined: are the human cognitive processes the same in Virtual and in Real Environments? Or do the experiments which take place in VEs exert in the subjects some different kind of brain processes that are somehow and somewhat different from the ones that they would employ in a similar setting, but real?

The question is fundamental especially for basic research, because of the large use of Virtual experimental settings to test and verify psychological and cognitive models of functioning in humans. This mass-use of the VR technology requires a strong validation of the tool itself, in order to be sure that the subjects behave in a certain way in a certain VE because the simulated environment or experimental setting is really realistic, and stimulates the same cognitive processes that researchers are actually investigating and not other ones, which occur only in VR but not in the real life, where they could be different or could be following different rules and modalities.

In turn, having a clear idea of how does cognition work in VEs is an helpful thing which can shed more light on the usability of the same, and directs programmers and computer scientists on their work of building VEs and tools in a way that is everyday better and realistic. It helps also the scientists which are interested in rehabilitation and trainings, since their work with VR will be for sure more successful and effective.

Anyway, despite all the positive reports about the use of VR in cognitive studies and researches, there are some authors who prefer to have a more cautious approach to this argument, and remark some issues that are still not clarified and could represent an obstacle to VR employment in research concerning cognitive processes. As Armbrüster and coll. (2008) point out, there are some limitations to VR applications, for example they remind that in experimental psychological research, it isn't often useful to use environments with much visual information as, for example, secondary depth cues or stereoscopic vision, as they may cause confounding effects on the visual scene, and investigated processes may not be genuine. Moreover, inter-individual differences (for example, in depth perception) are known to occur also in REs, and it is not answered yet if generalizability is given when using VR as a research tool, particularly when the data depend on correctly perceived distances, for example the use of spatial clues, navigation and so on.

1.3.4 Informatics and technologies in cognitive psychology research

In the first chapter I showed that research on cognitive psychology is intimately related to the development of informatics and computers in general. From a scientific-theoretical point of view, there are people who consider already the use of the computer for testing human processes a sort of "virtualization" of the real life. In fact, even before the establishment of VR technology, psychologists who were interested in investigating, for example, perception or attentive processes such as masking, crowding, priming and so on, were administering the subjects with some images presented on a computer screen, producing answers that then the scholars were gathering, interpreting and debating in the scientific community.

From a practical point of view, the use of the computer to build experimental tasks and easily gather, store and analyze the results simplified a lot the efforts of psychologists to investigate specific processes, for example by means of programs like Matlab or e-Prime, as it is testified by the famous "Posner's Paradigm" (Posner, 1980), or by the famous theories of the attentional filter from Treisman (1960), which are based on experiments built and presented through a PC screen. As is known, some scholars, inspired by the "ecologic" movement leaded by Neisser (1976), criticized these methods, because the stimuli, the way of presentation and also the task itself (i.e. pressing a button when a certain thing happen on the screen or remembering matrices of numbers) is very far from everyday life tasks, contests and activities in which people are normally involved.

By the way, regardless the naturalness of the tool, the use of the computer in experimental psychology consistently speeded up the validation of theories and models of cognition.
If the introduction of this “new” tool represented a revolution in experimental psychology, the use of VR represents an even bigger revolutionary innovation: by means of VEs is possible to investigate cognitive processes and human behavior with the advantage of automatically collect and store data in output and at the same time the possibility to create an “ecologic” situation which allows the subjects to be tested in an “everyday life” scenario more than what it is possible to do in the laboratory experimental settings. The “ecological” environment and the natural way of perceiving it are aimed, hopefully, to somehow counterbalance the scientific need to produce controlled settings and automatically registering the answers of the subjects, which has always been in the center of Neisser’s criticism to scientific lab-experiments.

As we saw in the previous chapter, VR is far away to be a well-defined tool, and moreover it is possible to find very different set of situations, conditions and features, which are not only limited to the different scenario that scholars use and for what reason (literally, the VE that they use: if it is representing an open space or a closed one, if it presumes interaction with the subject or if it is a simple passive presentation, if it is used as a rehabilitation tool or it presents a task that the subject has to perform to be evaluated to support a certain cognitive model and so on), but regard also the technical features of the machine employed for the investigation (that is, different Visualization Systems, VSs: if it has a big or small flat screen or if it is a 180° or 360° projection system, if it allows stereoscopy or not, and so on). Reviewing most of the works that have been carried out in scientific research with this instrument, we can identify *at least* four categories of VR (see Fig. 5):

1. HMDs (Head Mounted Displays ; see Fig. 5-A1 and A2), helmets or glasses which display a virtual scenario covering the whole Field of View (FOV) of the subject (Lin et al., 2004; Weiss et al., 2004; Wraga et al. 2004; Parsons et al., 2007; Kelly et al., 2007; Gèerin-Lajoie et al., 2008);

2. Projection-based (for example, CAVE™ ; see Fig, 5-D3) (Cruz-Neira et al.,1992; Cruz-Neira et al., 1993; Rosen, 1999; Riecke et al., 2007; Sharples et al., 2008 ; Takatalo et al., 2008), but also 180° (Fig. 5-D1) and 360° circular displays, like the Elbe Dom (Fig. 5-D2), which has been used for the present sperimentation, for example (Schoor, et al., 2007).

3. Fish Tank (limited FOV), namely, a normal PC screen, or one with bigger dimensions (Ware et al., 1993; Sherman& Craig, 2002; Stanney, 2002; Weiss et al., 2003) like the Engineering Workstation (EW; Fig. 5-C);

4. Augmented VR Systems (Merians et al., 2002; Mou et al., 2004; Botden et al., 2007). This is what is actually called "mixed reality", where the subjects observes the real world but receives some super-imposed information (Fig. 5-B2) by means of special lenses, connected to a PC. From a certain point of view, they are similar to HMDs because they show the additional information on mounted glasses or displays that are worn from the user (Fig. 5-B1), similarly to the previously described HMDs, but they still allow perception of the "real world".

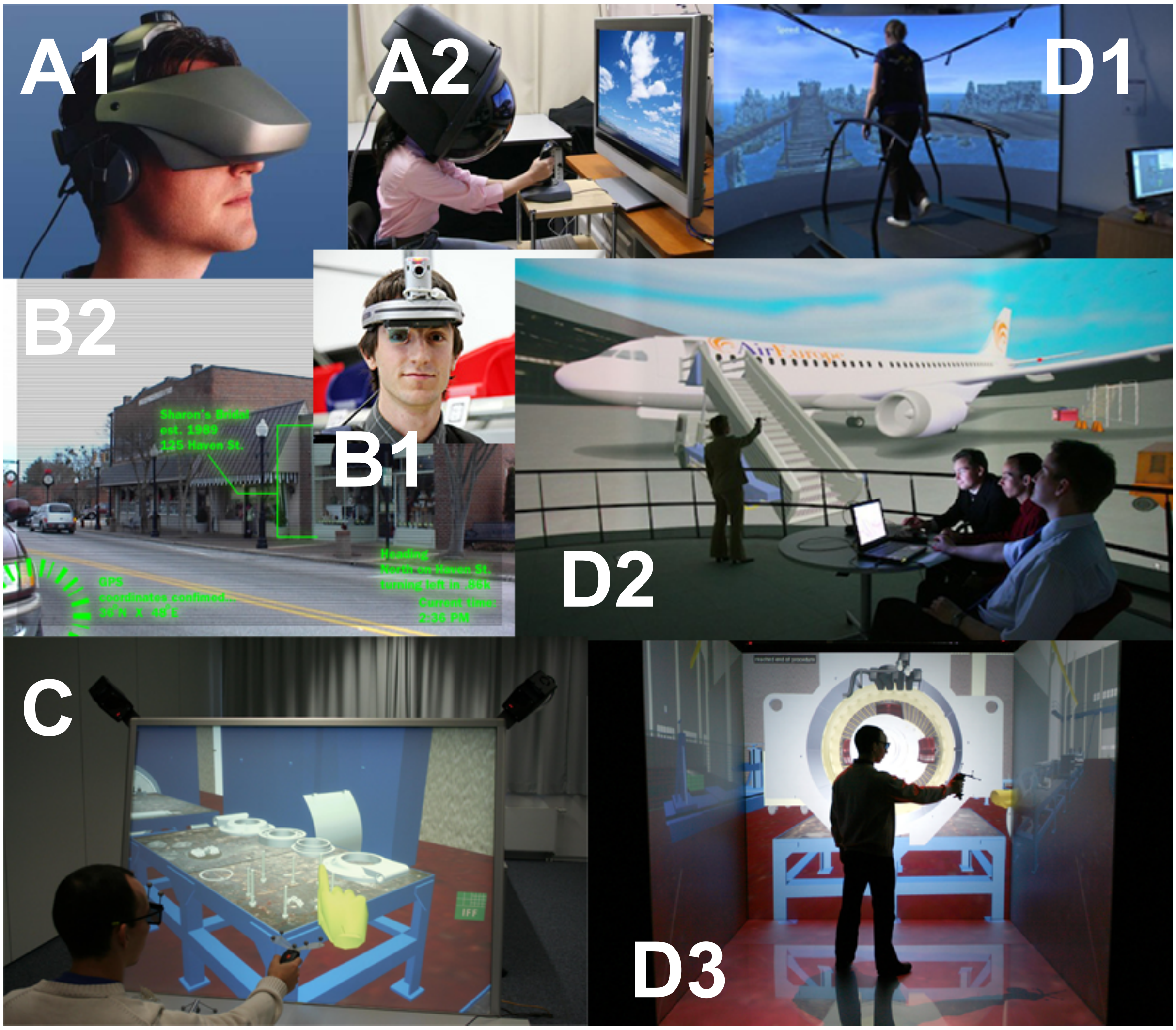

Fig. 5: Different Visualization Systems (VSs) and technologies to visualize virtual environments and augmented reality: different kinds of Head Mounted Displays (A1-2) and the one for the Augmented Reality (AR; B1) with an example of AR visualization (B2). In the lower-left, the Engineering Workstation (EW; C), a Desktop-VR, also defined "Fish tank VR". Up, right: a 180° (D1) and a 360° (D2) projection system for the visualization of 1:1 environments. In the lower-right

The first two categories of VSs cost usually a bit more, but allow the best VR experience, in terms of FOV and immersivity. These two features in turn concur to provide a better "sense of presence", which I will discuss deeper in the following paragraph. The third, which is the actually most used device to present virtual scenarios, is a simple Personal Computer (PC), and binds together the economic advantages and the easiness of use and portability.

While at the beginning of the 1990s the interest in this new technology of VR was raised and developed mostly regarding the HMDs, joining together the immersive visual experience to the use of data gloves, later the enthusiasm diminished a bit, with the increase of side-effects reports (like the Simulator Sickness, which will be addressed later in this thesis) and of economic cost of the tools, so the focus moved from the "immersive" VEs to the so-called "non immersive" VEs (Sharlpes et al., 2008). The "non immersive" VEs were typically shown by means of "Desktop VR" (that means, PC screens), and in the beginning was not even considered "true" VR.

As I will discuss also in Chapter 3 in the introduction to my experimental section, some studies were conducted to evaluate which, amongst the features of these VSs, interfered more with human cognitive processes and behavior. For example, some studies were interested in investigating whether the HMD was too much heavy for the users, affecting their performances (see for example Willemsen et al. 2004; Plumert et al., 2005), or in evaluating the advantages of a small-FOV screen-presented scenario with respect to the same scenario presented in a full-immersion mode, or projection-based display systems (Sharples et al., 2008).

From a methodological perspective, the use of these tools has been widely discussed from scholars, and some work has been done to validate one or another aspect of psychological research and one or another specific tool, scenario or visualization system to display the environments, but still there is no agreement on which should be the limits of usage of the VEs, nor guidelines to help a scientist in the process of choosing the best suitable VS to his research purposes.

In general, both advantages and disadvantages of the use of VR applications in psychological research have been discussed (Loomis et al., 1999): on one hand, as we already pointed out, high ecological validity, experimental control, generalizability of experimental findings, experimental realism, the use of "impossible" manipulations, and the ease of implementation and conduction of experiments; on the other hand, imperfection and high complexity of hardware and software, the difficulty of setting up high-quality virtual environments, high costs, and side effects (Armbrüster et al., 2008).

The high costs of high-tech equipments, in particular, is one the main reason for a “better than nothing” choice for many labs. This is also the main reason why most of the research has been carried out by means of normal PC desktops (the already discussed “desktop VR”, or “fish-tank”).

1.3.5 Technical features reproducing cognitive aspects in VR.

When we are in a real space (for example, in our living room, or in our office), we experience a series of mental processes, which go from the basic perception and cognition of the place, to the ability to perform actions, successfully navigate, remember landmarks and configurations of objects in it. For having such an “awareness” of the space, we need first to have a clear information about our position in the space: without this information, we would not be able to place ourselves in the environment and therefore we would not even able to build a correct representation of it. This “proprioceptive information” is something strongly needed in order to provide a successful sense of “being” in whatever place or situation. And, unfortunately, it is still somewhat missing from the VR setting that scholars are using to evaluate cognition in humans, except for some centers where some devices are developed in such a way.

Generally talking, VR aims to reproduce reality, or better, to create an artificial world that can be perceived as real thanks to the right stimulation of peripheral sensorial systems. This is still far from happening in this precise moment, but the idea is not completely wrong, and for sure it will lead to great improvements in the next future: as far as we know, from how the brain works, we could even be nothing else than brains in some tubes receiving inputs from a perfect informatics system, a supercomputer able to generate the information for an entire non-existing world and universe and delivery all this information to the cortical areas of our brains, in a way that could “feel like real” for us.
But, even without going so far to such extreme scenarios (proposed in famous movies like Matrix or Animatrix, for example), we can still say the purposes of VR are to give the feeling of something true, basing on how human perception works. For this reason I called this paragraph “Technical features reproducing cognitive aspects in VR”, because, besides the informatics processes and knowledge that it is necessary to build such technologies, the only way to make them work is to rely on our knowledge of human cognition and perception. To understand how these technologies work, a small description of models and

technical features is needed, even though for the purposes of this work it is not necessary to go too deep into technical details.

Multisensorial experience

Nowadays, actually, we are able to exploit only communication channels like vision and sound, and sometimes also touch, as in the case of "virtual gloves" or touch screens. But, still, this definition endorses the final aim of VR to completely "immerse" the user into an artificial world.

Burdea completed in 2003 his idea of VR by introducing the concept that was bounded to become famous amongst the VR theorists, creators and users: the 3 "I"s of VR, that I briefly introduced in the chapter 2 talking about definitions of VR (see Fig. 4).

The first "I" refers to "Interaction": to be able to talk about "VR", it must be possible for a user to produce actions within the environment, and observe immediate and appropriate consequences; of course, the way by which the virtual world must respond to the user's input has to be a dynamic way, to make it more "natural" and realistic. The second "I" means "Immersion". Immersion is the feeling of "being present" into the computer generated virtual world, and it will be deeply discussed later in this chapter, since it is recognized to be extremely important in whatever application of VR, from rehabilitation to simulation, from architectural modeling to safety evaluation, from manufacturing plant layout to training professionals, from research to learning, and so on.

We can say that Immersion-Interaction is a "twin element", and denotes the VR users' capability to interact with the artificial environments and scenarios through all human sensory and input and output channels. Finally, the third "I" of virtual reality stands for "Imagination". Imagination has also a "creational" meaning, as it can be related to the human capacity of being creative, referring not only to the capability to imagine something as real, but also to human's imaginative inventiveness to produce valuable applications for VR technology. Virtual environments take advantage of the imaginative ability of people to psychologically transport them to other places (Rey & Alcañiz, 2010).

Fig. 6: Interaction

ig. 7: Immersion (Calit2 project scientist Jurgen Schulze navigates "virtually" the first floor of a computer model of Calit2's headquarters building at UC San Diego).

Fig. 8: Imagination (a modified image from the Matrix).

But how does a complex VR system work? How can these assumptions be fulfilled by technical implementation? How the complex net of chips and plug-ins, processors and wires interface with the user offering him/her such an integrated, dynamic and interactive experience?

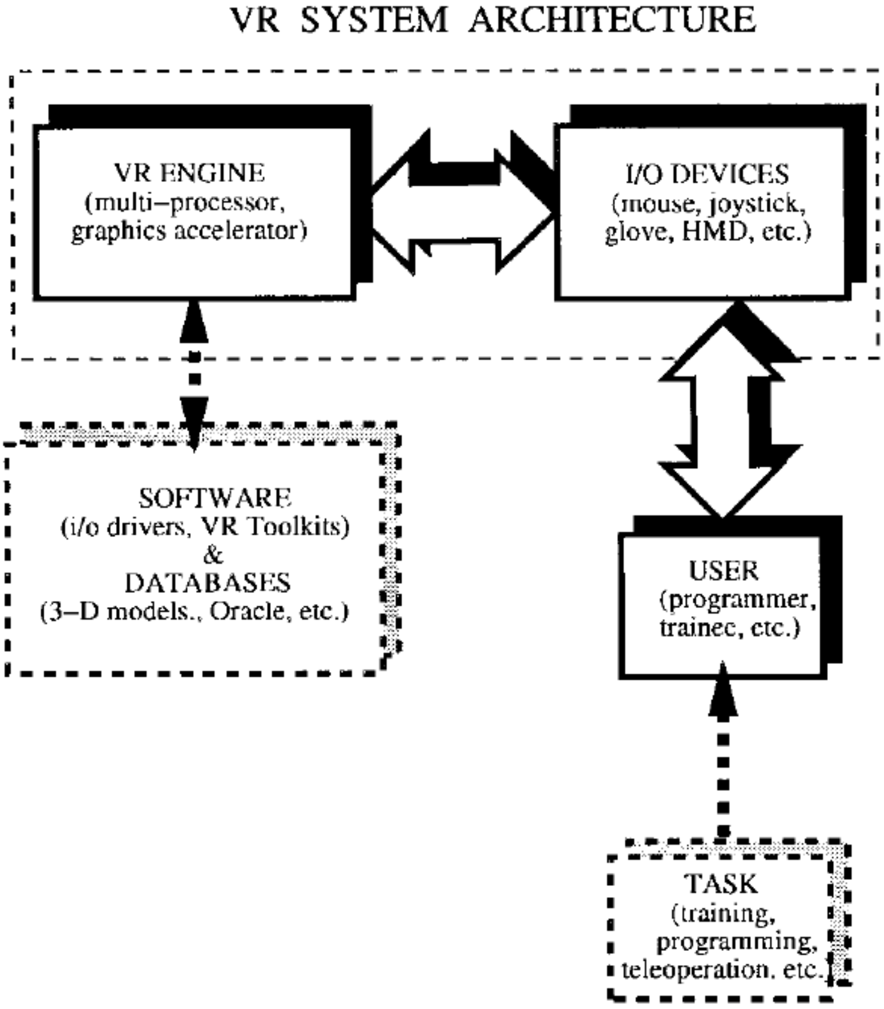

Fig. 9: VR System block diagram adapted from Burdea, 1993 (Burdea, 1999).

Fig. 9 illustrates a typical single-user VR system (Burdea, 1993; Burdea & Coiffet, 2003). Its main component is the “VR engine” which is a multiprocessor graphics workstation. Input/output (I/O) devices regulate the interactions between the user and the VR engine by reading user’s input and feedback simulation results. In case of simple tasks, joysticks or three-dimensional (3D) trackers, but also more common devices, such as mouse or playstation joypads are used as interaction tools, while sensing gloves such as the “CyberGlove” or “data Glove” are used in case of more complicated interactions or manipulations of the environment for haptic interaction. Visual feedback from the VR engine is offered typically through stereoscopic head-mounted displays (HMD’s) or large-volume displays such as the CAVE, the Elbe Dom or other cylindrical or semi-cylindrical displays, but in most of the cases the presentation is simply on a PC display. Simpler applications, in fact make use of standard monitor displays, the already mentioned “Fish Tank VR” (Ware et al, 1993). For what regards sound, spatially registered sound (called “3D sound”) is often provided to enrich the virtual experience, or force/touch feedback. As an answer to user’s commands, the VR engine responds by changing the view to, or composition of, the virtual world. The modeling of this artificial world is previously off-line-produced using dedicated software libraries and databases. Subsequently the models have to be rendered in real time (at 30 frames/s) and this thing strongly limits the geometrical complexity of the most commonly used virtual worlds. But this is something extremely important for realism’s sake: if the scene takes too long to be displayed, the feeling of immersion is already lost.

Usually, to allow huge Visualization Systems to work, several computers are networked, each having in charge some aspect of the simulation. This happens also because of the quite heavy computation load that the VR engine has to overcome to produce object dynamics, collision detection, physics and contact force for interaction between the virtual objects.

Sense of presence

In the previous chapters and paragraphs I already mentioned the concept of “sense of presence”: which are the origins of this concept?

The term “presence” actually indicates a true condition when an object is actually present in the physical, but the term may also connote a personal perception of the real world, embodied in a feeling or belief , that could be wrong at times, for example when a perception of presence occurs when an object is not present in the real world ("illusion of presence"; Heeter, 1992).

One of the interests in VR technologies developers is, without any doubt, the understanding of how is it possible to create the illusion of presence and use it for positive outcomes.

The online edition of the Visual Thesaurus (Visual Thesaurus, 2004) defines the word "experience" with the following key points: (1) experience has two meanings: it can be something one has gone trough and gained knowledge of or it can be the content of direct observation or participation in an event, (2) experience may have both mental and bodily states, and (3) it is closely related to feelings and emotional sensations. Direct observation or participation in an event requires ongoing interaction between person and an environment. The experienced content of this interaction is affected by the memory and knowledge based on previous experiences (Glenberg, 1997), and gives an experience meaning and value.

The process also causes emotional changes in bodily states, which are felt as "feelings". These "somatic markers" provided by the body have an effect on perceptions, cognition and behaviour, and deepen the quality and intensity of the experience itself, so the mind of the perceiver is linked to the body of the perceiver (Damasio, 1994). All subjective experiences are quantifiable only by the person experiencing them (Schuemie et al., 2001). But, since almost all experiences arise from the interaction between a man and his environment there are common patterns in various experiences (Dewey, 1934).

The investigation of these patterns in restricted environments such as 3D interactive virtual environments (VEs), is likely to expand knowledge concerning both subjective experiences and interactive VEs (Takatalo et al., 2008). The problem of "presence" has been addressed in the last decade as more and more researchers are employing VEs to verify their hypotheses, and the general aim of technology, machines and software builders is to improve the quality of VR and the feeling of being in an integrated environment.

VEs are considered capable of producing a sense of physical presence, which is defined, e.g., as the user's feeling of ''being there'' in a mediated environment (Ijsselsteijn et al., 2000). A more precise definition of "presence" is the one offered by Slater (2002): "it is the total response to being in a place, and to being in a place with other people. The 'sense of being there' is just one of many signs of presence – and to use it as a definition or a starting point is a category error: somewhat like defining humour in terms of a smile".

IJsselsteijn et al. (2000) distinguished between "social presence" (the feeling of being together and communicating with others) and "physical presence" (the feeling of being physically located in a place). Similarly, Heeter (1992) distinguished between three different types of presence: personal presence (the extent to which the person feels physically present in the VE), social presence (the extent to which other beings, living or synthetic, also exist in the VE), and environmental presence (the extent to which the environment itself recognizes and reacts to the person in the VE).

Interaction between the subject and environment ("environmental presence") is acknowledged as one of the prime causes of presence in VEs by many authors (e.g., Draper et al., 1998; Lobard & Ditton, 1997; Steuer, 1992). Especially, ecological view (Flach & Holden, 1998; Zahorik & Jenison, 1998) emphasizes the role of functionality in generating presence experience. In this perspective presence is more related to the functionality of the VE than to its appearance (Flach & Holden, 1998). Some authors also emphasize the role of emotions in presence experience (Huang & Alessi, 1999; Baños et al., 2008).

In the real life presence and interactivity are difficult to define and measure. However, measures concerning how the well-defined VEs is perceived and how its functionality is evaluated have a clear role in the psychology of the virtual. It is a holistic human experience, which depends not only on *"what the organism perceives, but how it takes what it perceives"* (Fodor & Pylyshyn, 1981).

To study human experience from this viewpoint other psychological and emotional components should be taken into account. For example, the interplay between the level of skills possessed by the subjects and the challenges provided by the situation or the task and its different experiential outcomes must be considered, as also arousal, control and valence (considered as basic emotional dimensions by Wundt (1897).

Indeed, scholars and researchers acknowledged also that the sense of presence is a complex and likely multidimensional construct (Sheridan, 1992, 1996; Biocca & Delaney, 1995; IJsselsteijn, 2000) and could not be considered only by the side of the user features or only of the media characteristics. Recent theories try to explain presence with reference to both perspectives, and their interaction.

Novak et al. (2000) showed in their work that a better measurement of presence as well as interactivity is needed to fully investigate the relationship between the concepts of interactive speed and challenges in the optimal experience (also defined "flow", that is an optimal state of consciousness characterized by a state of concentration so focused that it amounts to absolute absorption in an activity; Csikszentmihalyi, 1990).

Riva and colleagues (2003) faced the problem of presence considering two dynamics. On one side there are optimal experiences, as the result of the link between the highest level of presence-as-feeling with a positive emotional state, while on the other hand there are the so-called breakdowns (Winograd & Flores, 1986) which occur when, during our activity, an object or an environment becomes part of our consciousness, making our attention shift from the action we were performing to the object/environment to cope with it, for example when a wall stops our movement.

They believe that it is possible to design mediated situations that elicit exceptionally high presence. In particular, they argue that virtual reality is the medium able to support the highest level of presence because it can trigger at the same time all the three layers, phylogenetically different, and strictly related to the three levels of “self” identified by Damasio (1999):

- **The proto self:** a coherent collection of neural patterns that map, moment by moment, the physical state of the organism;
- **The core self:** a transient entity which is continuously generated through encounters with objects
- **The extended self:** a systematic record of the more invariant properties that the organism has discovered about itself.

In their review from 2004, Riva and colleagues express their observation that, in experiencing an interesting and immersive VR experience, for example, spatial presence, vividness and engagement will be activated by the medium, but if we are in an immersive VR experience, you are pre-occupied with personal worries and the mediated content is not very engaging, spatial presence and vividness will be invoked by the medium, but not “extended” presence. The possibility of activating all the three layers at the same time reduces, in turn, the occurrence of breakdowns.

In humans the sense of presence-as-feeling is thought to be a direct function of these three layers: the more they allow the cognitive system to separate between "internal" and "external", the more is experienced the “sense of presence”, the better is the quality of interaction and experience within a certain virtual environment.

One of the main goals of VR is therefore to maintain users' attention in the content/illusion of a VR system in order to give the subjects the perceptual illusion of non-mediation, produced by means of the disappearance of the medium, which activates the highest level of presence.

With the aim of building assessment instruments for detecting whether a VE is able to induce or not the “presence” feeling in subjects, some work has been done to produce questionnaires and factor analysis as evaluation tools and measurements.

In a very recent work, Takatalo et al. (2008) investigated the field of presence using the “Big three” (Laarni, 2003) physical presence components: the realness of the VE (presence as realism), the ability of the VE to induce a sense of spatial awareness to the user (presence as transportation) and the users psychological immersion, i.e., attention to the

VE instead of the real world (presence as immersion). Physical presence components were thought to cover perceptual and attentional aspects of being in the VE. The purpose of their study was basically to find a way to profile patterns of various experiences received from the VE by using different components of both physical presence and flow in a CAVE. They concluded that being physically present, situationally involved or competent is not alone enough to create a positive and rich experience in VE. The participants having unsteady profile lacked feelings of playfulness and "being there", and they did not regard VE to be as impressive or socially rich. In some cases the experience was unpleasant, negative in valence and anxious. Some of these participants experienced, at least in some extent, physical presence but not flow. This indicates the role of presence as a prerequisite of flow in mediated environments, as Novak and coll. pointed out in their previous work (Novak et al., 2000), discussed above.

From another point of view, Baños et al. (2008) conducted a study to verify if VR most peculiar features, which are stereoscopy, the illusion of depth and 3D imaging, were the main responsible (as some other studies argued: Hendrix & Barfield, 1996; Freeman et al., 1997) or not of the sense of presence and mood intensity in VEs. Their results indicate that there are no differences between stereoscopic and monoscopic presentations for both presence and emotion measures, so results do not replicate previous findings, which claimed that subjective feelings of presence are enhanced by stereoscopic stimuli presentation. For what regards mood intensity induction, resulting data support the hypothesis that stereoscopy does not affect the intensity of mood induction. That is, similar emotional reactions are elicited by both monoscopic and stereoscopic presentations, and this replicates previous findings (Baños et al., 2004; 2006) that indicate the subjective sense of presence is related to emotional reactions.

Indeed, in the study from Baños and coll. the VEs were designed especially for inducing positive moods, the other works employed neutral VEs. So the authors conclude that maybe for the specific purpose, stereoscopic presentation is not as critical as supposed before and that technological factors are more relevant for non-emotional environments than for emotional ones.

Thanks to presence, not only knowledge acquisition is possible in VR, but also this acquired knowledge can be transferred in a real environment. This evidence, coming also from different neuropsychological studies (e.g. Morganti, 2004), adds value on VR use in the rehabilitation of highly social disabling cognitive functions, highlighting how goals reached in controlled settings may be transferred on patients' everyday life, simply by "training" their cognitive system to respond in the correct ways according to the situations and giving them some cognitive tools and coping schemes to face them.

Therefore, here an “Immersive VE” (iVE) will be considered an artificial environment that perceptually surrounds the user, increasing his or her sense of presence or actually being within it (Beall & Jin, 2008).

Stereoscopy

The attempt to develop the stereoscopy technology shows that the future of imaging is going in the direction of creating everyday more “lifelike” artificial images and, thus, improving a user’s “sense of presence”. According to what found by Baños et al. (2008), stereoscopy does not improve the “sense of presence” in a VE, since they found no difference between monoscopic and stereoscopic view of the same VE. Nevertheless, there are still some works proving the opposite (Hendrix et al, 1996; Freeman et al., 1999; Freeman et al., 2001; IJsselsteijn et al., 2001). As I will explain in the experimental chapter, it looks like the possibility to use stereoscopy, gives a “nicer” and more compelling way of watching at a 3D scene, but in the matter of fact, the artificial graphics and the attempt to produce “depth” are not exactly comparable to the real environments, where the objects are more “stable” and real.

From which cognitive base is stereoscopy implemented in VR?
Our ability to coordinate the use of our left and right eyes and to make use of subtle differences between the images received by each eye allows us to perceive stereoscopic depth, which is important for the visual perception of three-dimensional space (Parker, 2007). Binocular neurons in the visual cortex combine signals from the left and right eyes. On this basis, tridimensional effects are reproduced on computer-generated images following the functioning of human perceptual system by means of “stereoscopy”: doubled images and special glasses which provide selective visual information for one image for every eye allow the objects represented in some of the newest Visualization Systems and 3D displays to “pop-out” from the screen and acquire a certain depth (Parker, AJ, 2007).
The visual impression that stereoscopic images offer is very sensitive to the geometry of the visual system of a user, the geometry of the display environment, and the modeling geometry assumed in the computation of the scene (Hodges and Davis, 1993).

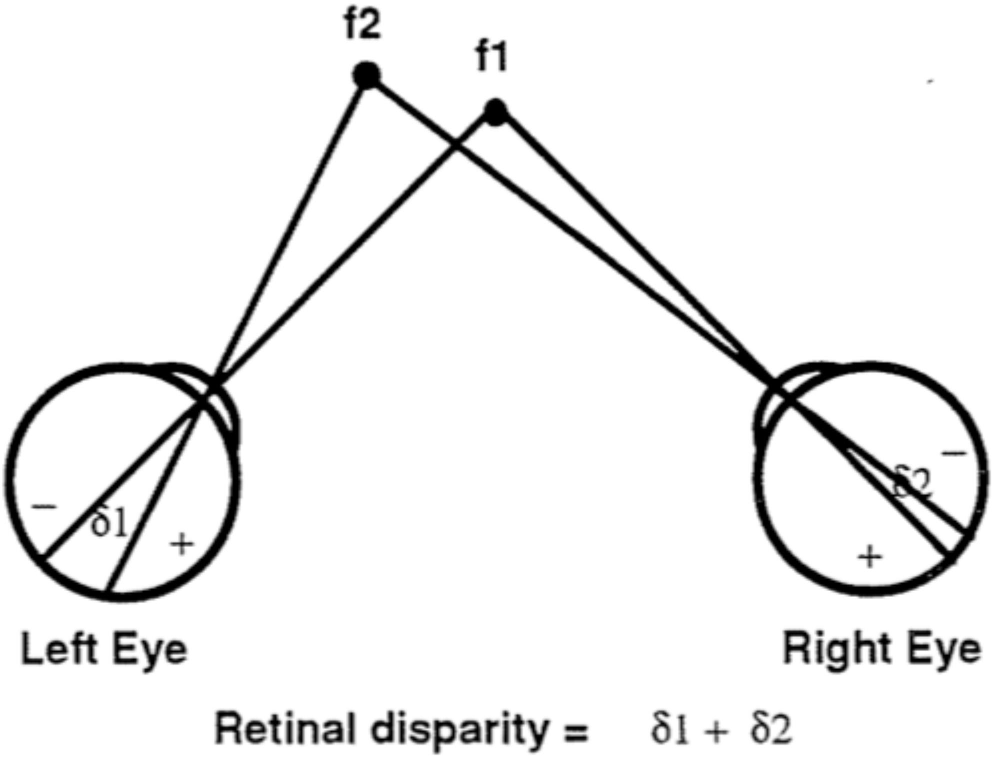

Fig. 10: a scheme from Hodges and Davis (1993) describing the functioning of binocular disparity, basic knowledge on which the stereoscopy is based to recreate the impression of depth in VEs.

Stereopsis, in our natural visual system, results from the two slightly different views of the external world that our laterally-displaced eyes receive (e.g., Schor, 1987; Tyler, 1983).
If both eyes are fixated on a point f1, in space, then an image of f1 is focused at corresponding points in the center of the fovea1 of each eye. Another point, f2, at a different spatial location, would be imaged at points in each eye that may not be the same distance from the fovea. This difference in distance is quantified in terms of retinal disparity.
Usually it is measured as sum of the angles δ1 + δ2 (as shown in the Fig. 10), where angles measured from the center of fovea toward the outside of each eye are negative.

To provide stereovision in artificial technical apparatuses, slightly different images must be presented to the right and left eyes with little if any cross talk between the two images (Kenyon et al., 2004). In some systems this depth-feeling is provided by using field sequential stereo in combination with liquid crystal shutter glasses (StereoGraphics, Inc). In systems like the ones used in the Fraunhofer, in which stereoscopy was provided by means of stereoglasses, the right liquid crystal lens is clear while the left is opaque and the perspective scene generated on the screen is that for the right eye.

Then the left eye lens is clear and the right is opaque and the left eye's view is displayed. This method of producing stereo has found its way not only into projection-based systems (Kenyon et al., 2004), like the ones used in the Fraunhofer's VDTC, but also in the already described desktop systems (or "fish tank VR"; 1993).

Another way of producing stereoscopy effects in other systems are the use of an head mounted display (HMD) worn by the person, where the right and left eye each see a dedicated display so that the computer generates a left and right eye perspective image and each image is connected to the corresponding monitor. Such systems use miniature CRTs, Liquid Crystal Displays, and Laser light directed into the eye to create the image on the retina (Tidwell et al., 1995).

Despite stereoscopy it is quite in the vanguard for giving the users the feeling of 3D, though, a last category of screens suggest us that stereoscopy “with glasses” may already be “antiquate”. In contrast to the systems mentioned above, in fact, an auto-stereographic system displays stereo images to the person without the aid of any visual apparatus worn by the person (see for example Sandin et al., 2001).
In these systems, the person merely looks at the screen(s) and sees stereo images as he/she might do in the natural world. Because of their ease of use by the subject and their versatility these new and experimental systems have the potential of becoming the ultimate VE display when large motions of the subject are not needed (Kenyon et al., 2004).

2. Experimental section

2.1. Introduction and background

Basing on the concepts presented in the previous chapters, and aiming to shed more light on the employment of VR in research in spatial cognition, a project, which could allow the investigation of spatial processes at different levels, has been developed in the frame of a collaboration with Fraunhofer IFF and the Interuniversity Centre for Research on Cognitive Processing in Natural and Artificial Systems (ECONA), by means of an agreement promoted by “La Sapienza”, University of Rome.
“*Space cognition in Virtual Environments*”, in fact, is a multilevel project which gradually tackles basic problems, like how humans build a mental representation of the spatial relationships between the objects and between themselves and the objects inside a Virtual and a Real Environment, and then pursue the integration of this bottom-up information in more complex processes, which presume spatial awareness and include the association of high-level and top-down information, like for example a navigation task in a 3D maze and the planning of an optimized route.

As we saw briefly in the previous discussion on the use of VR in psychological research (chapter 1), VEs have been widely used to study cognitive processes, and in particular the studies investigating spatial abilities are the largest number. This of course happens because of the affordances suggested by the VEs themselves, which are typically representations of closed or open spaces, and usually are the preferred scenarios in which navigation tasks could be quite easily performable.
As discussed in the previous chapter, the highest number of studies were aimed to clarify some aspects of spatial cognition using a 3D representation of particular environments, “like if” the VE was a direct representation of the real world, concluding therefore that the obtained results of these works could be used to build a good model of functioning of human brain. Indeed, all these works on navigation, spatial memory, mental rotation, spatial anxiety and so on, actually take for granted something that at the present has not been deeply investigated, yet, which is the question about how the human brain creates a

consistent representation of a virtual environment basing on perceptive cues like depth, spatial relationships, shapes and shadows. We know from direct observation that these pictorial cues are enough to give a sense of “tridimensionality” even on a screen with 2D image representation (and this is true especially in art: just think to all these naturalistic paintings, defined “trompe l’oeil”, in which the artist gives the spectator the illusion of a continuous space beyond the walls on which the scenes are painted only relying on a skilful and clever use of the perspective’s laws); but what allows the human eye to distinguish a picture from a real image? And, more interestingly for the present work aims, by means of which cues the human brain manages to understand the concept of “space” and distinguish a real (or artificial) tridimensional view from a simple image of the same scenario?
In the previous chapter we saw which principles the modern VR technologies rely on to give the viewer a sense of tridimensionality in artificially generated environments. The most used “trick” to deceive the human visual perception and suggest the presence of the depth even when there is not, is the use of the stereoscopy. But does it work in a way that we can define reliable? The question is central in scientific research, but also for applied research and other purposes, like for example trainings, because if the method is wrong itself, and gives a wrong perception of whatever virtual scenario, then all the results obtained with means of it, all the tools produced, all the training proposed and whatever other device is intended to develop, then all these things would be biased from the very beginning. All the judgments about distances, lengths, dimensions, time-to-walk, reciprocal distances between objects and in worst cases even proximity of some objects to the viewer, could be basically wrong.

Even though, as shown in the previous chapter, the use of stereoscopy as it is known by scholars (that is, with the use of glasses) could be actually already “outdated” and probably stereoscopy itself will soon change its features, still vision in artificial environments through stereoscopy is an issue on which it is necessary to shed more light, in order to produce usable tools and be able to collect interesting and informative results in scientific researches performed with VR, especially when they presume a correct perception of the spatial relationships and a consequent correct mental representation of that space.
For this reason I decided to address this central problem performing an evaluation of distances experimental paradigm in VEs (section 2.3). In literature, there are already some works trying to understand if the perception of the depth in VR is more or less similar, or at least follows the same rules, of depth perception in the real world. What has been found, is a general tendency of the subjects to compress the perceived distances in artificial scenarios, independently from the methodology used (numeric estimates, Loomis

et al. 1996; time to walk, Plumert et al., 2005; indirect measurement, Sahmet al. 2005; and so on).

Although the distance compression in immersive VEs has been widely proved, the causes why this happens are not fully understood (Loomis & Knapp, 2003; Thompson et al., 2004). In the attempt to find out the mechanisms underlying the sistematic underestimations in VEs, several recent investigations have found out some experimental manipulations that can *at least* attenuate or alleviate the mistakes. As Waller & Richardson (2008) point out in their review on the topic, these manipulations include: a) asking users to estimate distances in a known familiar environment (Messing & Durgin, 2005; Interrante et al., 2006), b) presenting the environment on a large projection screen instead of an HMD (Plumert et al., 2005), c) providing users with explicit feedback about their distance errors (Richardson & Waller, 2005), and d) providing users a brief period of interaction with the environment before having them make distance judgments (Mohler et al., 2006; Richardson & Waller, 2007). The latter procedure seems to be particularly valid and feasibile, as it is almost always possible to allow the subjects to interact with and explore the environment and it does not require too much time. An initial period of familiarization would be therefore necessary for the subjects before they are given their primary tasks.

But even after all these studies, a direct confrontation between perception with or without the use of stereoscopy is still lacking, and this motivated one of the experiments performed in the Fraunhofer Institute in the frame of my doctoral project (in particular, I investigate this point in the experiment 1 discussed in the paragraph 2.3.2, but also indirectly in experiment 3, paragraph 2.3.4).

Another problem in research paradigms supporting the use of VR, is the issue of which kind of VE has to be used to fulfill one's research purposes. Or, better, which kind of Visualization System (VS) is the most appropriated to be employed in order to display a certain VE, according to its features and capacity to collect the required data about the desired variables.

As we saw also in the previous chapter, since different VSs generate different degrees of "immersivity", they're also able to exert different levels of "sense of presence", and this makes it possible that even cognitive processes have different features in every single VS and, of course some of them cannot support stereoscopy. For this reason, in my *preliminary study* I have first addressed this issue in order to a) define the different features of every VS (immersivity/stereoscopy) in relation to perception of depth and distances and b) be able to perform the further experiments on distances estimates (paragraphs from 2.3.2 to 2.3.4) starting with some well-defined basis.

From a practical point of view, it is pretty well known that the most used technology is the so-called "Desktop-VR" (that is, a simple Personal Computer), because it has some good features for displaying virtual scenario in lab experiments. For example, it is less expensive than, let's say, a CAVE or a 180° projection system. Moreover, it takes less space and it is simpler than other complex machineries, and it is usable by any user, even without technical experience. Third, the fact that it is actually nothing else than a computer, makes it easier to interact with it, and does not require complicated modules of 4 or more connected PCs to work, like instead is required for CAVEs or projection systems with 180° or more degrees displays.

But of course, it also has some black spots: the "immersion" in a scenario is not completely possible, and this does not give the observer a good "sense of presence", being just a "fish tank" (Jayaram et al., 1997) inside which something happens, but out of which the real world is still visible and tangible *([1])*.

Some works show (as for example the one from Westerman, et al., 2001) that spatial tasks requiring navigation are better performed in a Desktop-VR than in an immersive VS (iVE; in these studies, generally a HMD is used, and this is considered as an iVE). They explain their results by commenting that when the subjects are left completely without any point of reference of the reality, they have a worse performance. Another possibility, investigated in the present doctoral work, and more precisely in the first experiment ("Navigation and visuospatial planning in a 360° immersive projection system", in the section 2.4) is that the HMD is simply not good enough in representing an environment for navigation, and it is probably not even suitable as the most famous representative of iVEs. To investigate all these issues, two experiments have been performed and will be discussed in this chapter.

In paragraph 2.2 I make a brief overview of some of the VR technologies present in the Fraunhofer, as they are the ones that I used to perform the experiments described in both section 2.3. and 2.4. In section 2.3, I first address and discuss the first argument of my study, starting with a general discussion about the distances estimation as a basic process for spatial perception and representation. Then, in the following paragraph (2.3.1) I will present the preliminary study and the results in base of which I defined my work hypotheses.

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[1] This is not completely true, for example, in the case of some modern videogames, which are so well-designed, involving and have such good quality image-rendering, including perfect dynamic audio sources, that the player is often "lost" inside the game-scenarios, feeling literally "inside" the game's world, practically being able to exclude from the stream of consciousness all the information about the small room where they are physically in the moment. These features of certain videogames are making it possible to overcome the limitations of a small screen or limited FOV display, but unfortunately for our goals, in most of the scenarios used in research, the quality of graphics and motion levels are not comparable to the videogames industry, limiting the possibilities to have a realistic and convincing tool at lower costs without the need to build, for example, a CAVE.

In paragraph 2.3.2 (experiment 1) I investigate if stereoscopy in VEs is really helpful for a correct depth perception. In paragraph 2.3.3 I present the experiment 2, where I show how different distances estimates are in Virtual compared to Real Environments. The last experiment (paragraph 2.3.4) is intended to define a measurement tool which could let researchers understand if people who cannot judge correctly metric distances still have a more or less correct representation of a virtual space, represented by the scenarios; in this experiment, I show how the modality of the answers (metrical or non-metrical) requested to a subject in a distance evaluation task brings to very different performances independently from the presence/absence of stereoscopy.

In section 2.4 I define the outlines of the second issue addressed by my research: if navigating in a VE brings different performances in a spatial cognitive task and which are the discriminants that make the difference between virtual and real environments and between different VSs. The first part of the investigation (paragraph 2.4.1) is related to the evaluation of the test itself and the differences that it is possible to observe in the performance obtained with the same task in a Desktop VR (a normal laptop, namely Personal Computer, PC) and in a 360° projection system Environment. I was here interested to see if the VE allowed a better performance and different use of navigational strategies with respect to the performances obtained with the PC. The second part (paragraph 2.4.2) regards the interaction within the environment itself. Since it is known that such huge iVEs are very easily inducing Motion Sickness symptoms in the user, I was interested in understanding if the use of a more "naturalistic" way of interaction (i.e., with a Tracking System able to acquire at any time the movements and position of the subject, who could *physically* turn right or left in order to turn right or left in the environment, without using the joystick commands "left/right", but only pressing "forward" after turning left or right with his/her body) could have been helping in reducing SS symptoms as well as improving the performance to the task. In the section I address these hypotheses, discussing the obtained results and offering ideas to improve such a possibility of interaction.

2.2. Visualization Systems used in this project

In the previous chapter I made a general distinction between the different technologies commonly used as Visualization Systems (VSs) for reproducing Virtual Environments (VEs). In the VDTC Fraunhofer IFF a huge number of machineries and technologies are available, but the ones that have been employed for this scientific work were the following four (see Fig. 11):

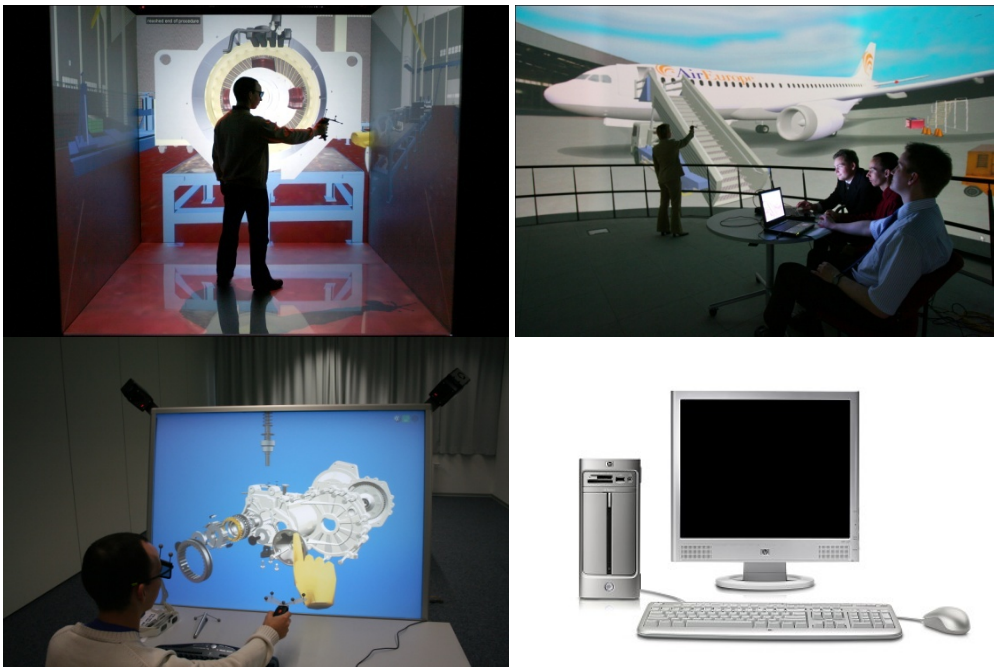

Fig. 11: the four technologies for VEs visualization that have been used in the present work. From the top-left: a) the CAVE, b) an internal view of the Elbe Dom, on the bottom-left c) the Engineering Workstation and d) a classical Personal Computer at the bottom-right.

Fig. 12: 3D glasses with IR-cameras receivers for tracking the eyes position.

1) The CAVE (see Fig. 11a): is a cube where floor, front, left and right walls show projections of a coherent image. It allows stereoscopy by means of special 3D-glasses for passive stereo view on which some receivers (see Fig. 12) for the 6 infrared (IR) cameras, which in turn are placed on the top of the structure, allow the tracking system to record at any time the position of the user, and especially the direction of the gaze, in order to “adapt” the shown image to look “like if he/she was

really looking at that object”. For example it would be possible to appreciate the posterior side of an object presented as very close to the subject by just leaning forward and turning the head as if one was “looking behind” the object. The whole system is composed by a total of 8 PCs running at the same time, controlled by a master PC.

Fig. 13: external view of the ED.

2) The Elbe Dom (ED; see Fig. 11b, internal view, and 13, external view): this huge semi-immersive VS is a quasi-cylindrical perforated wall, 16 meters in diameter and 6.5 meters high. The entire screen is aluminum and spans a surface area of approximately 330 m^2.

A PC cluster consisting of 7 high-end PCs is used for image generation. Each PC is responsible for generating the image for one projector.

The seventh PC supplies the geometry and kinematics data for the other nodes and synchronizes them. The result is an extremely realistic high-quality image presented in a 1:1 dimension.

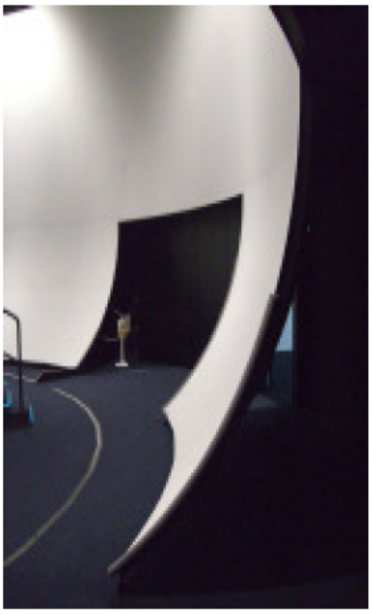

Fig. 14: the base of the screen of the ED.

The diameter of the lower portion of the screen is slightly constricted (see Fig. 14) to create the illusion of ground projection since users look at the screen from a circular platform in the center of the setup. Also here tracking is allowed by means of 12 infrared (IR) cameras and a tracking cap/collar with three passive IR markers.

3) Engineering Workstation (EW; see Fig. 11c): it looks like a huge pc-screen where a binocular disparity-image is projected from two parallel beamers standing behind the screen. It allows the view of tridimensional objects with 3D-glasses, and it also has a small tracking system of 1 camera situated on the top of the screen, in front of the subject, to be paired with the receiver-glasses described for the CAVE (see Fig. 11a). It can be used also like a normal PC with extraordinary dimensions of the screen without stereoscopy.

4) Obviously, also normal Personal Computers (PC) were available (see Fig. 11d). As already underlined in the previous chapters, this is the most used technology in research (known as “desktop VR”), because it is present in every lab, does not cost a lot, programs for 3D Environments creation and representation can be accessed easier and in case of laptops, they are also portable. In two of my experiments I compare the performances obtained within PC and the other VSs.

In particular, all the 4 VSs have been employed only in the preliminary experiment. In the following experimentation EW has been used (Experiments 1, 2 and 3) and ED (Experiments 4 and 5) have be used.

All these technologies rely on a special VR programming tool developed from (and for) the Fraunhofer IFF, called “VR Author”, visualized with OpenSG, which works on C++ programming language, and requires a Windows operative system. By means of this program, virtual worlds can be created, and with the addition of patches and special programming tools, it is possible to add, for example, physics and gravity, the binding with the tracking system, dynamic shadows, points of references and so on. All the VEs used in this work have been created with the “VR Author” program.

2.3. Spatial processing: Evaluation of distances in VR

Human spatial behavior, and in particular the production of goal-directed actions in the space, such as spatial navigation, wayfinding, and so on) depend on a correct perception of distances (Carey et al. 1998). Research concerning the depth perception and judgments of distances in the real world is well documented since the mid-twentieth century (Gilinsky 1951; Loomis et al. 1996), but since the 90s the use of Virtual Environments (VEs) in research on spatial cognition started to require the same investigation in the new artificial environments, to evaluate if the cognitive system relies on the same basic processes of distances and depth perception in the same way, or in a similar way, of the natural ones. As pictured in the introduction of this chapter, a correct perception of the distances in an environment is a basic process for spatial perception and representation of that environment. Without knowing if people are able to perceive, process and use the correct information of the relative distances between objects, or between the objects and the perceiver, we will not know exactly if they have a similar mental picture of it.

In other words, if we are not sure about what happens at the level of lower processes (visual perception), we cannot be sure that the higher-level processes observed in some comparative or behavioral studies within VEs are coherent with a cognitive model functioning that we use for explaining processes in Real Environments (REs). Theoretically, we could not make any inference about subject's performances in a navigational task in a VE if we do not have a previous knowledge of how the people process the visual information and then use it to build a mental representation of VEs in general.

To clarify this point, some work has been done in cognitive psychology field since the very beginning. For example, Waller and Richardson (2008) performed a review of 14 independent studies investigating distance estimation in immersive virtual environments (Durgin et al., 2005; Henry & Furness, 1993; Interrante, Anderson, & Ries, 2006; Knapp, 1999; Messing & Durgin, 2005; Mohler, Creem-Regehr, & Thompson, 2006; Plumert, Kearney, Cremer, & Recker, 2005; Richardson & Waller, 2005; Sahm, Creem- Regehr, Thompson, & Willemson, 2005; Sinai, Krebs, Darken, Rowland, & McCarley, 1999; Thompson et al., 2004; Willemsen & Gooch, 2002; Witmer & Sadowski, 1998; Witmer & Kline, 1998), showing that, across this literature, users' estimates of distances in immersive VEs are, on average, only 71% Æ 8.2 (for a 95% confidence interval) of the modeled distance. The authors underline that this tendency to underestimate in iVEs is quite remarkable, since it is established that distance estimates in natural environments (not mediated by computer interfaces) under comparable viewing conditions show an average 99.9% Æ 2.8 (for a 95% confidence interval, estimated from another review by Loomis & Knapp, 2003).

It is now clear that systematic errors of distance compression when acting in the virtual space, occurred disregarding the modality of distances estimates: verbal reports (Loomis et al. 1996), blind-walking (Witmer and Sadowski 1998), and even throwing to targets on the ground plane (Sahmet al. 2005). In the attempt to explain this bias in behavior, scholars examined technical aspects of VEs such as, for example, the limited field of view, eventual problems with binocular stereoscopy in HMDs, or addressing the quality of computer graphics and HMD mechanics themselves (Knapp and Loomis 2004; Thompson et al. 2004; Bingham et al. 2001; William et al. 2001;Creem-Regehr et al. 2005). Some studies showed the usefulness of feedback in learning how to perceive distances (Richardson & Waller, 2005; Mohler et al. 2006), finding that, actually, there is a strong improvement in perceived distances after learning the internal set of measurement a of a VS. Anyway, there is still no agreement on the reasons of this bias or on how it is possible to avoid it *in general*.

In the following section 2.3, I’ll discuss about the same problems (compression of distances, iVEs and stereoscopy) I have also encountered in my experiments.

For my research purposes and in order to build the paradigms of my experiments, I performed a review of literature on VR and cognitive psychology, and I collected some basic information, which I’ll discuss briefly here in order to make the following content more clearly understandable and methodologically solid.

In Psychology there is a distinction between different sections of the space, considering the perceiver’s body and space of action. As known from some studies (Cutting 1997; Cutting and Vishton 1995; Previc 1998; William et al. 2001), the tridimensional space surrounding our bodies can be divided, in fact, in three spaces: the peripersonal space refers to the space that can be reached by our hands, generally distances up to 1.5 m. Distances beyond 1.5 m and 30 m are classified as extrapersonal (or “action”) space, where the subject can move and touch objects around himself, interacting with the environment, while the objects situated more than 30 m far are considered as in the vista space (or background). This means that, according to the purposes of the perceiver, some objects could be considered differently according to the portion of space where they lie in.

Another important distinction in psychology of spatial cognition is the one existing between egocentric and allocentric (or exocentric) spatial relationships: in literature, scholars refer to egocentric estimations of distances when the requested measure is the perceived distance between the observer and an object, while the allocentric (or exocentric) distance is the judgment about the relative distance of two objects, external to the perceiving subject (Paillard 1991; Pani & Dupree 1994; Klatzky, 1997; Zaehle et al., 2007).

In egocentric frames of reference the organism is at the centre of the surrounding space, and this means that mental spatial representations are stored in memory accordingly to the perspective under which the spatial information has been collected, while allocentric frame of reference are independent of body's position, and allow derived mental representations to be centered on objects or environmental features (Iachini & Ruggiero, 2006).

Most of the experiments performed on evaluation of distances in VR in literature are focused on egocentric distances (Sinai et al., 1999; Willemsen & Gooch, 2002), which induced the subject to define the distance between the objects and him/herself. This is actually very important to investigate, since most of the studies about navigation and spatial memory discussed briefly in the previous section usually require a correct perception of the objects as the subject perceives them, and the optic flow is also centered on the first-view perspective (route navigation). But a mental representation of an environment, as we saw before, does not only rely on the subjective perspective, since the human vision system needs also to make judgments on relative distances of other objects. Without this ability, we could not understand if we are able to pass through a door or a narrow corridor, or between a chair and a table, or if some objects are close enough to be reached with the same action (for example, grasping). Moreover, other processes, like spatial memory or spatial learning, are strictly related to a correct knowledge of both allocentric and egocentric distances of an environment.

In the present study, the egocentric distances were directly confronted with the ability of the subjects to discriminate the distances between external objects, which obliged the subjects to reflect on the spatial relationships of all the objects present in the observed scenario. For this reason the questionnaires built for our experiments contained both questions about the distances of some objects from the subject (egocentric) and questions which asked for estimates of distances from objects to other objects (allocentric) in the presented scenarios.

Another issue, discussed for example by Ärmbrüster et al. 2008, is the difference between closed scenarios (which show an "inside" environment, as for example a room or a house) and open ones (showing the "outside", that is, a naturalistic scenario, or the representation of a city or a fabric, and so on), finding that, even if the difference was not significant, there were less underestimations in the open environments with respect to the closed ones.

For the purposes of our project, another aim was to test this finding in relation to another fact: the presence or absence of stereoscopy, assuming that the simulation of the binocular disparity would have been more evident in a closed environment.

Moreover, Ärmbrüster et al. 2008 assumed in their work that a single-object presentation would avoid confounding effects for the subjects. To verify if such an effect took place, they evaluated the subject's answers with a growing number of objects surrounding the target, and actually, they found no "crowding" effects, so they proved that to present one or 10 objects at the same time was not confounding enough to change significantly the answers to the questions. Following these authors, and aiming to use the most ecological setting possible, I decided to set up two realistic (enriched) environments for the "evaluation of distances" scenarios, one showing a room inside a house and another one showing a garden and a naturalistic panorama on the background with a certain number of objects, in order to be able to ask the subjects judgments about the ego- and allocentric distances between these objects (see fig. 15).

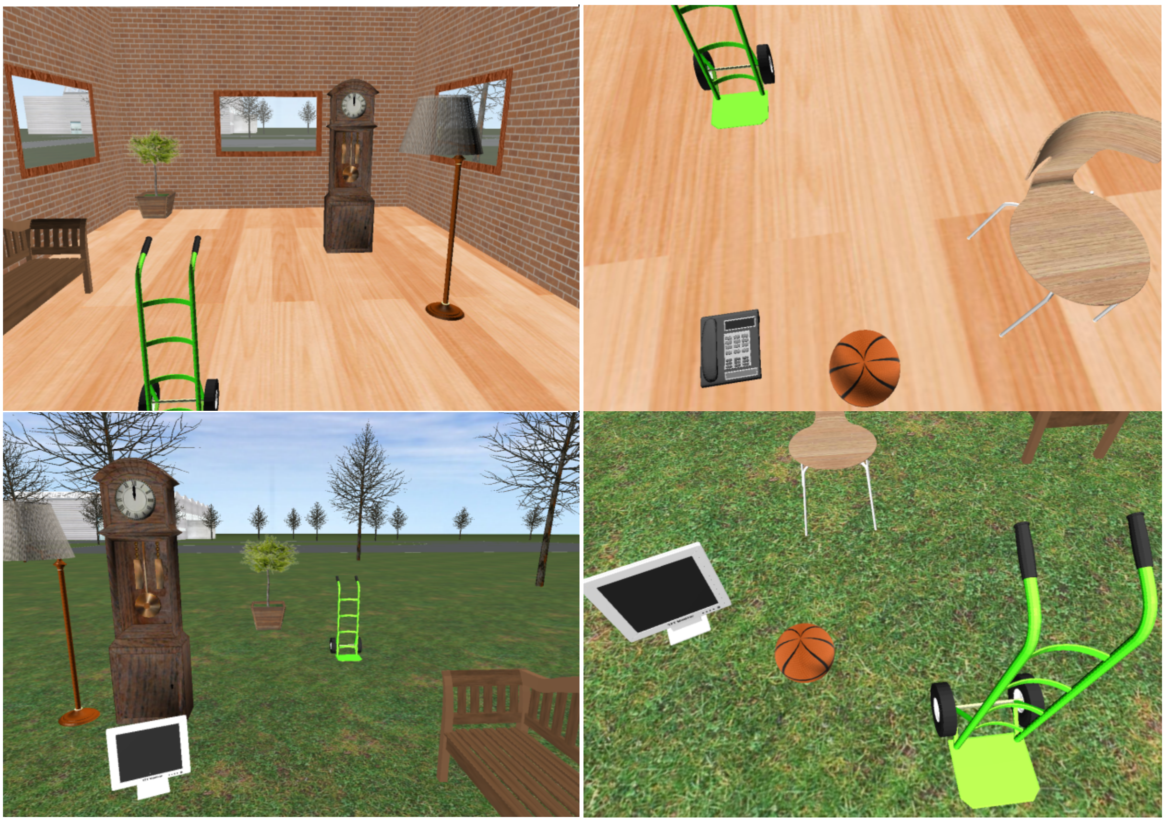

Fig. 15: starting from the up-left corner, a) inside, far objects; b) inside, close objects; c) outside, far objects, d) outside, close objects.

For the following studies about evaluation of distances (Experiment 1, 2 and 3, paragraph 4.3.2, 4.3.3 and 4.3.4) we used these two artificial environments, with 4 different configurations of objects for the randomization of the conditions, to evaluate different effects of spatial knowledge in VEs.

Moreover, as a cognitive style measure, we wanted to evaluate if the spontaneous perceived rhythm could be significantly related to subject's performances on spatial tasks. Providing some evidence of a distinct modality of processing of the visual scene, Olivetti Belardinelli (1974; 1978 and 1993) showed that subjects with a spontaneous rhythm based on a binary partition process the information according to the signal features (automatic processing, supported by the dominant binary occidental culture), are faster but make more errors because their focus is more on the requirements than on the structure of the problem or of the visual scene. On the other hand, ternary subjects (structural, non-automatic processing) tend to focus their attention on the structure of a situation more than on the demand of a task, because they are not supported by cultural cues, being forced to actively look for a non specie-specific structure and this takes time and makes their answers slower, but more precise and not tied to elaboration processing errors.

2.3.1. Preliminary study: Distances evaluation in different visualization systems.

Background and motivation of the study

Basing on the existing studies in literature on the argument of distances perception, the aim of this preliminary study was to understand if there are some relevant differences amongst the different Visualization Systems (VSs) due to their different technical features. In fact, the most of the studies on this argument are performed with Head Mounted Displays (HMDs), and show a typical compression of perceived distances, but it could be actually possible that HMDs does not represent the best way to display a virtual scenario where a person is supposed to navigate or interact, or maybe it has to be improved in order to display open spaces.

As a preliminary study I decided to use some simple, geometrical objects, to avoid confounding effects or biases that could have affected the perception of distances and relative estimates of the subject. As Ärmbrüster et al. (2008) showed in their results, there are no effects due to overcrowding of objects on the scene, so I built a scenario where 7 cubes were present at one time. The cubes where differentiated by color but not by dimensions, in order to give the possibility to calculate the possible distance by actually observing the pictorial cues and perceived dimension. To avoid learning effects during the different conditions, we created 4 different configurations of cubes: 1, 2, 3 and 4, each with a different position (that is, different x and y coordinates but the same rotation degree on the z plane) in the space and even different distances (to have an idea of the different settings and configurations, see fig. 16). In the beginning of the experiment, the subjects were told that the cubes' side was 1 cm, independently from the VS they were experiencing.

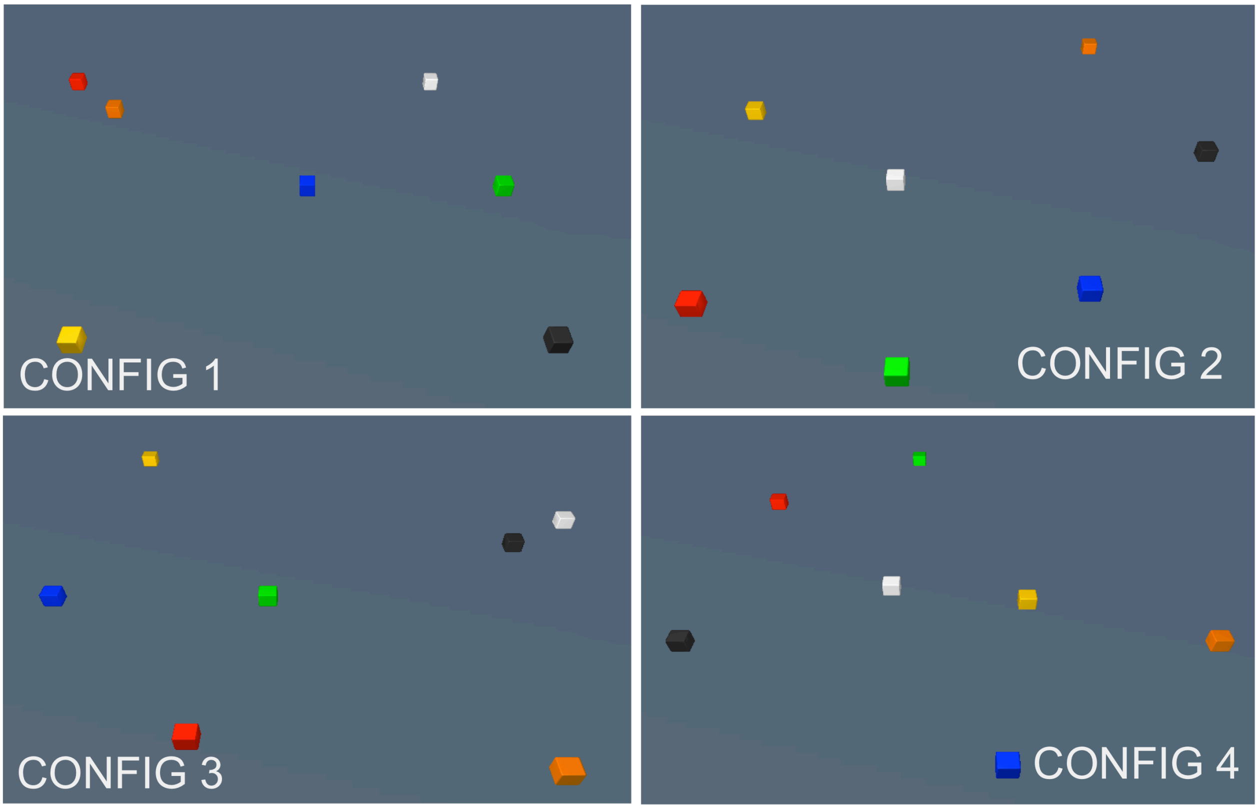

Fig. 16: the 4 configurations of the scenario

Then, a series of 21 questions (7 egocentric, 7 allocentric and 7 "control" questions of simple judgments, that is, non-numeric estimates) were asked the subjects, like for example: *"How far do you think the black cube is from you?"* (egocentric question) or *"How distant do you think that the blue cube is from the yellow one?"* (allocentric question). In addition, as a "control", I asked in every condition 7 additional "non metric" questions, that did not require the subjects to give a numeric estimate, but just a judgment of proximity (for example: *"Is the distance between the red and black cube half of the distance that there is between the white and the green?"*). In this way, I could have a measure of how people perceived the scenario independently from their ability to give numerical estimates of distances. This was repeated for a total of 4 times, one for every VS, in order to make the VS variable a within subjects variable and observe the differences of performances of the same subject through the 4 VSs. My aim was to evaluate if subject's estimation of distances are 1) congruent with the actual object's distances as defined in the absolute coordinates in the 3D program, 2) congruent with the finding, in literature, of the different estimates of distances considering ego- and allocentric measures, 3) qualitatively and quantitatively different according to the visualization system by which the 3D VE is represented, which are: CAVE (CV), Elbedom (ED), Engineering Workstation (EW) and a Personal Computer (PC).

Hypotheses

The hypotheses of this preliminary study were basically, according to what found in literature, that:

a) VEs scenarios, especially when visualized in immersive Visualization Systems (iVSs) produce a compression of distances.

b) Nevertheless, stereoscopy should help perception of depth in VEs, as it is offering a tridimensional perspective of the objects, being based on the same psychophysiological processes of normal binocular vision.

If these hypotheses were true, then this kind of results were expected:

> a) The perceived estimated distances in the virtual scenarios would have not been congruent with the actual object‘s distances.
>
> b) General underestimations are expected in ED and CV, since they are the most immersive systems.
>
> c) In VSs where stereoscopy is available, less error should occur with respect to ED and PC.

Methodology

Subjects: 15 male subjects answered the 21 questions about distances of 7 cubes for 4 times (one in each of the 4 VSs), randomizing either the order of questions and of VS presentation sequence.

Tests used: 4 questionnaires for evaluation of distances (one for each VE); virtual scenario with 4 different configurations of 7 cubes.

Statistical analysis: Because an error of 10 cm in a distance of 40 cm is not worth the same as in a distance of 250 cm, for example, I calculated for each estimate a scaled error, considering the total real distance and dividing the error for this value. So, the dependent variable that I used for the analysis was the average optimized error of estimated values for each condition, calculated with the formula (Graham, Joshi, Pizlo, 2000):

$$\frac{\text{Subject's Estimated Distance} - \text{Correct Distance}}{\text{Correct Distance}}$$

On these new data, repeated measures ANOVA was performed considering two Measures (“absolute” and “with sign”), and consisted in the 2 versions of the dataset collected in my experiment:
a) the absolute average values of the errors committed by the subjects in every VS and
b) the mean values with the sign (plus or minus) which showed the direction of the errors (over- or underestimations).

For both of the Measures a 2x4 analysis was performed, where the first factor was represented by the allocentric/egocentric questions (“alloego”, 2 levels) and the second factor was the one representing the 4 Visualization Systems (“vissys”, 4 levels: ED, EW, CV and PC). Both the factors were within subjects. No between subjects variable was considerable in these analysis. For the post-hoc analysis and main effects comparisons, a Bonferroni correction method was used.

From the 7 “control” questions about proximity judgments I derived other 4 variables, each for one of the VSs: ED, EW, CV and PC (the variables were therefore named “control_ED”, “control_EW”, “control_CV” and “control_PC”), which have been analyzed as covariates in the Repeated Measures analysis.

In my analysis, as also all the following experiment data analysis in my research, significance levels are considered for every $p<0.05$, and in addition, also partial eta-squared values are taken into account, in case of the presence of interesting almost-significant results, as some authors suggest (Pierce, 2004).

Results and discussion

The results of this preliminary investigation are differentiated according to the set of data I used:

a) The dataset considering the **absolute quantity of errors** (Measure “absolute”) showed a significant effect of “alloego” variable (p<0.05; F(1,14)=5,195; eta-sq: ,271), and the results of the analysis show that egocentric estimates caused the highest number of errors if compared to allocentric ones (see. Fig. 17).

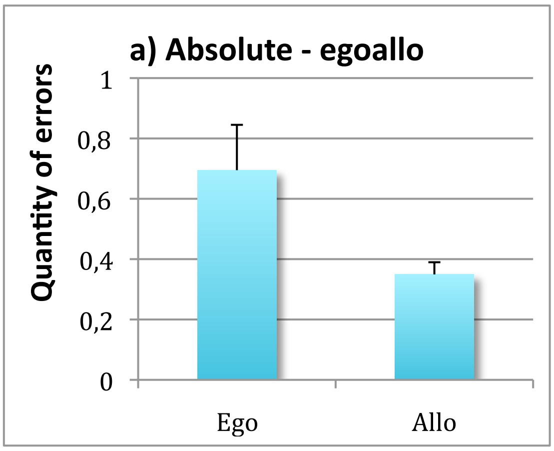

Fig. 17: “alloego” variable is significant in the Measure “absolute”.

The interaction between the “alloego” factor and the “vissys” is also significant (p<0.05; F(3,42)=3,443; eta-sq: ,197; see Fig. 18), and it shows that EW and CV are the VSs that register the bigger quantity of misperceived distances respectively in the egocentric and allocentric measures. Post-hoc analysis showed that for the absolute values analysis, only “EW” VS is significant for p<0.05, and CV is almost-significant for pairwise comparisons with “egoallo”.

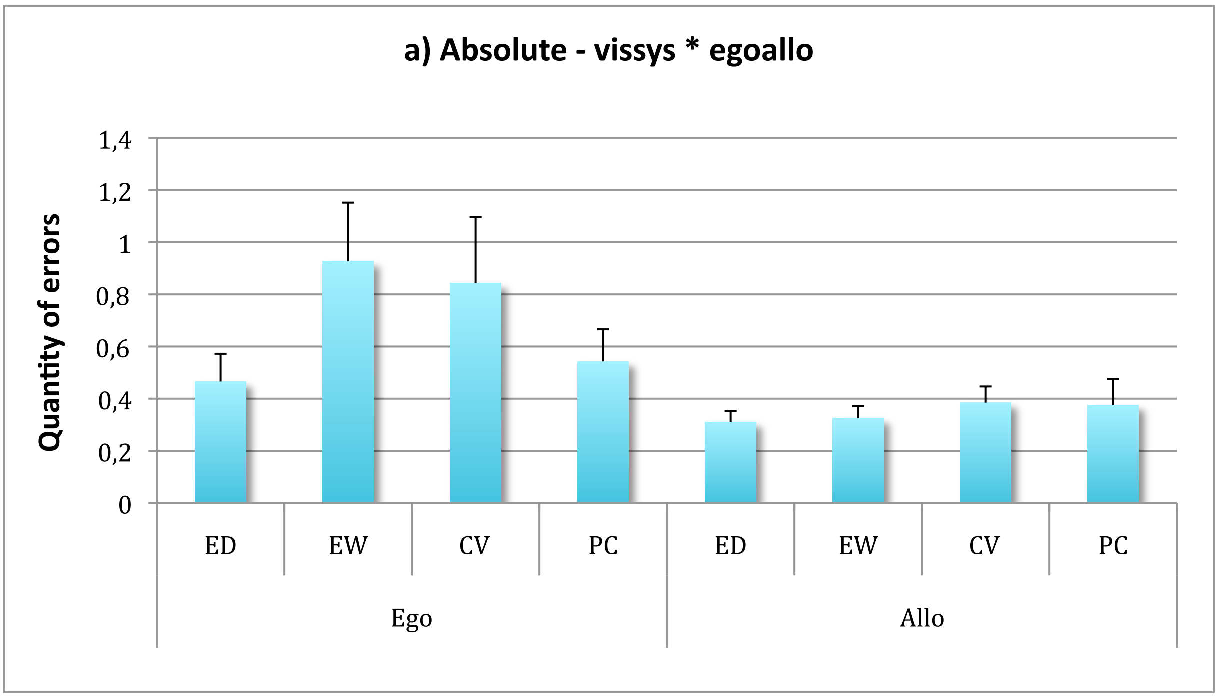

Fig. 18: significant interaction between the “alloego” and “vissys” factors for the Measure “absolute”.

Contrarily, the ED looks to be the VS that yield the less quantity of errors in both the modalities, but since it’s not significant, we cannot say it is a result, but a tendency. From these first results we can at least say that egocentric distances estimates produce more errors than allocentric ones (consistently with literature; see Iachini & Ruggiero, 2008 for example). Interestingly, the VSs with stereoscopy produce the higher quantity of errors, suggesting that stereoscopy is an interesting issue to investigate more deeply in the future.

b) Repeated measures ANOVA on the **mean values of errors with the sign** (Measure “sign”) shows basically the same results as the previous measure, but gives us more information about the direction of the errors, in terms of over- and underestimations of distances. So, also here “egoallo” variable is significant ($p<0.05$; F(1,14)=5,770; eta-sq: ,292), in particular there are underestimations in the allocentric questions.

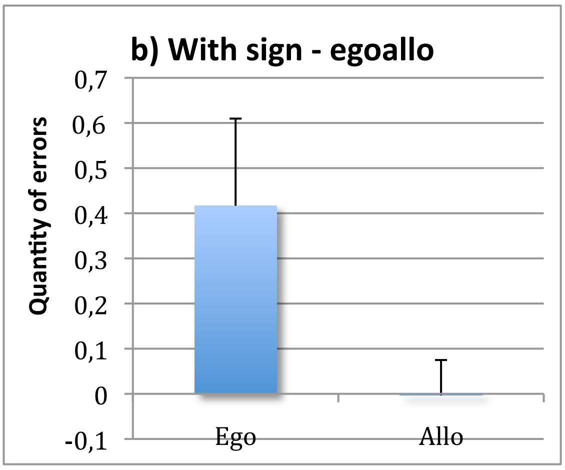

Fig. 19: The factor “egoallo” is significant in the Measure “absolute”.

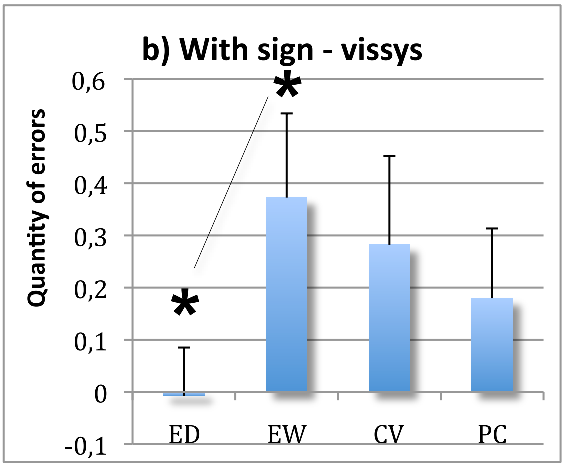

Fig. 20: The significant interaction effect of “vissys” for the Measure “sign”.

Differently from the results obtained with the other Measure, this time the variable “vissys” effect is significant ($p<0.05$; F(3,42)=3,139; eta-sq: ,183; as shown in Fig. 19), but the interaction “alloego * vissys” is not. This could mean that the VSs are different to a high extent, and this difference is better visible considering the direction of estimates errors than the absolute quantity of errors: in the ED, for example, there is a clear tendency to underestimate, while it does not happen so clearly in the other VSs. Moreover, this effect is not significant when it is considered in interaction with the “alloego” variable, which could simply mean that the effect previously observed about egocentric distances yielding more errors than allocentric (and here we learn that they are overestimations), is not necessarily linked to the environment, even if it is pretty clear from the results that the only place where it happens is the ED. This environment does not allow stereoscopy, so again a deeper investigation of the topic is suggested. A possible explanation is that, probably, the stereoscopy conditions generate more errors because of too much artificial information that appears quite unnatural without cues like shadows and therefore it brought misleading information to the visual system. In fact, with post-hoc pairwise comparisons, the only significant interactions were between ED and EW.

Besides ANOVAs, also a distribution of frequencies analysis has been performed on the four VSs in order to see the distribution of the errors for each of the 4 conditions (Fig. 21). As the images show, in the ED we have the highest number of underestimations, while in the CAVE there are quite a large number of mistakes even in the other direction (overestimates), making standard deviation values higher.

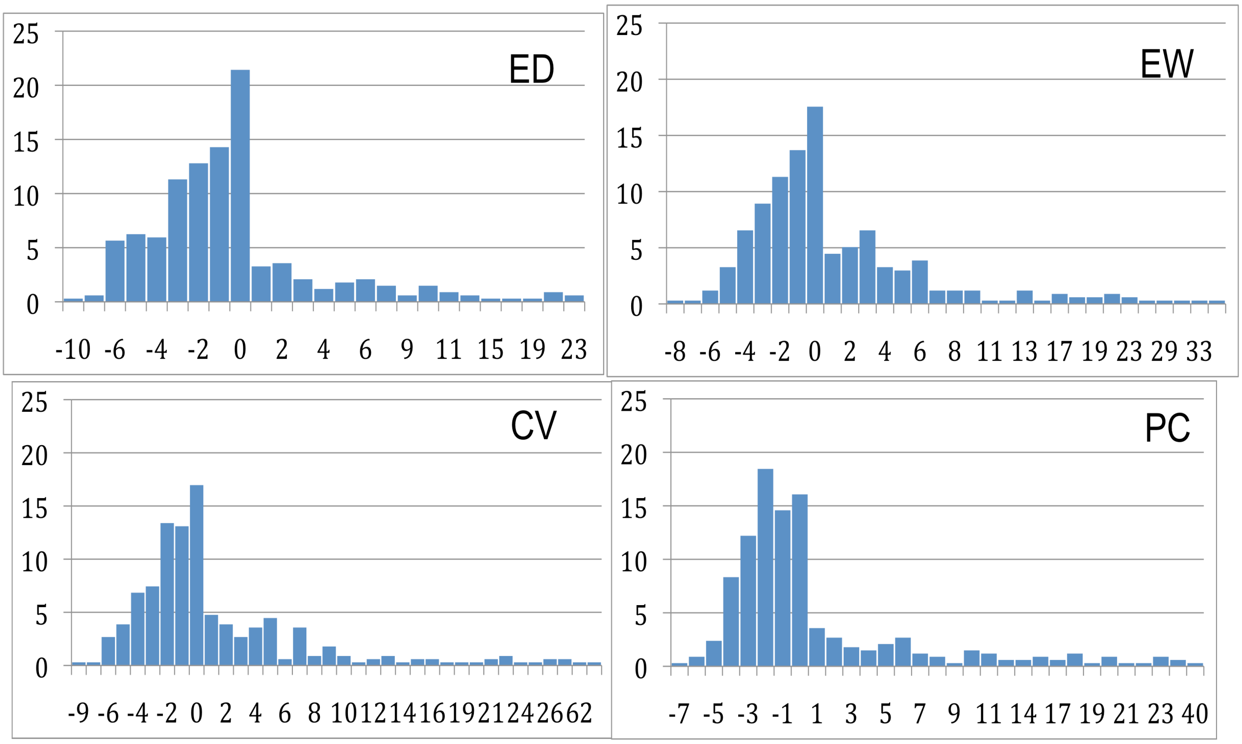

Fig. 21: frequencies of errors according to every VS. The y axis indicates the number of times a certain "wrong quantity estimated" was given, which are in turn expressed in the ordinate axis.

Conclusions

The results support the hypotheses only partially. In fact, we obtained that a) the perceived estimated distances are not congruent with the actual object's distances, and in particular, b) underestimations were expected in ED and CAVE, since they are the most immersive systems, but we found it true for the ED, not for the CAVE; c) in VSs where stereoscopy is available, although less errors were expected with respect to ED and PC, actually the opposite situation was observed, in fact in ED and PC less errors were registered, and the EW and CAVE were the VSs with the highest rate of errors in estimates. Probably, the unexpected results of higher underestimations in ED (but not in the CAVE), could be explained in the frame of the results obtained with stereoscopy, which seem to induce more errors than regular 3D scenarios: in the CAVE, stereoscopy is available, and this could have represented an important difference with respect to the ED, accounting for our results of underestimations only in the ED but not in the CAVE.

Considering the results of this pilot study, I got some interesting information about my future work and the following experiments that I wanted to perform.

First of all, a deeper investigation on stereoscopy is needed in order to understand if it actually helps or not the perception of distances. Moreover, as observed by the subjects themselves while performing the tasks, some ordinary objects from everyday life like bottles, tables, chairs, lamps, etc, (and not geometrical objects) should be used, in order to make the scenario look more “ecologically” natural. In the virtual scenario, shadows should also be used, because they are an important perceptual cue, useful to determine the positioning of the objects on the frontal plan. Finally, it emerged that a different way of measuring distances, not involving metrical answers, could give different results in such a task, as I could notice from the “control” questions. For all the following studies I decided to use an equal number of male and female subjects in order to evaluate gender effects in spatial cognition in VEs. All these clues have been taken into account for the planning of the main experiments of my research.

2.3.2. Experiment 1: Is stereoscopy in VEs really helpful for a correct depth perception?

Background and motivation of the experiment.

As we saw in the previous Chapter 3, the possibility to learn in a VE promoted the use of Virtual Trainings (VTs) instead of the real ones, because they're less expensive, not affected to biases or human mistakes, not subject to changes and different conditions in the real world, they provide complete control on the argument and actions to-be-trained and most of all they're safe, as any wrong action of the learner does not have any consequence in the real world. Thanks to these features, successful VTs have been already developed for the training of pilots (Lintern et al. 1990), drivers (Mahoney 1997), divers (Fröehlich 1997), parachutists (Hue et al. 1997), fire-fighters (Bliss et al. 1997), console operators (Regian et al. 1992), surgeons and other medical staff (Aggarwal et al. 2006; for a systematic review, see Sutherland et al. 2006; for an historical review, see Satava2008).

Usually, visual cues of 3D images in VEs and VTs are provided by means of stereoscopic 3D displays which deliver the projected images separately to each eye and require the viewer to wear polarized or shutter glasses for active view, or 3D glasses for passive view. These systems render the tridimensional environment from one single viewpoint, thus making any viewer movement in front of the screen quite unnatural (which means that even static objects rotate a bit with a lateral head motion; for this and other problems related to stereoscopy, see for example, Oddsson et al. 2007). That is why, where it is possible, VSs like CAVEs, for example, allow the use of a Tracking System (TS) which is directly related to the subject's head position (by means of infrared receivers built on the stereoscopic glasses) and changes the displayed image's perspective showing the represented object as it would look like if the person assumed this position of the head in the real life; for example, it would be possible to "look behind an object" just going a bit forward and rotating the head in a natural way.

The claimed utility of VEs, especially in the listed kind of trainings, where the correct perception of space and depth are crucial, increases with the likelihood of spatial judgments in the real world, so the question of how the perception of artificial binocular disparity works inside artificial VEs should be answered through careful investigation in VR scenarios before using them as tools for trainings or scientific evaluations and research (Saracini et al., 2009).

In my preliminary study I was interested in verifying if the different VSs had technical features which could differentiate subject’s answers, and I found that, even in such easy and simple scenarios, compression of distances actually takes place, especially in the Elbe Dom. Another fact that I could observe from the analysis of “absolute” averaged errors was that in the CAVE subjects made quite a high number of errors, while actually this feature was thought to yield better performances. Therefore, I explained this result with a possible “unnatural” effect of stereoscopy in that VS, which could have represented an obstacle, instead than an help with respect to the other VSs. In order to evaluate this evidence of stereoscopy in a more “ecologic” and comprehensive condition, I planned the following experiment.

In the setting described in section 2.3 (see fig. 15) of a room inside a house and its garden, I was therefore asking the subjects 16 questions about ego- and allocentric distances of the 6 objects in 4 different conditions: a closed/open environment and with/without stereoscopy. The sequence of the presentation of these combined features was randomized to avoid habituation effects or biases related to the binding of in/out scenario and stereoscopy presence.

The VS that I used was not the CAVE, which allows only stereoscopy, but the EW, because I could use the same screen for presenting the scenarios in both conditions, with and without stereoscopy, and thus made a direct confrontation of the two conditions within subjects. If I did on the EW and a PC, I could have obtained biased data due to the different dimensions of the screen; using the same screen and only changing the modality of presentation, prevented me to collect biased data from the beginning.

In order to place of the objects, I relied on the distinction, discussed in the beginning of this chapter (see paragraph 4.1), between peripersonal and extrapersonal space.

Basing on this knowledge, and following Armbrüster et al. (2008), the objects have been placed at 6 different distances:

- 3 peripersonal: 40 cm, 75 cm and 100 cm
- 3 extrapersonal: 200, 350 cm and 500 cm

Before starting everyone the 2 conditions with stereoscopy, the subject was asked to set the personal values of doubled-image (binocular stereo-image) distance in order to correctly perceive the tridimensionality given by the stereoscopy. In fact, every person has a different ocular divergence value and needs different distances between the doubled 2 images projected by the beamers in order to correctly perceive them as one.

Hypotheses

Following what found in the preliminary study, the hypotheses were different, as it was clear that stereoscopy does not help in performing correct distance estimates in VEs, in particular it was thought that:
a) Artificial binocular disparity (stereoscopy) doesn't represent correctly depth in VEs, so guessing precise metric distances is more difficult and performances are worse than with normal pictorial 3D.
b) Interpretation of artificial secondary cue information is mediated by individual differences, as for example gender and cognitive styles.

If these hypotheses are true, and also following what suggested in literature about gender differences in evaluation of distances and perceptual styles of people with different spontaneous rhythm, then these results were expected to be found:

a) More errors in the stereoscopy conditions.
b) Women have general worse performances with respect to men.
c) Ternary subjects make fewer errors than binaries

Methodology

Subjects: 20 subjects (10 males, 10 females) answered 12 questions (6 ego- and 6 allocentric distances) for a total of 4 times (one for every combination of the variables "in/out" and "stereo/no stereo"). In this way I could have performed the analysis with the independent variables within subjects, without using "group" as a between subject variable.

Tests: 4 questionnaires for evaluation of distances (to be randomized within the different 2x2 conditions); "in/out" virtual scenario for EW with and without stereoscopy with 4 different objects configurations; computerized version of perceived rhythm (for the evaluation of binary/ternary cognitive style).

Statistical analysis: as described in the preliminary study (Paragraph 4.3.1), the dependent variable that I used for the analyses, was the average optimized error of estimated values for every condition, calculated with the formula (Graham, Joshi, Pizlo, 2000):

$$\frac{\text{Subject's Estimated Distance} - \text{Correct Distance}}{\text{Correct Distance}}$$

Similarly to the preliminary study, also here two different datasets have been considered for repeated measures ANOVA’s factors: absolute values and with sign. Differently from the other analysis, in this experiment we first observed the means of absolute values in order to get a measure of the general distribution of errors in the different conditions and between the subjects, and then we performed the measures on the dataset with sign, but considering this time all the answers to the questions (6x2; 6 questions for egocentric estimates and 6 for allocentric ones).

The design of the two sets of analysis was, therefore:

a) For the **absolute mean** values of errors, repeated measures ANOVA 2x2x2 (stereo/nonstereo; in/out; ego/allo) on the between subjects variables of SEX and RHYTHM.

b) For the **all-questions errors with sign**, repeated measures ANOVA 2x2x2x6 (stereo/nonstereo, in/out; ego/allo; question1, question2,[…], question6) on the between subjects variables of SEX and RHYTHM.

For the post-hoc analysis and main effects comparisons, a Bonferroni correction method was used.

Results and discussion

a) Within subjects significant main effects using the **absolute means** dataset have been found on “stereoscopy” (p<0,05; F(1,16)=5,155; part.eta-sq: ,244), indicating that a bigger quantity of errors were committed in the “stereoscopy” condition.

From the graphic in Fig. 22 is in fact possible to notice how stereoscopy, when visualized on a desktop interface, does not make it easier to understand distances in Virtual scenarios, although it was thought to be a facilitation, since it is based on a natural way of working of the visual system, that is, by means of binocular disparity.

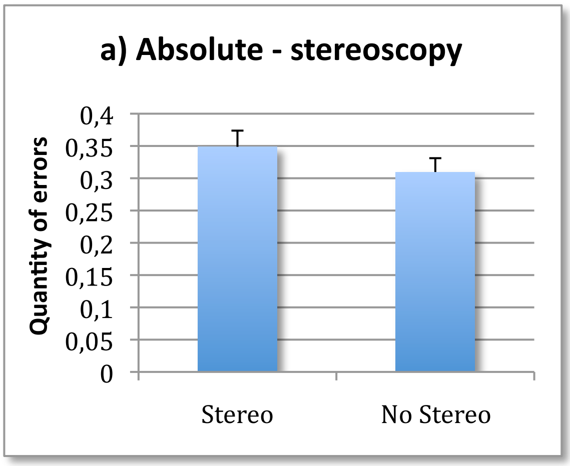

Fig. 22: “stereoscopy” significant main effect.

On the Fig. 23, another result is represented, that is the interaction “stereo * inout * egoallo” (p<0,05 (F(1,16)=6,359), part.eta-sq: ,284). This gives an interesting hint on how subjects differentiate in ego- and allocentric estimates according to the condition of the scenario (if it is inside the house or outside in the garden), finding that with stereoscopy there is more difference between ego and allocentric distances (following the already found scheme of more errors for egocentric questions with respect to allo) inside the house, while without stereoscopy there is more difference between ego and allo in the “outside” scenario; the post-hoc analysis showed that, in particular, there is an almost-significant effect of stereoscopy in the “inside” scenario in the egocentric estimates (p>0,05, but part.eta-sq: ,218), while in the “outside” scenario the stereoscopy effect is in the allocentric distances (p>0,05, but part.eta-sq: ,190). Interestingly, there is a significant effect in the “inside” scenario with stereoscopy of the egoallo variable (p<0.05 (F(1,16)=8,658), part.eta-sq: ,351), and this is somehow in line with literature where egocentric estimates are more difficult, even with stereoscopy. Anyway, as it is possible to see, without stereoscopy the level of mistakes is always lower than with stereoscopy.

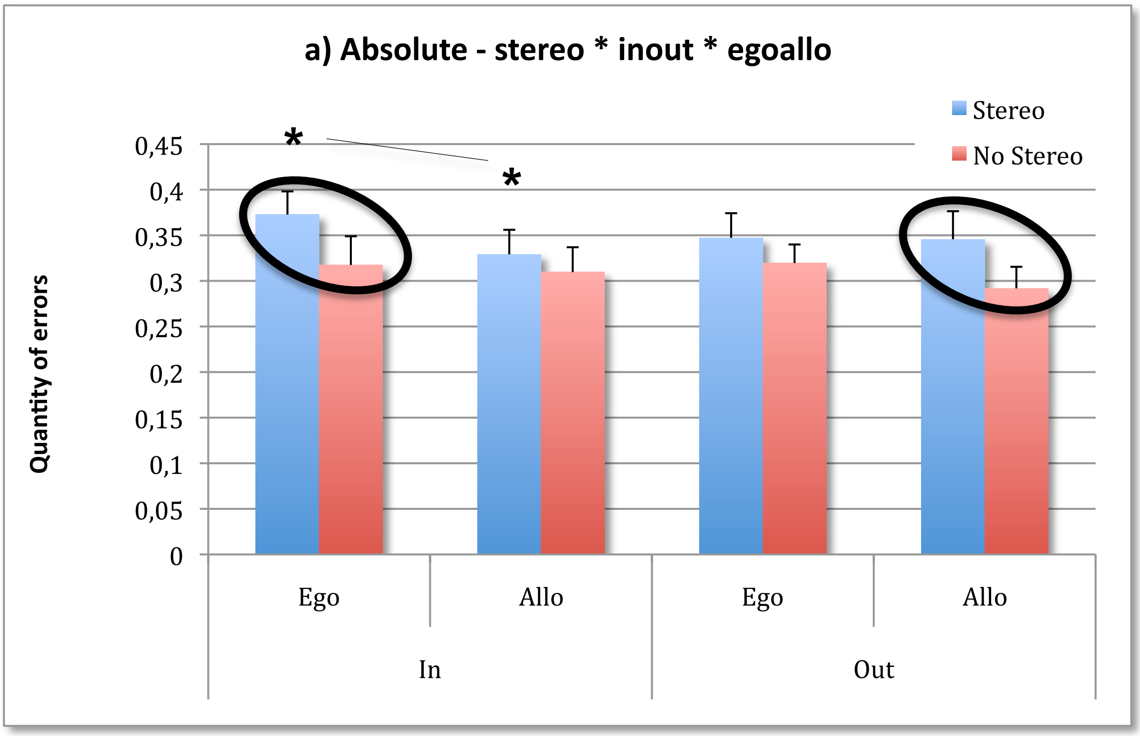

Fig. 23: within subjects factors’ significant interaction: “stereo*inout*egoallo”.

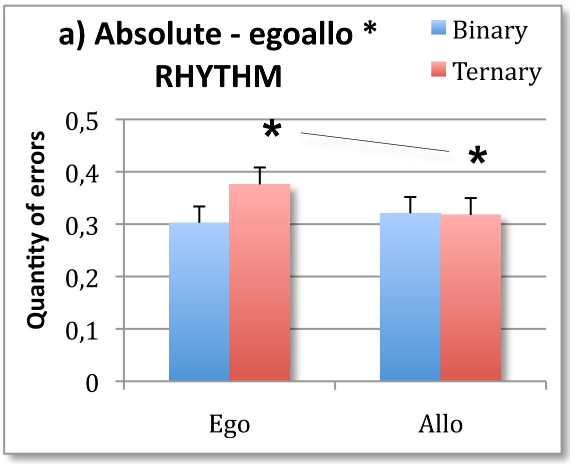

Fig. 24: significant interaction between “egoallo * RHYTHM”.

In this interaction between the within subjects variable “egoallo” and the between subjects variable “RHYTHM” (p<0,005 (F(1,16)=11,485), part. eta-sq: ,418), it is possible to notice how the subjects differentiate in ego- and allocentric estimates according to their cognitive style, in particular according to their spontaneous perceptual rhythm (binary or ternary, as

explained in the introduction to the experimental paragraph).
This could mean that egocentric distances are structurally more complicated to process, as we can notice that only the ternaries have bigger problems in this kind of distances, while for the binaries there is not a strong difference; in fact, the post-hoc analysis performed on this interaction showed that only for ternaries subjects significant levels are reached for the egoallo variable (Ternary: p<0,005 (F(1,16)=13,403), part.eta-sq: ,0,456). Probably it happens because the subjects were in front of the screen and their head movements were simulated by the rotation of the mouse: the subject could look around in the room, but not actually with his/her head, so they had to estimate the distances by observing a “fake” view, which required the ternaries to “refresh” the structure of the visual scene. For the binaries it was not such a big problem, because they only had to register the stimulus’s features and compare the distances, while for the ternaries the comparison was between a fake point of reference out of their bodies, and this could have been compromising their ability to make correct estimates, while in the allocentric situation they did not have any problem because the task was to confront directly external objects, which were equally represented on the screen (object-centered point of reference).

b) Analyzing **all the questions** and keeping trace of the **sign** of the over- or underestimations, I obtained also interesting results. First of all, even if in these results the “stereoscopy” variable was not significant (p>0.05, but part. eta-sq: ,193), it had nevertheless a quite good partial eta-squared rate, which suggests that, increasing the number of subjects for every condition, also the significance should increase.

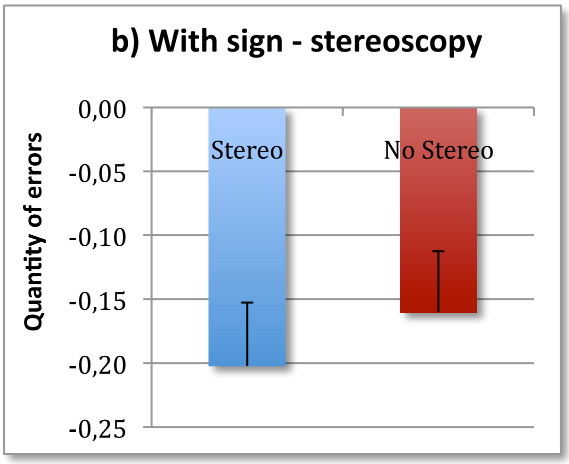

Fig. 25: not significant effect of stereoscopy in analysis with sign

In Fig. 25 is possible to see that, even performing this analysis, the same results of general better performances (that is, fewer errors) without stereoscopy is obtained. The fact that it is not significant, probably because the dataset with sign is a “difficult” one, but has a good eta-squared value, allow us to say that anyway, the tendency observed with the other analysis is highly probable.

A first main effect is on the “questions” resulted significant (p<0,001;F(1,12)=6,313; part.eta-sq: ,345; see Fig. 26), and here it is possible to observe also another effect, discussed in paragraph 4.3 and related to the different “zones” in which the surrounding space can be divided. In this case, peripersonal distances (questions 1, 2 and 3) yield more underestimations than extrapersonal ones (questions 4, 5 and 6). I consider the fact that no significant effect was found in an interaction between stereoscopy and questions as a sign that this kind of effect between peri- and extrapersonal distances is typical from VEs and it does not rely to the presence or absence of stereoscopy.

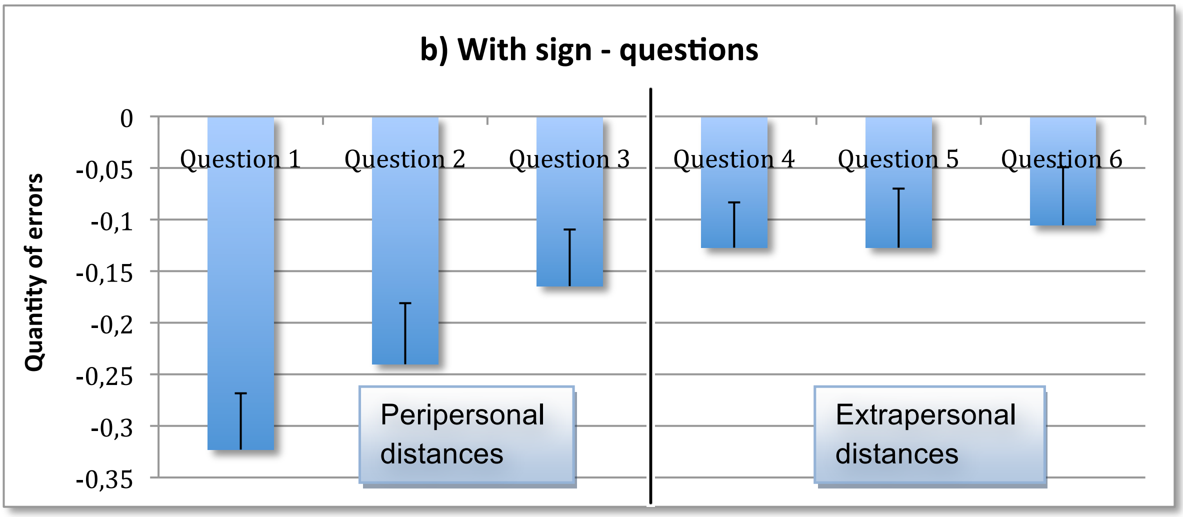

Fig. 26: Questions variable.

Some other significant within-subjects results were obtained with this analysis, but here I will discuss only the most interesting to the aim of a better understanding of the intimate reciprocal connections between the use of stereoscopy and gender differences in evaluation of distances. For example, the "Questions" variable looks to be strongly different between males and females, as it is possible to see in the Fig. 27:

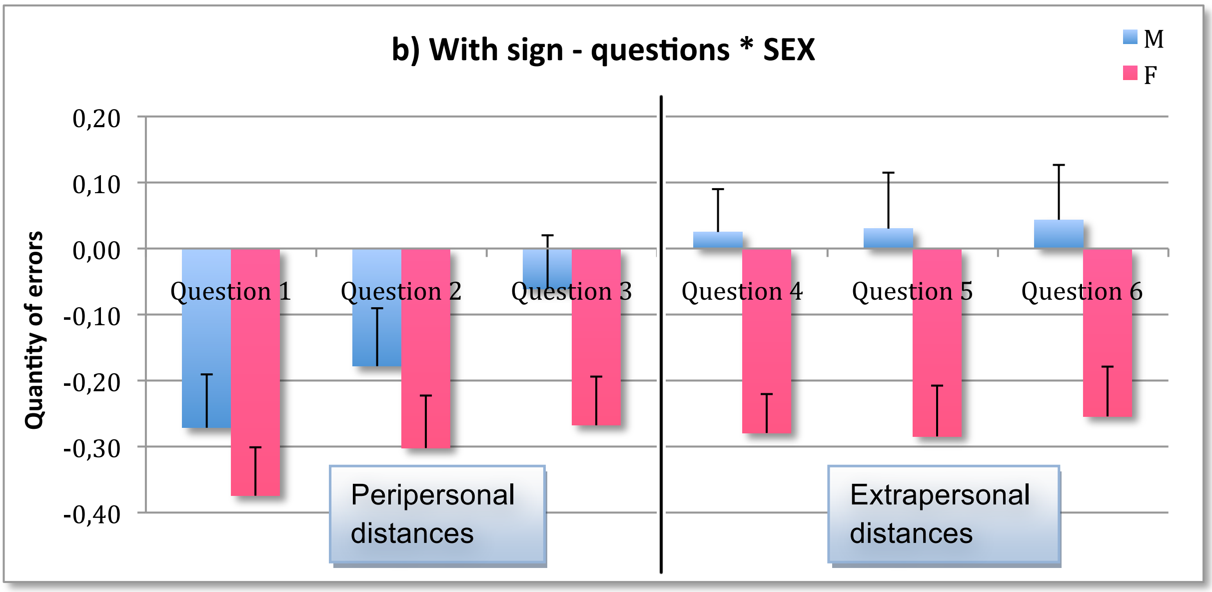

Fig. 27: significant interaction between questions and SEX.

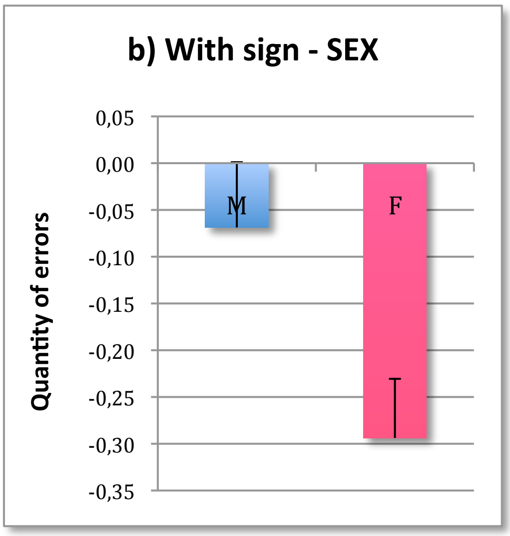

Fig. 28: Variable SEX is significant.

In this significant interaction ($p<0.05$; F(5,60)= 2,475; part.eta-sq: ,171) it is showed how the peripersonal and extrapersonal distances differentiate according to the gender of the subjects: while females distribute more or less equally the errors in all the 6 questions, men show a tendency to overestimate in the extrapersonal distances, and for both males and females in the peripersonal distances the quantity of errors seem to diminish as the distance of the objects increases, with anyway more underestimations of women with respect to men.

Only one between subjects variable resulted significant, and it is the variable SEX ($p<0.05$; F(1,12)= 5,714; part.eta-sq: ,322; see Fig. 28). As it is possible to see in the picture, and consistently with what already found in literature, men commit fewer errors than women in "evaluation of distances" tasks. In particular, the direction of these evaluation errors goes to more underestimations for women with respect to men.

Conclusions

The results of this experiment proved the initial hypotheses only partially: a) the presence of stereoscopy did not actually help in having a precise estimate of metric ego and allocentric distances of objects, and b) women have worse performances than men, especially within the stereoscopy condition; finally, c) I found that actually binaries make average less errors than ternaries, but after a deeper evaluation of the results it is possible to notice that the higher quantity of errors is made by ternary subjects in the egocentric distances, probably due to a mismatch between the egocentric perspective in the VE and their actual position, but in the allocentric ones they score the same as the binaries. This may be due by intrinsic mechanisms of stereoscopic binocular presentation, which combined with the processing style of ternaries and binaries, responding respectively to the structure and to the signal, may find it easier to find the required information in the frontal plane with respect to the vertical plane (egocentric distances) in the case of the ternaries. According to this explanation, this could happen because the egocentric view in the VE was on a different frame of reference (on the screen) with respect to how it would look like in the real life (that is, subject-centered) and this could represent a problem for the ternary subjects, who do not find a match with the structural relationships between the objects and themselves, but not for the binaries, who simply respond to the signal and judge the distances for what they observe on the screen.

If this explanation were true, a comparison between the performance of the ternaries in Virtual and Real Environments would show a smaller number of errors of the ternaries in the egocentric condition in RE, because the frame of reference in the RE would be the “usual” one, matching with the structure of the visual scene. That was a suggestion for a direct correlation of performances in VEs and REs, which in fact I implemented and I will discuss in the following section.

Anyway, the stereoscopy has been found to be not a good way of supporting a correct perception of distances in a virtual environment. This could be due to different reasons, first of all the “unnaturalness” of this “trick” that, as we discussed in chapter 3, has been invented to deceive the visual system by doubling the images and make every eye perceive a different one. So probably, it is the quality of images, or simply the depth is not enough well represented by means of this tool. Anyway, since some authors (for example, John, 2002; Rosahl et al., 2006) claim that stereoscopy allows more efficient trainings, it would be interesting to evaluate if the problems with stereoscopy are only when the subjects are obliged to give a metric answer, without providing them any feedback and not promoting learning of the internal set of coordinates of the VS. I will explore this issue in paragraph 2.3.4.

2.3.3. Experiment 2: Differences in distances estimates in Virtual and Real Environments.

Background and motivation of the experiment

A classical question in my previous discussions in this doctoral work was: “are the cognitive processes in a VE the same, or comparable, to the ones occurring in REs?”. In order to find an answer to this primary question, I tried to compare directly the performances at the same task in a VE and in a RE. The same paradigm used for the previous experiments was used, but this time I asked the subjects to perform distances estimates in the Engineering Workstation (EW) and in a Real Environment (RE; as a real setting, I used my office) with a certain number of objects.

In order to avoid learning effects, the distances of the objects in the RE were still in the same range of those used by Armbrüster et al. (2008), but slightly different from the ones used in the VE (for a description of the objects’ positions, see paragraph 2.3.2):

- 3 peripersonal: 45 cm, 70 cm and 150 cm
- 3 extrapersonal: 300, 400 cm and 450 cm

Also in this case, the different configurations of objects were randomized between the subjects, but this time I used only the “inside” version of the scenario, to make it more directly comparable with the RE situation, which was in a closed room, and no stereoscopy was used, since in my preliminary study (see paragraph 2.3.1) I could see no improvement with the use of this feature in EW. Also in the RE, 4 different configurations of objects were used, randomized amongst the subjects.

To avoid biases related to the environment with which the subjects started, I also randomized the sequence between VE and RE, so that half of the subjects started with VE and other half with RE.

The same frame of reference from the literature described in the past paragraphs suggested us the main hypotheses for this work: first of all, the compression of distances in VEs with respect to a tendency to overestimate in REs (Loomis & Knapp, 2003; Waller & Richardson, 2008), but also the gender differences in performances within evaluation of distances paradigms (women make more metric estimates errors than men, Iachini et al., 2008; in particular, more underestimations for females have been found; see Armbrüster et al., 2008). Considering these findings, we hypothesized that there is a qualitative difference in evaluation of distances according to the environment where the estimates are done: the fake 3D scenario of a VE make the spatial relationships between objects shorter than in a RE, causing the compression of distances observed also in literature. In particular this should be more relevant for females, who make generally more mistakes, so they should underestimate even more in VEs. Finally, if our explanation of the results of the first experiment (paragraph 2.3.2) were true, then the kind of spontaneous rhythm typical for every subject should modulate the processing of visuospatial information according to the signal or to the structure (respectively, binary or ternary rhythm); in particular, the egocentric distances, which require a complex shift in the frame of reference to understand the structure of the visual scene, should be more complicated to understand in VEs, because the vertical displacement on the screen requires an additional elaboration before simulating one's head position in the scenario before re-processing the spatial information as if the head was really observing that scene. This is not required in REs, so ternary subjects, who showed a small impairment in evaluating egocentric distances, should make less mistakes in the same kind of distances in REs.

Hypotheses

According to the results of the previous experiments, but also considering what found in literature, the hypotheses were suggesting that:

a) In VEs distances and depth are not perceived in the same way as in REs.
b) Nevertheless, individual differences (as for example gender or spontaneous rhythm) should take place even in VEs, since at higher levels they represent a general way of functioning of women and men regarding spatial processes.

Following the hypotheses, we expected the following results:

a) In VEs subjects will make more errors than in REs, especially there will be more underestimations because of a compression of distances.
b) Women should show worse performances than men and more underestimations.
c) Subjects with spontaneous ternary rhythm are expected to have better performances in egocentric distances in RE than in VE and make fewer mistakes than binaries.

Methodology

Subjects: 20 subjects (10 males, 10 females) gave 12 metric estimates of distances between the objects both in the VE and in the RE. Of these estimates, 6 were egocentric and 6 allocentric.

Tests used: 2 questionnaires for evaluation of distances (one for VEs and one for REs); “in” scenario for EW without stereoscopy; computerized version of perceived rhythm (for the evaluation of binary/ternary cognitive style)

Statistical analysis: In the original data file, errors have been re-calculated according to the already described formula from Graham et al. (2000):

$$\frac{\text{Subject's Estimated Distance – Correct Distance}}{\text{Correct Distance}}$$

After performing this equation on the original data, since I was interested in getting either a measure of how many errors are generated in every condition and a direction of the errors in terms of over- or underestimations, as well as the weight of all the answers of the subjects, three different datasets have been created:

a) One with the **means of the absolute values** for every subject both for ego- and allocentric questions in VE and RE.

b) Another with the **means of the values** including the **sign** (plus or minus) of the estimate.

On this basis, the data of a) and b) were collapsed on a single dataset, on which a repeated measures ANOVA was performed with 2 measures (“absolute” and “sign”) on a 2x2 factors design: the first dependent variable within subjects was “environm” (2 levels, VE/RE) and the second one regarded the kind of estimate that was to be given, “egoallo” (2 levels, ego/ allo). As independent variables were here used SEX (2 levels), RHYTHM (2 levels) and VE-RE (2 levels), this last indicating the sequence in which the subjects underwent the experiment, starting with the RE and then proceeding with the VE, or the other way around.

c) Additional analysis were performed on all **the answers** to all the questions in every condition in order to see if there were some other significant effects, that could have been lost by calculating only the means.

For the post-hoc analysis and main effects comparisons, a Bonferroni correction method was used.

Results and discussion

Results from the repeated measures ANOVA on the new dataset obtained by collapsing a) and b) (see above for a description) show significant effects mostly in the "sign" measure, so for a discussion it seems to be more interesting to start from this dataset: the two factors of "environm" (p<0.005; F(1,12)=15,185; eta-sq: ,559; see Fig. 29) and "egoallo" (p<0.005; F(1,12)=13,519; eta-sq: ,530; see Fig. 30) are both significant.

In the first main effect, data show that initial hypotheses are supported, also following what has been already found in literature, because it is clear that estimates in the VE are significantly worse than in the RE. This of course happens because of the sign, but the results on the absolute values that I'll discuss later go in the same direction. Moreover, in VE there is a general tendency to underestimate distances, while in the RE the tendency is, on the opposite, to overestimate. The other main effect on "egoallo" (see Fig. 30) shows the tendency, already found in the other experiments, to underestimate more the egocentric distances, with respect to the allocentric ones.

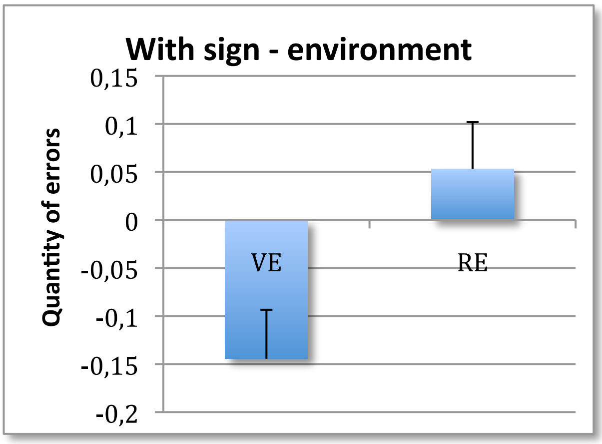

Fig. 29: the "environment" factor.

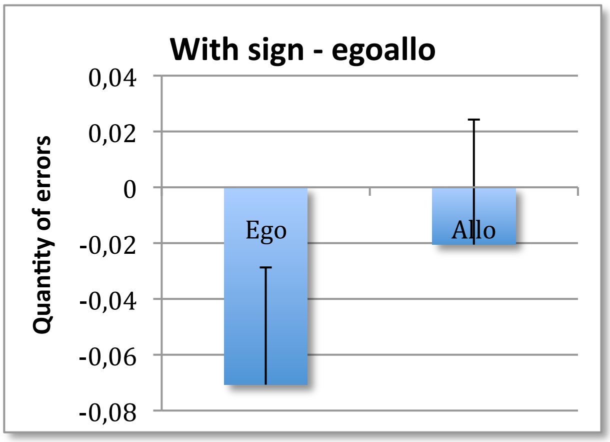

Fig. 30: the "egoallo" factor.

Other significant results are the interaction between "environment *egoallo * SEX" (p<0.05; F(1,12)=5,487; eta-sq: ,314; see Fig. 31) and "environment * egoallo * RHYTHM" (p<0.05; F(1,12)=7,652; eta-sq: ,389; see Fig. 32), showing that not only these two factors are relevant in this task and differentiate between the two environments, but also that they have a significant interaction with two of the between subjects variables of SEX and RHYTHM. In particular, observing the graphics is possible to see that, first of all, in RE there are more overestimates, but only for men, while females sometimes underestimate, especially in the egocentric estimates (see fig. 31). In the VE, females strongly underestimate, while men only underestimate the egocentric distances.

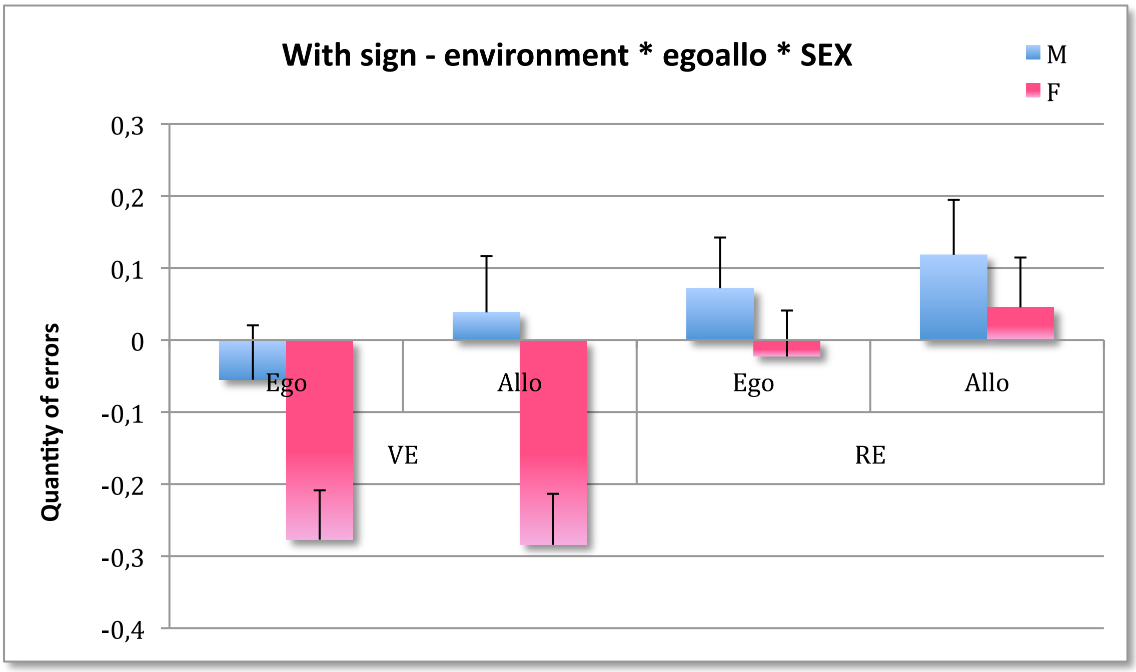

Fig. 31: the significant interaction between "environ*egoallo*SEX".

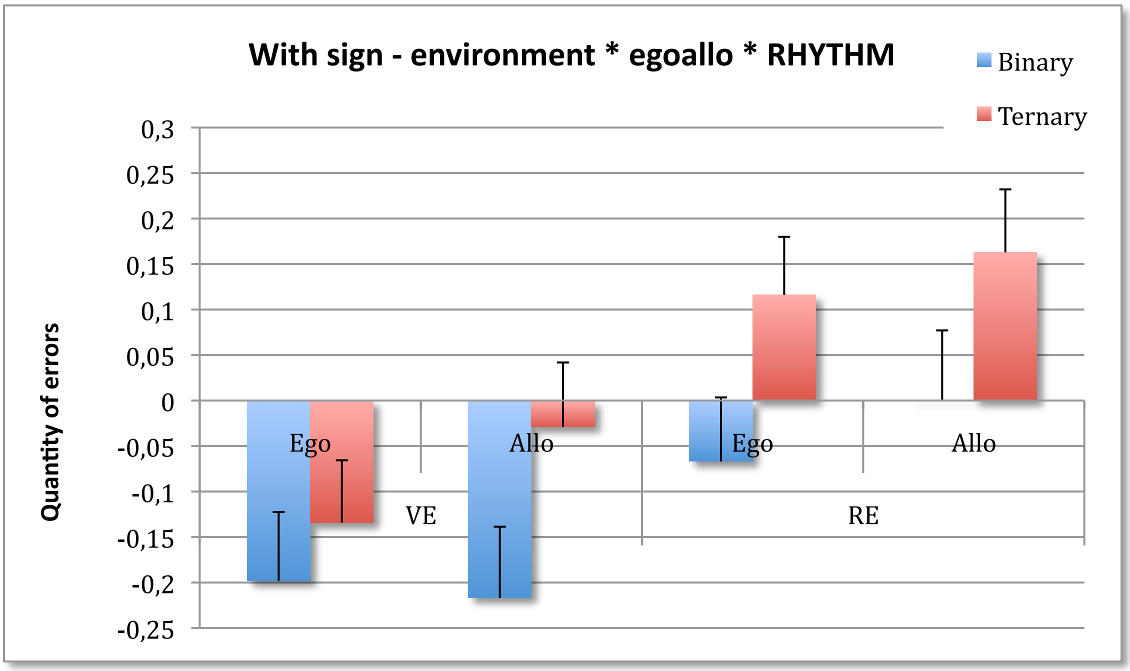

Fig. 32: the "environment" factor in interaction with egoallo and RHYTHM variables.

Regarding the rhythm, differently from experiment 1, we have that binaries make more errors than ternaries in the VE, even though they all underestimate, and for ternaries egocentric are still worse than allocentric answers. In RE the subjects with ternary spontaneous rhythm instead overestimate distances, especially the allocentric ones. In this case, our hypotheses about ternaries are supported by the results, in the measure of fewer mistakes in the egocentric than allocentric distances for ternaries in the RE. Anyway, binary subjects are behaving the opposite: they tend to make fewer mistakes in allocentric than egocentric distances in the VE, while they show more difficulties in the RE for the judging egocentric distances.

A result that is not significant, but could help for a better interpretation of the interaction between these variables, is the one observable in the fig. 33.

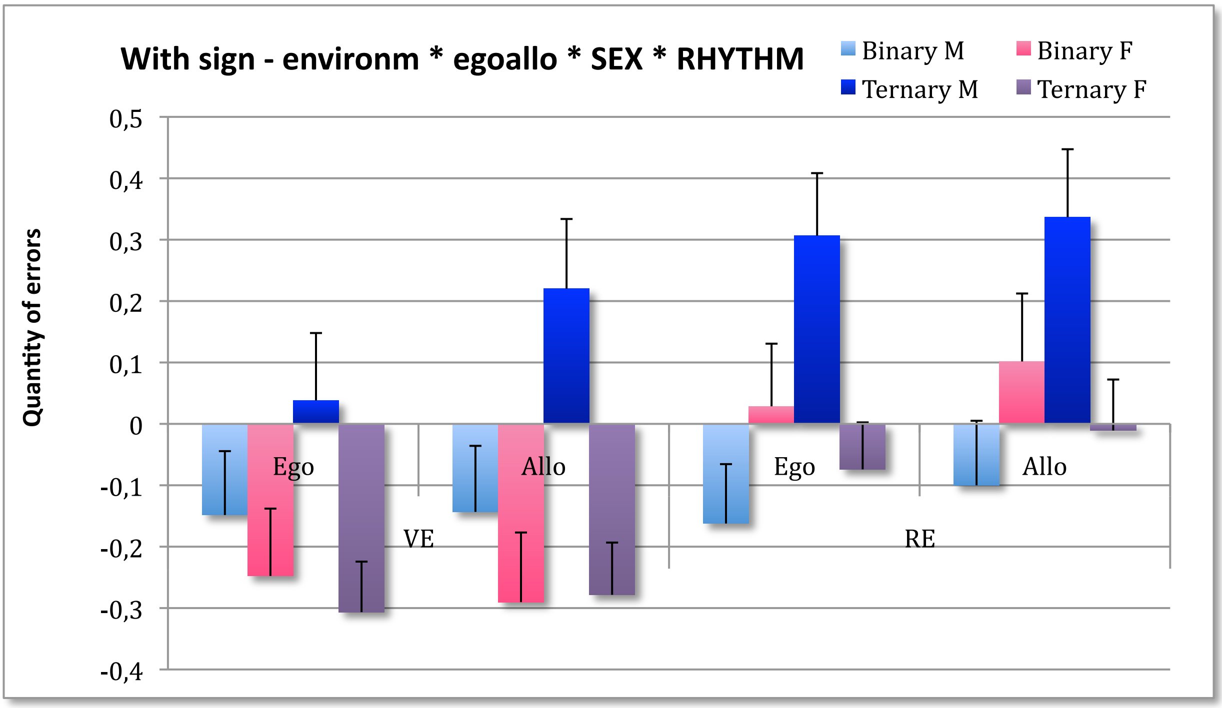

Fig. 33: the "environm" and "alloego" factors in interaction with the between subjects variables SEX and RHYTHM. The interaction is not significant.

In the graphic, is possible to observe that the males performing the overestimations (both in VE and RE) are the ternary ones, while in the RE, the binary females are the ones who overestimate.

Binary males look like setting their performances always around the same values (only underestimations), while the others oscillate a lot between large and minor underestimates.

The results on **absolute** values did not offer so many significances, maybe right because, in such an experiment, errors can only be explained by considering also the direction of the missed estimates. Anyway, the binding of the same variable (or interaction between

variables) considering the 2 respective measures ("absolute" and "sign" measures) can give some good insights on the quantity of errors and relative direction of these errors.
An interesting effect has been found in the sequence of environments to which the subjects were exposed during the experiment: half of the subjects started with the questions in the VE first, while the other half started with RE. This "randomization" was meant to avoid biases due to exposition to one or another environment first in the results, and in fact, performing analysis on this sequence as a between subjects variable (VE-RE), it is possible to notice that (see Fig. 35), when subjects started with the VE, they performed more errors than when they started with the RE. This difference is almost significant only for the dataset with absolute values (p>0.05, but eta-sq: ,231), while the results on the data with sign are not significant, but observing the fig. 35 it is possible to notice how starting with RE first may lead to more underestimations, while the under- and overestimations in the case of VE-RE sequence are balanced enough to keep a lower level of underestimations, even though we can see from the absolute analysis that the absolute values of the error committed when starting with the VE are higher.

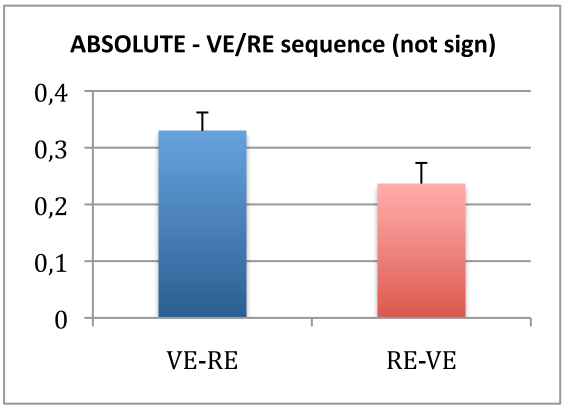

Fig. 34: absolute almost-significant effect of VE-RE sequence of presentation.

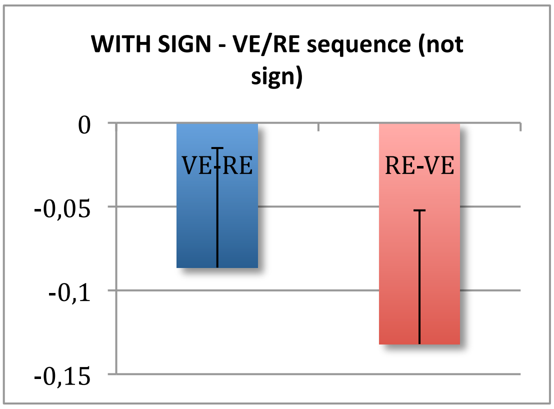

Fig. 35: non-significant effect of VE-RE sequence of presentation with sign.

So, it looks like the sequence of the environments in which the subject has to give distance estimates first, somehow affects the judgments in the one that is presented for second: observing the results with both absolute (Fig. 34) and with sign (Fig. 35) datasets, we can see that in general subjects made more mistakes when they started with the VE, but in particular these mistakes (underestimations in VE) seem to be counterbalanced by overestimations in the RE (see Fig. 35), this could happen because subjects are required to answer the questions in the RE after trying to answer the same kind of questions in the VE, for which they had to previously "set" their mind on a different and completely new environment (making of course more mistakes), but when they repeat it in the RE they at least already know the task, and moreover it is performed in their acquainted and "known" real world, so overestimations in the RE contrast the underestimations done in the VE. On the contrary, when they start with the RE (the spatial reference system of which should be already known, although the task itself is probably new, since few people are required to give precise metric estimates of distances between objects in everyday life), they could find it more difficult to get used to the new, perceptually compressed artificial environment after setting their mind to the metrics of the real world, and they tend to produce far more underestimations later in the VE, explaining the tendency of the result represented in the Fig. 35 (although it is not significant, due to a high standard deviation for individual differences), which is anyway a condition producing less mistakes than starting with VE.

Conclusions

As conclusions of this experiment, I could confirm the findings, showed in literature, that performances with distances estimates in VEs are generally worse than in REs, and that the direction of the errors is a general tendency to underestimation. In particular, I found that a) In the VE subjects underestimate more than in RE, where instead there is typically a tendency to overestimate distances; b) women underestimate more than men, making in general also more mistakes than men.

c) Subjects with spontaneous ternary rhythm have better performances in egocentric distances in RE than in VE and make in general less mistakes than binaries, who very often underestimate more than ternaries, especially women.

It could be appreciated the intimate relationship between the performances and other cognitive aspects, as for example, the spontaneous rhythm and the interesting interaction of this feature with the gender of the subjects, showing that ternaries and binaries show different performances according to their gender, indicating that ternary subjects improve their performance when the characteristics of this style of analysis (analysis of the structure) matches with the most typical male profile, who has more geometrical and analytical abilities, while the best expression of women, who are known to have more a “global” approach, probably fit better with a binary profile, since they are used to answer to the signal more than the structure.

As many studies on spatial cognition, I also found a gender effect, showing that men are generally better than women in judging distances estimates, but this does not happen in all the conditions and by the way the differences are not so strong.

A final interesting effect was the one found on the sequence of presentation of the two environments, showing that the experience in one environment is directly influencing the performance on the other. Going a bit further these results, an interesting idea would be to let subjects undergo a pre-training in the RE in order to make them familiar with the task in the real world. Starting with such a training, they should make fewer errors in the same task successively repeated in the VE. To avoid high quantity of underestimations, coming from a different “set of depth rules” in the VE, it would be necessary to repeat a brief training (with feedbacks) to the subjects also in the virtual scenario, in order to let them understand the new environment spatial rules and take confidence with the depth perception inside this new world. It is therefore probable that, after a “training” period in both the environments, the differences found in this experiment would be reduced, as also some other authors (Richardson & Waller, 2007) prove in their work, especially underlining the importance of given feedback (Richardson & Waller, 2005).

Anyway, although in REs people make mistakes in giving numeric measures about objects’ relationships, it is clear that they’re still able to move in a space and not only completely understand and represent a scenery, but also move inside it and perform actions and use objects correctly.

For this reason, an improvement to this paradigm could be the possibility to give distances estimates in a non metric way, that is, not asking for numeric measures, but only proximity judgments or confrontation amongst perceived distances. This could limit the difficulties of some subjects to give a numeric estimate and help us to evaluate the usefulness of VEs and VTs independently from this personal ability.

Therefore, two kind of works could be implemented in order to fulfill this gap: a) a paradigm where also non metric answers could be given for distances estimates in VEs and b) a learning task to measure learning curves, timings of learning and habituation by simply offering the subjects a feedback about their answer and suggesting the correct measure (as suggested in Richardson & Waller, 2005). In the following experiment 3 (see paragraph 2.3.4) I will try to implement the first paradigm.

2.3.4. Experiment 3: Metrical and non-metrical answers modality in a distance evaluation task in VEs.

Background and motivation of the experiment

As we stated before, Virtual Trainings (VTs) are commonly used in VR. It is also clear that there are biases in understanding the distances in VEs. Anyway, as we saw already in paragraph 1.3.2 of the first chapter, some authors still claim the effectiveness of VTs, stressing the fact that even in REs people commit mistakes in distances estimates, but they are nevertheless perfectly able to use objects, perform actions and navigate through environments pretty well. This perspective, which is based on a more ecologic view of spatial cognition investigation, still supports VEs as tools for successful trainings, which could be effective even if a compression of distances has been proved to take place.

Some of the already cited works (for example, Plumert et al., 2005; Sahmet al. 2005) showed how simple judgments or performed actions are generally more accurate than metric estimates, and this somehow supports the idea that people can build a mental representation of a scenario even without having consciousness of the metric relationships between the objects. In my preliminary study (see paragraph 2.3.1) I obtained as a result that the numeric judgments covariates with the estimates in different VSs, and suggested me that measuring non metric evaluations of distances was a good way of investigating the relationship between these 2 different modalities of processing and representing an environment.

In my third experiment, then, I directly compared subjects' performances within the same environments by asking them to give 16 metric estimates of distances between objects and between the objects and the subjects, but also 16 non metric judgments about spatial relations in the same environments, randomizing the order of the metric and non metric questions in order to avoid learning effects or biases. Therefore, we used the same scenario used in experiment 1 (with and without stereoscopy, to see if in this case stereoscopy can help with the judgments) and we added a set of nonmetric questions about the reciprocal relationships between objects and randomized the order of the questions for every subject.

Hypotheses

The work hypotheses were based both on what found in literature (already discussed in the previous paragraphs) and the results of the previous experiments of this thesis. It is hypothesized that:

a) The metric modality for a distance estimates paradigm is in general more difficult than a nonmetric modality of answers. As also other studies show (Loomis et al. 1996; Witmer and Sadowski 1998, Sahmet al. 2005), either verbal or nonverbal reports of distances are easier if they do not require the subjects to quantify exactly how many centimeters the objects are distant from them or between each other.

b) Although stereoscopy seems to reduce the correct metric estimates, in the case of proximity judgments, it would help subjects' spatial representation because it gives a more "realistic" view of represented objects. The point is that, even if not knowing the exact measure of distances and the metrics, stereoscopy helps understanding the reciprocal distances between objects by "emerging" from the screen more than a "normal" 3D visualization. In this situation, especially women should be facilitated, since it is known (Iachini et al., 2008) that they have generally worse performances with metrics and distances estimates.

Therefore, expected results of this experiment were:

a) In general people would have committed fewer errors in the non-metric modality.

b) Stereoscopic conditions would have lead to better performances, but only in the non-metric modality.

c) Females still have slightly worse performances than men.

d) Less differences between egocentric and allocentric distances were expected in the nonmetric modality considering the quantity of errors.

Methodology

Subjects: 20 subjects (10 males, 10 females) answered 16 metric questions about estimates and 16 non metric questions about spatial relationships judgments in the 4 different configurations as seen in Experiment 1 (see paragraph 2.3.2).

Tests: 4 questionnaires for evaluation of metric and nonmetric distances (to be randomized within the different 2x2 conditions); "in/out" virtual scenario for EW with and without stereoscopy with 4 different objects configurations; computerized version of perceived rhythm (for the evaluation of binary/ternary cognitive style).

Statistical analysis: before performing analysis I changed the scale of the data collected in the metric modality in order to make it comparable with the nominal scale of the non metric answers, which was based on a yes/no (0, 1) answer modality. In order to do that, and similarly to Ärmbruster et al. (2008), I considered a cut-off of ±5 cm for the close distances (i.e. objects till 150 cm of distance, that means all those objects lying in the peripersonal space) and ±10 cm for the far objects (i.e. more than 150 cm, objects in the extrapersonal space) and then assigned 0 if they fell out of the cut-off or 1 if they were in the range.

Then I performed on the sum of all the correct answers for subject:

a) Repeated measure ANOVA with a 2x2x2x2 design factors (modaliy * stereo * inout * egoallo; each factor had 2 levels) and

b) Repeated measure ANOVA with 2 Measures (“stereo/no stereo”) on a 2 level factor (“modality”, 2 levels “metric/nonmetric”), collapsing the “inout” and the “egoallo” variable onto the averages according to their belonging to stereoscopic or non stereoscopic scenario. Between subjects variables were in both cases SEX and RHYTHM.

For the post-hoc analysis and main effects comparisons, a Bonferroni correction method was used.

Results and discussion

a) In the first set of ANOVAs, results indicated as significant factor the “modality” (p<0,005; F(1,15)=14,616; eta-sq: ,493; see fig. 36). In particular it is possible to observe that the non metrical modality of distances evaluation allows far more positive results than the metric one, and this finding not only supports the hypotheses, but also indirectly gives some contribute to the use of VEs as training or learning environments, since in rare cases the trained people are requested to know the distances or the exact dimensions of objects and places but it is

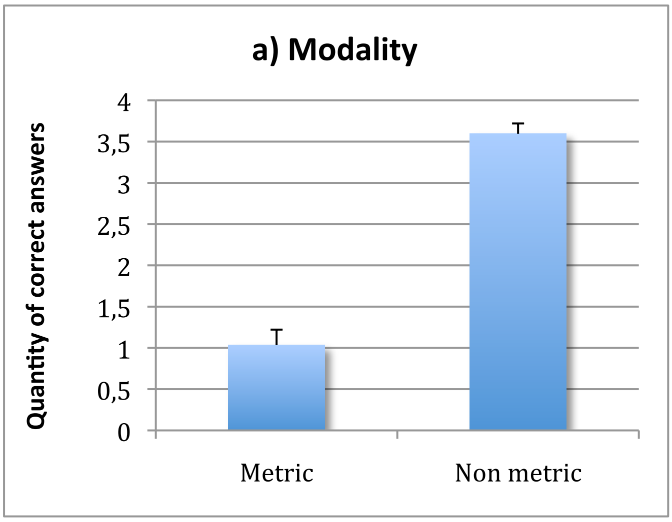

Fig.36: “modality” main effect is significant: nonmetric modality yields more correct answers than metric one.

important to prove that spatial relationships of VEs are nevertheless correctly understood.

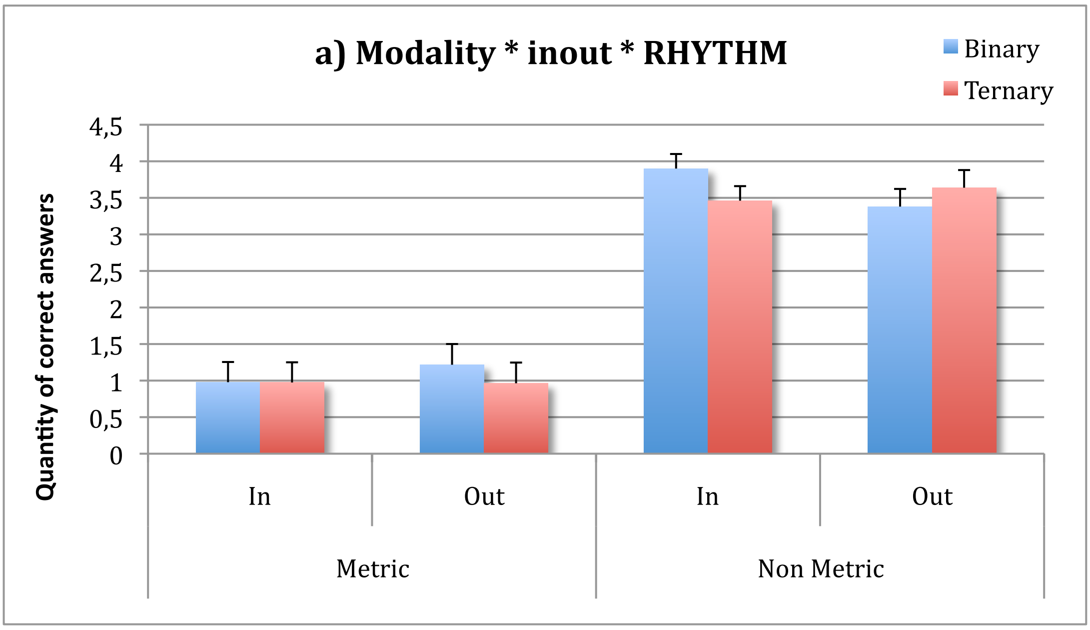

Fig.37: interaction between the dependent factors "modality", "inout" and the between subjects variable "RHYTHM". The post-hocs show that the modality is the only significant variable pairwise compared with RHYTHM and inout ones (all with p<0,001).

The first interaction between modality and other dependent variables to result significant is the "modality *inout *RHYTHM"(p<0.05; F(1,15)=4,988; eta-sq: ,250; see above fig. 37). In this interesting interaction, it is possible to notice how, when the subject had to answer with a number, the quantity of correct answers vary according if it was an "inside" or "outside" scenario, but this is true mainly for binary subjects, who answered generally better in the "out" condition. Instead binaries obtain more correct results in the "in" condition when they answer in a nonmetric modality, in which they do even better then ternaries. These, on the other side, do not show to be much affected by "in" or "out" scenarios in the metric modality, but in the nonmetric answers they perform slightly better in the "out" scenario.

From the results I obtained other significant interactions between the variables, but the most interesting to discuss are, first of all, the one between "stereo *egoallo *RHYTHM" (p<0.05; F(1,15)= 7,683; eta-sq: ,339) and the interaction between "modality *stereo *egoallo (p<0.05; F(1,15)= 4,757; eta-sq: ,241), shown in Figs. 38 and 39. In fact, in the first case we can observe the different behavior of binary and ternary subjects, which show the best performances both in the scenarios without stereoscopy, respectively in the ego- and in the allocentric measures. The egocentric estimates of the ternaries and the allocentric ones of the binaries in the condition without stereoscopy are instead the worse. In the other condition, with stereoscopy, the results are more distributed, and they follow the same pattern: binaries give more correct answers than ternaries both in ego- and in allocentric estimates. Post-hoc analysis showed that, anyway, the stereoscopy presence or absence was significant ($p<0.05$ ($F(1,16)=4,567$), eta-sq.: ,222) only in the allocentric condition for ternary subjects, while the ego/allo difference is significant ($p<0.05$; $F(1,16)=7,144$; eta-sq: ,309) only for ternaries in the absence of stereoscopy. The findings, together, confirm something peculiar for ternaries in processing spatial information with respect to the reference point.

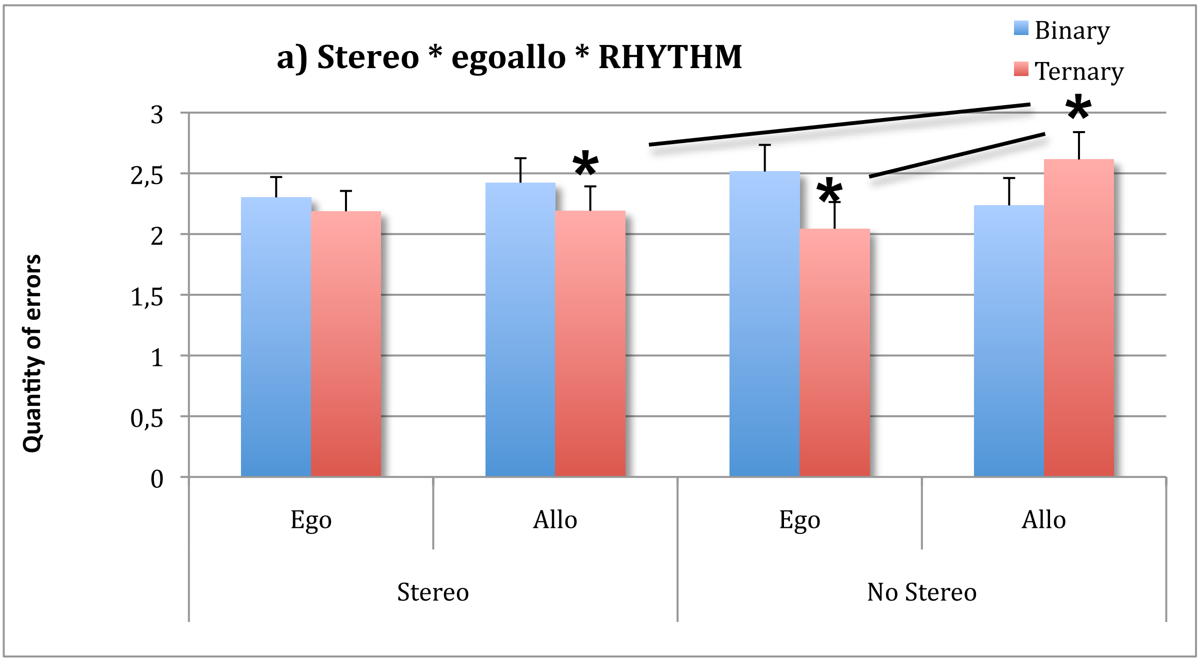

Fig. 38: interaction between stereoscopy, egoallo and RHYTHM.

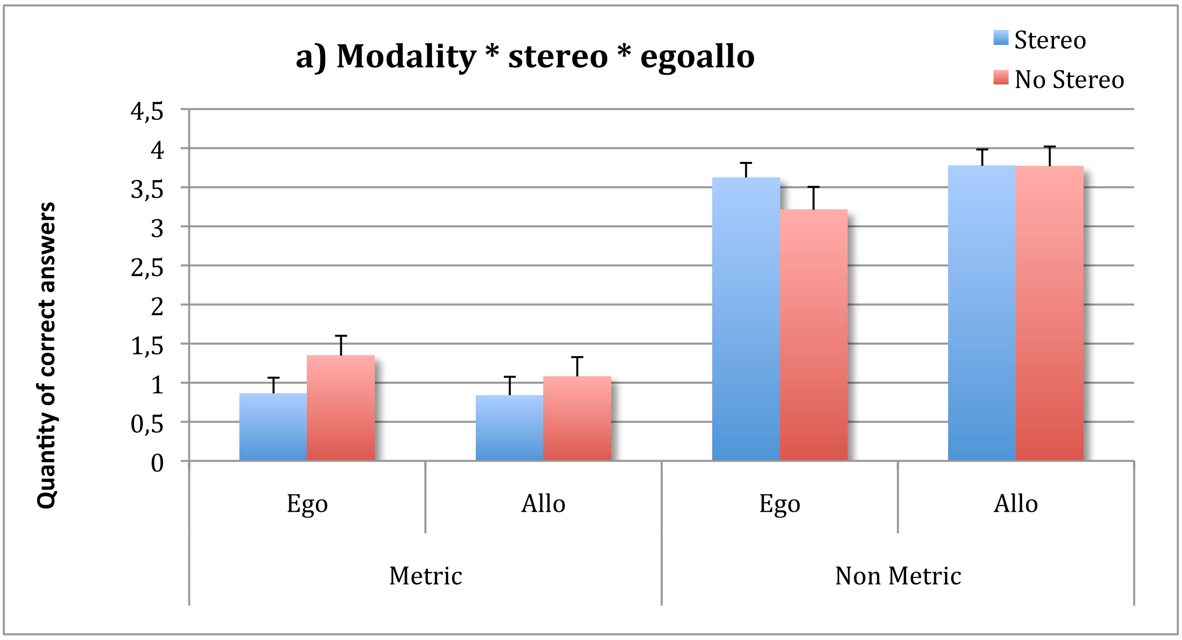

Fig. 39:interaction between modality, stereoscopy and ego/allo. Post-hoc shows a big significant effect (all $p<0.001$) for the modality as compared with egoallo and stereo variables

In the other resulting interaction (see Fig. 39), we can have a more precise insight about the relation between stereoscopy and modality of answers according to ego- and allocentric distances. Here we can notice that in a non metrical way of evaluating distances, stereoscopy is actually helping a bit in giving correct answers, especially in judging the egocentric distances, which is something pretty interesting to prove, since most of VTs are built in a first-view perspective and professionals have usually to learn how to use machineries and interfaces, and a correct understanding of stereoscopic distances from the user point of view is a basic thing to assess in order to consider these trainings effective. In the metric modality of answers, instead, the data are more or less replicating what already found in the Experiment 1 about the use of stereoscopy in VEs (see paragraph 2.3.2), and this, as already discussed, could simply mean that in a VE it is more difficult to assign numeric (metric) values to perceived distances.

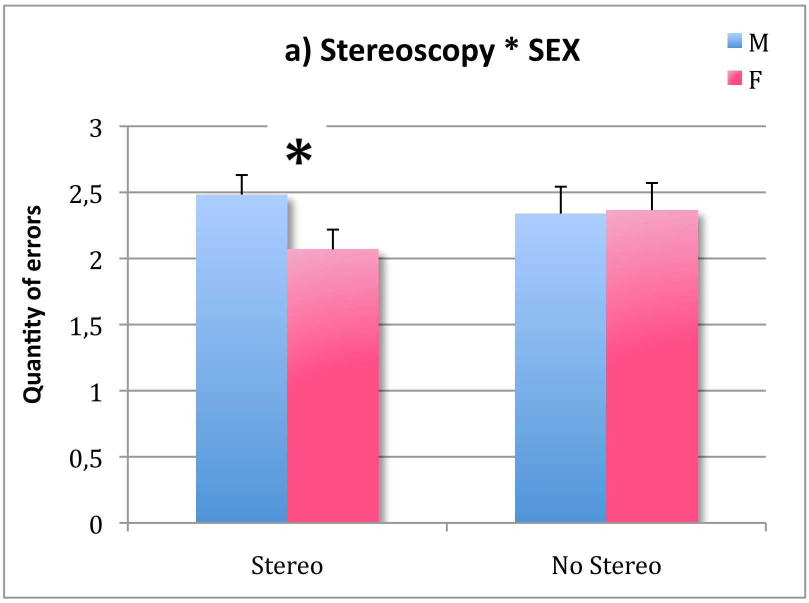

Fig. 40: Non-significant effect of SEX on stereoscopy.

An almost-significant interaction “stereo *SEX” (p>0.05, but eta-sq: ,187; see fig. 40) suggested me to perform a deeper analysis only on stereoscopy in relation to the modality of answers, since, as we can see from the graphic, the subjects who commit the largest number of errors are the females, who are known to be generally a bit worse than males in spatial and distance estimations tasks. With the post-hoc analysis we could define that, in particular, in the stereo condition, the difference in performances from males and females is significant (p<0.05 (F(1,16)=5,027); eta-sp.: ,239).

b) Other proof of the discussed interpretation of stereoscopy in VEs comes from the second set of analysis, performed on stereoscopy alone in order to shed more light on this question.

In fact, differently from the Experiment 1 discussed in the section 4.3.2, with this modality of answers it looks like the results about stereoscopy are actually showing better performances in the stereoscopy condition when the modality of answering is non metric. The first significant effect with the repeated measures is the “modality” factor (p<0,001

(F(1,18)=135,319), part.eta-sq: ,883; see Fig. 41). In the picture on the left, is possible to see that, as hypothesized before, stereoscopy is actually improving performances in the non metric modality, while in the metric one, as already found, yields a smaller number of correct answers.

In picture on the right (Fig. 42), the between subject variable "SEX" resulted also significant (p<0,05 (F(1,18)=4,173), part.eta-sq: ,329), but only in the "stereo" condition: as in the previous dataset analysis in section a), post-hocs show no significance of the variable in the conditions without stereoscopy; the result shows general better performances of males in the stereo condition with respect to women.

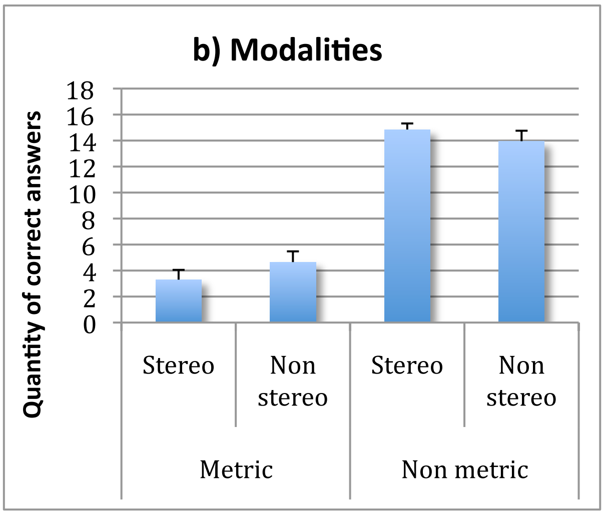

Fig. 41:stereoscopy in the different modalities

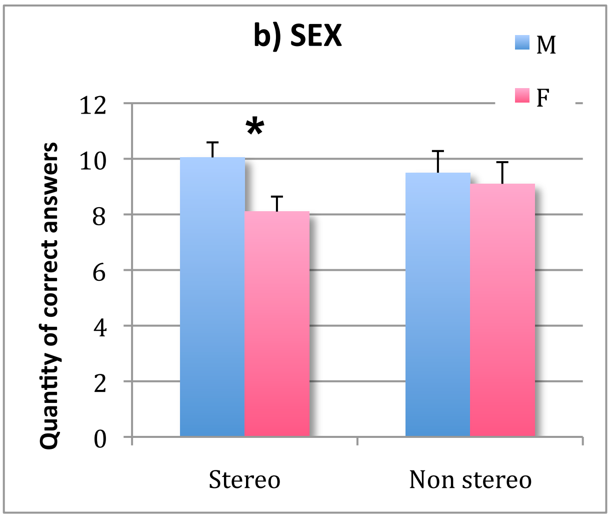

Fig. 42:SEX differences in the use of stereoscopy (asterisk: significant).

So, concluding, it is possible that the real support of stereoscopy is benefited only from men, while women do not find any help in estimating distances coming from stereoscopy. Their performance is almost comparable to men's performance in the normal bidimensional 3D scenario, but it drops in the case of stereoscopy.

This suggest that a deeper study investigating the reasons why women do not find it useful, or maybe find unnatural, the use of stereoscopy, could be done in order to shed more light on this issue.

Besides the gender effect, anyway, the fact that the same kind of environment, only changing the modality of expressing the distances, allows the subjects to give an higher number of correct answers in presence of stereoscopy, proves that the environment itself is quite well perceived by the subjects, even if they do not know how to express the spatial relations of this environment with metric answers.

As I could notice in experiment 2 (paragraph 2.3.3), a sequence effect exists between VE and RE: if subjects start with the VE, they make more easily errors in numeric estimates either in VE and in RE: the problem could be, in this case, that the subjects are not used to judge distances between objects in a precise way, neither in reality, but when they are asked to perform estimates in a VE, they find it difficult to "set" their mental metrics to the artificial environment, and this upsets all their measurement system, affecting also their estimates in the RE. On the other side, when they start from a real environment, they find it a bit simpler to express the distances in a known-world metric system, because they have more experience with it.

Conclusions

In experiment 1 about stereoscopy, I found no help in stereoscopic view for a better understanding of distances in VEs. With the present experiment, I confirmed this result, but only for the metric modality of answering to the questions. In particular, the results showed, with respect to the initial hypotheses, that a) fewer errors are generally committed in the non-metric modality; b) stereoscopy was helping in distances judgments with non metric estimates; c) females still have slightly worse performances than men, but an interesting finding shows that females in general perform worse with stereoscopy, while men perform better (either with and without stereoscopy); finally, d) I did not notice any significant difference between egocentric and allocentric, but if considered with other variables, egocentric distances still have the highest differences with and without stereoscopy both in metric and nonmetric modality. It is also interesting to notice that, in the nonmetric condition, more correct egocentric answers were given with the use of stereoscopy.

We can therefore conclude first of all that non metric judgments yield better performances than numeric estimates, indicating that the problem could not be in the VE itself, because the subjects have a good representation of the spatial relationships between the objects (allocentric distances) and the objects and themselves (egocentric distances). I explained these results with the fact that people have already "experience" of the real world, which instead is lacking in a novel VE. Most of the subjects never saw a 3D environment, and probably never experienced stereoscopy. This could suggests that, in order to improve people's performances in understanding environments, a short familiarization period is necessary: in this way, giving them feedbacks and allowing them to navigate freely in an environment (Richardson & Waller, 2005 and 2007), the situation will be more similar to a real environment, and then it would be possible to replicate evaluation of distances tasks in order to investigate if, with more experience, also the perception of the actual distances is improved. Another finding is related to stereoscopy, and it suggests that it is improving the performance of subjects, but it is appreciable only within a nonmetric paradigm of evaluation of distances. In general, studies on evaluation of distances in VEs are not suggested, but if they need to be performed, they should not use the stereoscopy, or at least not require the subjects to answer in a numeric way to estimations' questions. Anyway, there is a strong gender effect that bears another set of interesting issues related to stereoscopy, and this suggests further investigation: the reason why women seem to be more impaired than men by the use of stereoscopy in virtual environments. This last issue, seem to me to be closely connected with another problem that I address further in this work, in section 4.4, when I present some other experiments which show an extreme sensibility of women to artificial optic flow in huge environments, which in some cases ended in the expression of Simulator Sickness's symptoms. This may happen because some subjects seem to be more sensitive to the peripheral automatic visual processing which is used by our brain to build the representation of 3D space: in these subjects, when put in an "abnormal" situation, where the environment is proposing something that is, somehow, fake, there could be a stronger mismatch between what the visual system perceives and what the situation (artificially) is suggesting (in the case of stereoscopy, the existence of some depth or third dimension even where there is not, and in the case of simulator sickness, the presence of a movement which is not followed by changes in the proprioceptive information).

2.4. Spatial tasks in VEs: Navigation and Visuospatial Planning in VR

From a cognitive point of view, we know that spatial navigation involves the ability of finding our way (wayfinding) in an environment, making choices, recalling routes and/or creating strategies. Since wayfinding allows the selection of our path among several possible routes, to organize movements in order to perform actions and to achieve a goal, it should not be implemented as a process apart from our capacity to plan a route. Very little attention has been attributed to the question of which mechanisms, strategies and heuristics are applied during route planning that allow a navigator to derive the shortest path, the quickest path or the least costly path from spatial memory. Even less studies drew attention on the interaction between planning and wayfinding, using a planning task in either a real or a simulated environment (Burgess & Shallice, 1996).

The analysis of human performances in spatial cognition provided evidence for a fundamental distinction between two types of spatial representation according to a route or a survey perspective. Shelton & Gabrieli (2002) characterized route-based knowledge as the *“knowledge of spatial layout from the perspective of a ground-level observer navigating the environment”*. It relays on existing relationships among environment specific features, with a special emphasis on spatial relations between objects composing the scene an agent is situated in. In contrast, survey knowledge *“is characterized by an external perspective, such as an aerial or map-like view, allowing direct access to the global spatial layout”* (Shelton & Gabrieli, 2002).

The very fast advances in technology and image-rendering field made it possible to develop and improve amazingly realistic and compelling scenarios within always more precise Visualization Systems (VSs). The reliability of the use in research in cognitive processes of VEs instead of Real Environments (REs) is suggested from a series of studies which investigated how individuals learn to navigate through VEs and mentally represent those environments (Tlauka & Wilson 1996; Albert et al., 1998; Richardson et al., 1999; Albert et al., 1999), relying on the fact that involved mechanisms in virtual navigation are analogous to those activated in real space. They confirm that mental representations of space in virtual environment are quite similar to those implicated in navigation of real environment, and some other experiments (e.g. Burgess et al. 1999) provide a proof of the involvement, during human navigation in VEs, of the same brain areas found to be activated in REs navigating rats or in human’s brain activity investigated by means of fMRI

(Pine et al., 2002). Thanks to their features, numerous advantages are generally underlined when VEs are used in spatial cognition research field (Loomis et al., 1999): amongst them, high ecological validity, experimental control, possibility to generalize experimental findings, experimental realism, the use of “impossible” manipulations and situations, the ease of implementation and conduction of experiments and a complete safe environment which allow, in case needed, the accomplishment of dangerous actions without any risk for the subjects.

All these features concur to give the user a deeper “sense of presence” (Ijsselsteijn et al., 2000) with respect to the other “limited FOV” Visualization Systems, which is a critical concept for the effective utilization of VR (Takatalo et al., 2008).

To evaluate the benefits and advantages offered by a 360° immersive VE for the investigation of spatial navigation and visuospatial planning, I ran the “3D Maps” test (Saracini et al., 2008; the description of the task will be discussed later in this paragraph) in the ED and then confronted the performances of other subjects in the same test, but performed on a normal PC. I expected that the physical features of the ED would allow the subjects to build more precise and realistic mental representation of the spatial environment, and to perform natural behaviors like turning the head and looking around which easily permit to locate objects in the scenario and complete the task. The advantages that these technologies can offer to research on spatial processes are huge, but there is still the need to validate them in order to counterbalance the “ecologic” affordances and the “scientific” control of variables. This is the main goal in experiment 4 (paragraph 2.4.2).

Another remarkable fact is that, while interaction with the Desktop VR is often mediated by tools like mouse, arrow-keys and keyboard buttons in general, iVEs give the possibility to use user-friendly controller devices which allow a more direct interaction inside the environment, usually combined with a tracking system which recognized the subject’s movements. This brings a definitely lower cognitive cost for the user, allowing him to directly translate his intentions in actions, without “translating” them in a different language (the computer’s one), keeping the focus on the task and not on the modality of interaction (Bailenson et al., 2008). But this thing needs a scientific proof, and this was one of my aims in Experiment 5 (see paragraph 2.4.3). Related to that, the well known problem of Simulator Sickness (SS; Kennedy et al., 1992) is also addressed in the experiment, with the intent to evaluate if such an ecologic way of interacting with an iVE is of some help to reduce the SS symptoms by means of a reduction of the mismatch between proprioceptive information and visual information. This is supposed to happen thanks to the possibility for the subject to physically rotate left or right in the cylindrical environment of the ED in order to turn left or right in the scenario, since he/she is wearing a cap with some receivers the movement of which is captured by some infrared cameras disposed all around the cylindric wall.

So, we can say that the success of VEs in spatial cognition research is due to the fact that virtual scenarios allow researcher to create perfect environments for special tasks, otherwise really difficult to reproduce in the real world, but most of all without the comfort of receiving automatic outputs, control of all the variables according to the experiment paradigm and hypotheses. In the case of the present study, for example, the difficulty to create a maze with the exact features needed for the paradigm to work has been overcome by the possibility to represent a 1:1 environment, to switch very easily from a survey to a route perspective of the same, to present different configurations of subgoals time after time and to automatically save all the data in output files (times, errors, routes and so on) about the performance of every subject.
The task is described in the following paragraph.

2.4.1. The “3D Maps” and “VR-3D Maps” tests.

The task itself is a 3D version of a previously existing computerized version of the Traveling Salesman Problem (TSP; Cadwallader, 1975; Lawler et al., 1985). The previous 2D version of the task is a visuospatial planning task developed by Basso (see Basso & Bisiacchi, 1999 for a description of the tool) which presented, in a survey perspective, a grid with 7 green balls which could assume different configurations. The original TSP is a “closed” task, that means that the subjects were shown a map (always in a survey perspective) and they were told to find the most suitable route to perform in order to achieve all the displayed errands in the shortest route and time beginning from a starting point and ending in the same point (for example Dantzig et al., 2954; see Fig. 43).

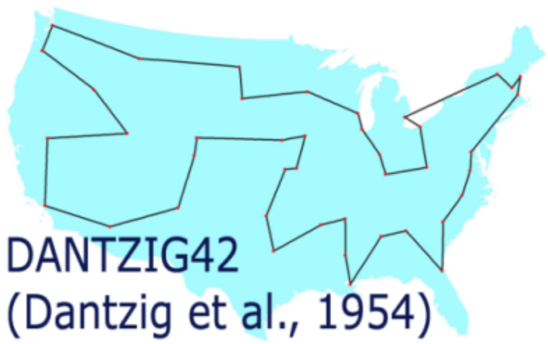

Fig. 43: The typical closed-TSP task.

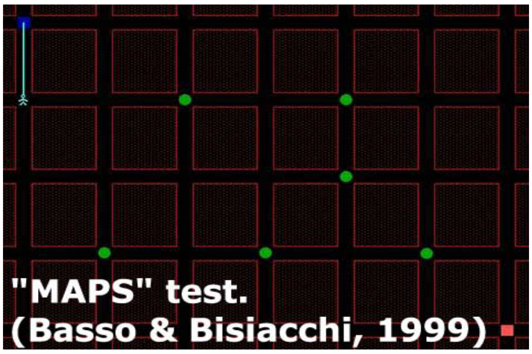

Fig.44: An open version of the TSP: “Maps” test from Basso & Bisiacchi (1999).

The “Maps” test, instead, represents an “open” variant of the problem, in which subjects are asked to perform an optimized route beginning from a starting point (the green one in Fig. 44) and ending in a different point (the red one in the same picture).
Bidimensional tests offer a survey perspective of the environment (the map) which is entirely visible at any time, even while the subject is navigating, so they allow the use of more flexible strategies, with frequent changes of heuristics even while performing the task. According to us however, this kind of task could better represent the strict connection between planning and wayfinding if it could give the subject the impression that he is navigating in the same environment he is acting inside. For this reason we developed a 3D version of a computerized version of the TSP. In the 3D version the subject has to use at the same time both survey and route knowledge, keeping the information in his/her working memory while navigating. In other words subjects must keep in memory not only the spatial configuration of the environment and the reciprocal relations between objects and locations, but also the sequence of turnings and subgoals he/she planned to reach during the survey presentation of the environment. The creation of a plan within a navigation task is based on the use of heuristics and strategies.
A strategy is a series of actions that guides the subject to the solution of the problem (Duncan, 1986). The heuristics are the list of actions to perform: an opportunistic combination of heuristics determines a strategy.

However, the selection of a series of actions is not completely reduced to an automatic process or application of heuristics, but it is carried out by comparing the actual state with the future behavioural state, determined by a feedforward process (Bryson 2002). Olivetti Belardinelli & Basso (2002) proposed that an on-line feedforward-based control is constantly enacted, allowing the on-going action to be rearranged towards the desired future behavioral state considering everytime the best heuristic to follow according to the situation.

In the “Maps test”, like in the “3D Maps” and its “Virtual version”, we consider heuristics and strategies as variables which indicate the quality of the optimization and their usage in all the different conditions. In particular, the interest, for what regards the heuristics, is to evaluate when the subjects are:

- Using the same heuristic for every situation (rigid application of rules; dist0)
- Use of different heuristic for every plan (flexibility of use; dist1)
- Changing more than one heuristic during the same navigation task (flexibility of plan; dist3).

While, for what regards the strategies, it is considered if they are:

- Not planning a strategy at all (st0)
- Using a single strategy (st1)
- Using strategy with changes (st3)

Thanks to the new technologies offered by the Fraunhofer Institut's facilities, we could create the "Virtual 3D Maps" test.

Both in the "3D Maps" and in the "Virtual 3D Maps" tests, the task is to first setup a strategy by looking at a survey-perspective of a schematic environment map containing 7 subgoals (plus the final goal). Then, the subjects has to perform the planned route in the same scenario, but in a first-person perspective, starting from the starting point (green ball), passing through all the 7 subgoals (blue balls) and ending at the exit-point (red ball), in an opposite position with respect to the starting point. The performances at the two tests (the "3D Maps, performed at the PC, and the "VR-3D Maps", presented in the ED) have been confronted in experiment 4 (paragraph 2.4.2), while the different interaction device and its ability to reduce Simulator Sickness was tested in experiment 5 (paragraph 2.4.3).

2.4.2. Experiment 4: Evaluation of planning and spatial navigation test in a 360° immersive laser projection system.

Background and motivation of the experiment

As already discussed in the introduction of the experimental section (2.1) and of the present chapter (2.4), one of the most explored topic in cognitive research by using VEs is the spatial navigation or, more in general, spatial cognition.
Everyday more realistic and compelling tools and machineries are created, like for example the already discussed immersive Visualization Systems (iVSs; for example, the Head Mounted Display, HMD) which completely integrate a user in a Virtual Environment (VE), allowing a very high level of realism, especially when they are used in connection with a tracking control-device. The difference from the so-called “Desktop VR” is mainly that in a normal PC screen, VR presentations only cover a certain area (more or less 60°) of a user’s Field Of View (FOV), and the dimensions of the scenario are reduced due to the limited size of a monitor. An immersive Virtual Environment (IVE), instead, is a system that perceptually surrounds the user, increasing his or her sense of presence or actually being within it (Ijsselsteijn et al., 2000; Bailenson et al., 2008). In an IVE, the sensory information of the VE is more psychologically prominent and engaging than the sensory information of the outside physical world. In the particular case of the Elbe Dom, that we discussed more deeply in the paragraph 3.2, the outside RE is almost completely excluded, since the cylindrical wall around the user displays the images of the VE and he/she cannot see the objects from the physical world, being completely “enveloped” by the synthetic information, and only the floor and the ceiling are still visible.
Therefore, I obtained a program which could allow to automatically save outputs files containing all the data about the planning time, the performed route, the order in which subgoals have been taken, the missed subgoals, the times at which every subgoal was reached and the total time of execution of the maze. These were also the main variables investigated in this study.

Hypotheses

The hypotheses at the basis of this experiment were that:

a) Bigger displays allow better immersiveness, which in turn make the task in virtual scenarios more ecologic and “involving”.

b) Ecologic VSs allow us to predict spatial abilities in real life, following the same patterns of physical spatial tasks, as in the already acknowledged gender differences.

If these ideas were correct, the following results were expected:

> a) In a 360° immersive VE such the ED there should be advantages with respect to the usually employed Desktop VR (PC screen) in terms of a better performance (shortest routes, less errors).
>
> b) The 360° visualization should also have some influence in the strategies employed by the subjects, which could benefit of a more life-like situation and use more flexible planning process, reflected in more changes of strategies and the use of different heuristics for single strategy.
>
> c) A strong gender effect was expected both in terms of quantitative (times, routes and errors) and qualitative (heuristics and strategies) results, in particular we expected higher times, fewer errors and a rigid use of strategies and heuristics for females with respect to males subjects.

Methodology

Subjects: 20 subjects (5 males, 5 females) performed the VR-3D Maps, the Virtual version of the 3D Maps test presented in section 2.4. Their performance has been confronted to other 20 subjects, who previously performed the 3D Maps test on a normal PC as a control. 20 subjects (“PC” group) were tested on a normal portable laptop, with a C++ program that enabled them to perform the “3D Maps” test.

Tests used: VR-3D maps (10 test maps + 2 familiarization maps); Corsi span test (Corsi, 1972); Mini Mental Status Evaluation (MMSE, Folstein et al., 1975; German, English and Italian versions); Trail Making Test (Spinnler & Tognoni, 1987); Edinburgh’s test for manual lateralization (Oldfield, 1971) and a short version of 12 items from the Raven’s progressive Matrices (as suggested in Mondini et al., 2003).

Statistical analysis: In order to get some variables and to compare all the data, some transformations on the original dataset had been performed. Following Basso & Bisiacchi (1999), we created the variable “steppao”, which calculates the length of the route considering also whether one or more subgoals were missed, in order to make comparable the length of the routes when the subject forgot to take a subgoal (which would be otherwise shorter) to the ones that are really shorter because a good and optimized plan was done. Other variables which have been created are: st0, 1 and 3 and disp 0, 1 and 3.

Two kind of analysis have been performed on the new data:

a) Quantitative analysis: ANOVAs were performed on the following independent variables between the two groups: Planning Times, Additional Steps and Errors. In this analysis I excluded the variable Execution Times because the two tests were based on different programs and the walking speed could not be directly comparable. The independent variables were SEX (2levels: Male/Female) and GROUPS (2levels: VR/PC).

b) Qualitative analysis: ANOVAs on dependent variables representing the use of heuristics (disp) and strategies (st): disp0 (0=all heuristics/100=only one), disp1-3 (1=unique/3=2 or more), st0 (no plan) and st1-3 (1=unique/3=with changes). Also here, the independent variables were SEX (2levels: Males/Females) and GROUPS (2levels: VR/PC).

For the post-hoc analysis and main effects comparisons, a Bonferroni correction method was used.

Results and discussion

a) The results of the **quantitative analysis** gave a main significant effect of the GROUP on 2 of the independent variables: “planning times” ($p<0.001$; $F(1,36)=30{,}035$; Fig. 45) and “additional steps” ($p<0.01$; $F(1,36)=8{,}419$; Fig. 46). The variable “errors”, instead (Fig. 47), is not significant but shows a tendency to make more errors in the PC than in the ED.

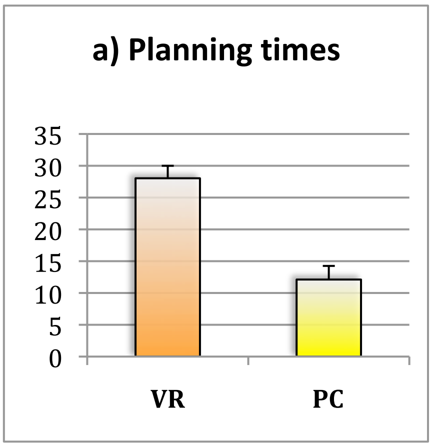

Fig. 45: Significant GROUP effect on planning times

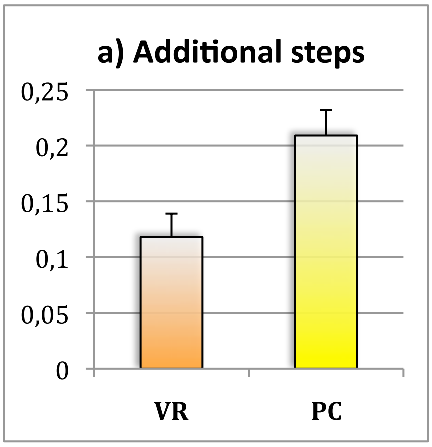

Fig. 46: Significant GROUP effect on the additional steps (length of the route)

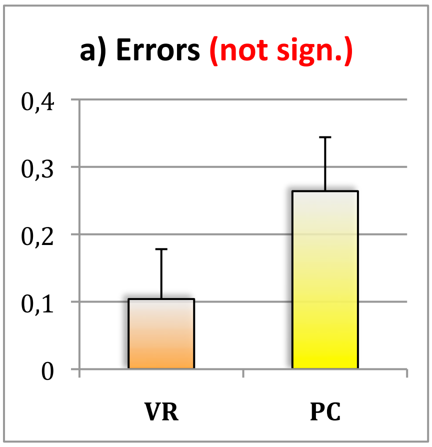

Fig. 47: Non significant GROUP effect on errors (missed balls)

The variable “errors” is not significant, even considering the dependent variable SEX, but there is a tendency of men to commit more errors with respect to females (as shown in fig.

50), result that was also obtained in previous studies with “3D Maps” (Saracini et al., 2008; 2010).

Planning times (p<0.01; F(1,36)=7,938; Fig. 48) and “additional steps” (p<0.05; F(1,36)=6,361; Fig. 49) instead, are significant and the obtained result shows a typical difference between men and women: the firsts are always faster of the latters, and manage to make shorter routes, too. Although not significant, the highest quantity of “errors” which men tend to commit, could partially explain not only the shortest routes and the faster times of execution of the mazes, but also the planning times, smaller in case of men: it is therefore probable that men spend less time planning the route, make more “improvisation”, more easily forget subgoals and, therefore, are faster and make less additional steps. This, of course, explains only part of the results, because we know from literature that men optimize more and are faster in spatial route following and navigation, because rely on configurational information like turnings, metrics and geometrical relationships.

The results about longer planning times for females were attended, but the finding that this happens more in VR was not expected. Probably due to the fact that in the ED the dimensions of the survey map showed in the planning phase are huge, and therefore it takes more to visually explore the map than in the small display of a desktop.

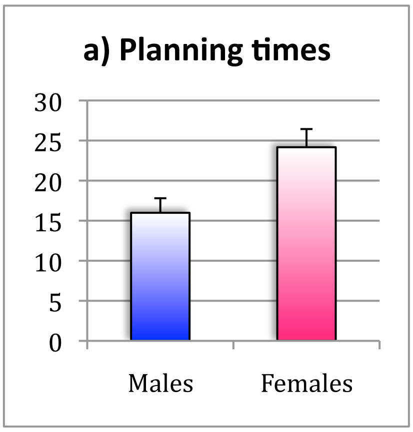

Fig. 48: Significant effect of SEX on planning times

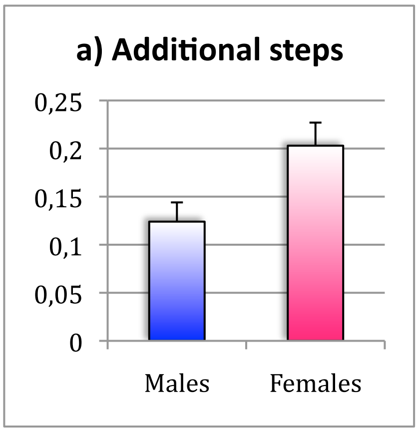

Fig. 49: Significant effect of SEX on the route length

Fig. 50: Not significant effect of SEX on errors.

We can then observe how the interaction between GROUP * SEX (Fig. 51) does not give almost any significance, except the “planning times” variable (p<0.005; F(1,36)=9,044). For the “additional steps”, instead, with the post-hoc analysis it has been possible to see that the length of the routes performed by the females in the ED were significant for the variable GROUP (p<0.01; F(1,36)=7,611), while the ones who performed the task at the pc resulted significantly related with the SEX variables (SEX: PC condition significant; p<0.05;

F(1,36)=7,088), which means that women are significantly doing more useless steps with the PC.

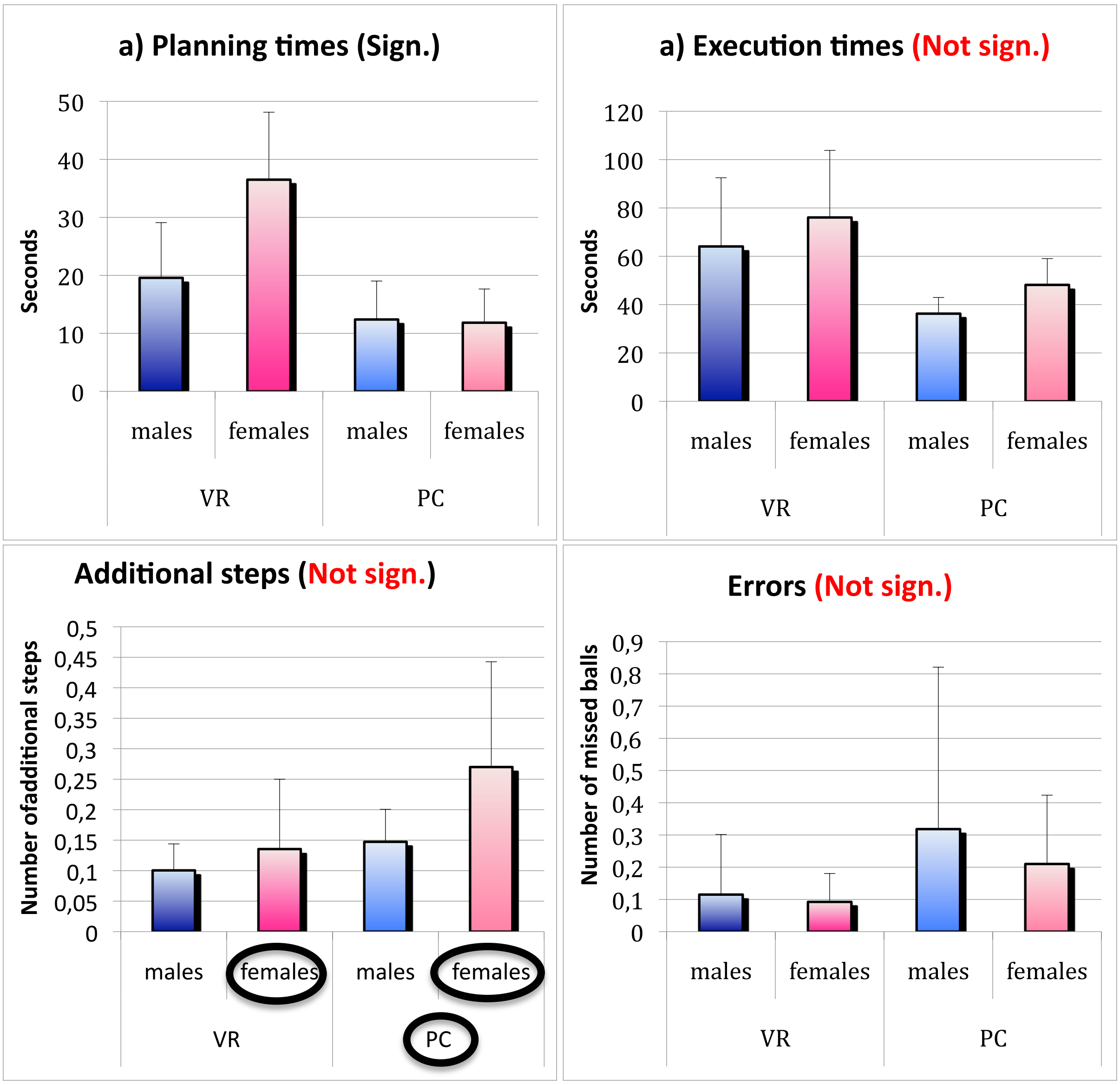

Fig. 51: Interactions between GROUP and SEX variables (only "planning time" is significant and "additional steps" in the PC condition for what regards females).

b) For what regards the **qualitative analysis**, instead, the main significant finding is an higher employment of strategies with changes in the ED, while with PC test shows less flexibility in the use of heuristics. In fact, as it also possible to see in the Fig. 52, the significant variable "st1-3" (F(1,36)=4,944, p<0,05) clarifies that the unique strategie (st1) is more employed in the task done at the PC than the strategy with changes. In the VR, instead, it is possible to observe the opposite situation: the most used are the strategies with changes, supporting the idea of a dynamic use of strategies in the VE with respect to the PC.

Finally, women tend to complete the tasks without a clear plan more than men (Fig. 53), and this is significant (F(1,36)=4,417, p<0,05).

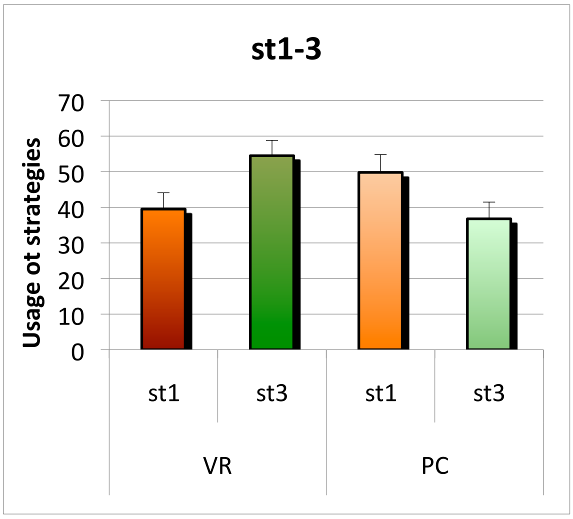

Fig. 52: The variable "st1-3" is significant for GROUP.

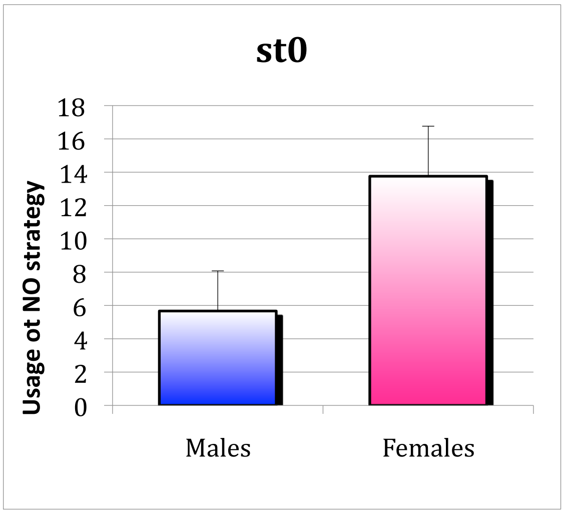

Fig. 53: Variable "st0" is significant according the gender of the subjects

The discussed results are observable in summary chart (Fig. 54), where it is possible to see all the effects for all the variables related to strategies. Altough the interaction amongst all the variables it is not significant, the chart allows to observe some tendencies that support the significant results. In the graphics, it is clear that st3 (strategies with changes) is the highest value in the VR for the males. Even amongst the females, is the highest rate of usage with respect to all the other strategies. Another thing looks interesting, ant it is the fact that in the VR (especially for men) there is a very low number of "no strategy" situations, and also the female subjects seem to diminsh the number of maps solved without any strategy in the VR condition, contrarily to what happens in the PC group.

The use of heuristics, instead, is explained by a significant result on the variable "disp1-3" on SEX (p<0,05; F (1,36)=6,671; see Fig. 54).

In the Fig. 55, it is clearly visible that men tend to use more heuristics in the same strategy than women, and that women seem to be strongly tied to certain heuristics, keeping on applaying them on the most of the mazes, without adapting them to the current situation. This explains also why they have in general worse results than men about the length of the routes and their optimization.

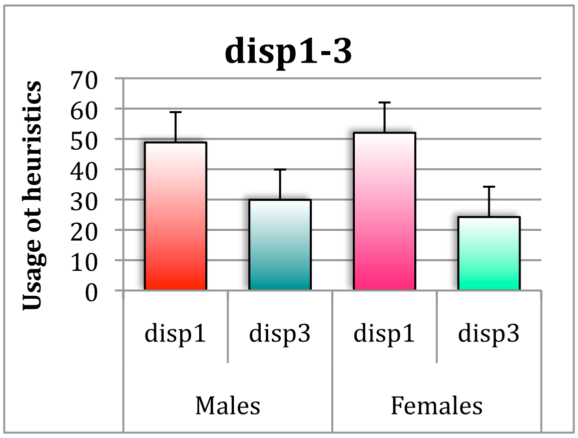

Fig. 54: the use of heuristics in relation to the independent variable SEX.

The dynamic use of heuristics allows to use for every situation the most suitable one: if the subject perseverate on using a single one or always the same for the whole task, there will be more possibilities that he will fail in the optimization task.

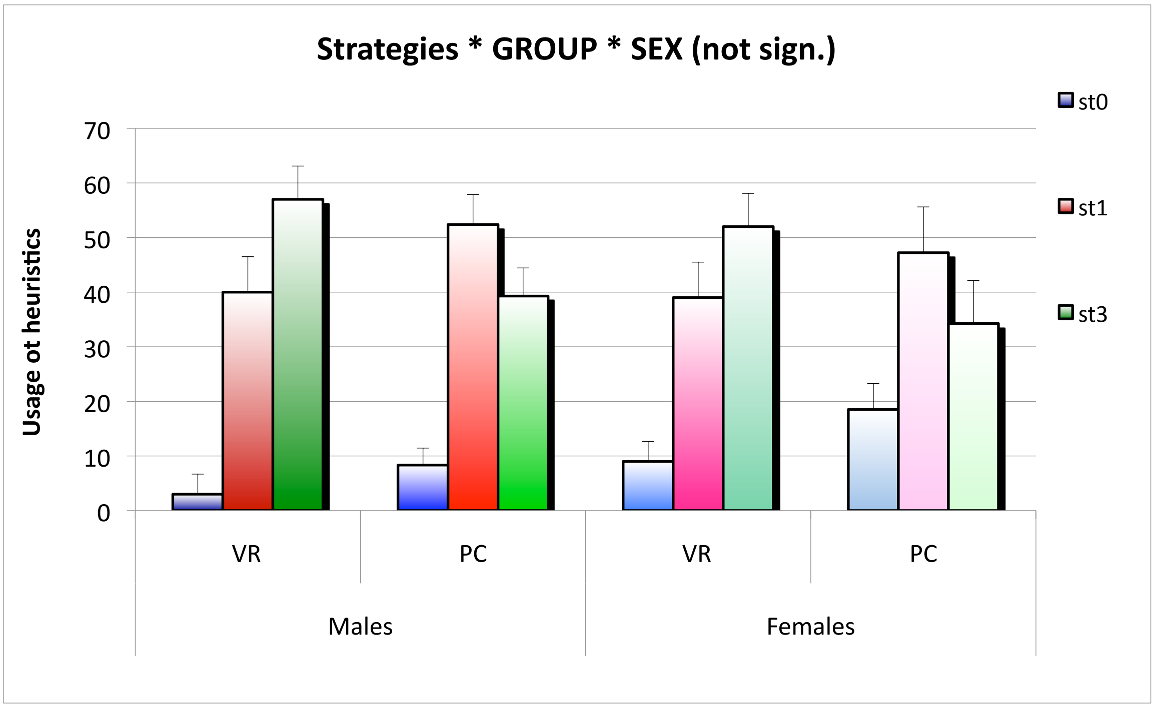

Fig. 55: Non significant effect of all the variables according to SEX and GROUP

Men have very low results on st0 (=no plan), collecting in average more than one heuristic per map (higher disp3 and st3 rates). This was also expected from previous experiments, while the tendency of women to not use strategies is less strong in the ED than at the PC, supporting the effectiveness of VR in performing these kind of tests. In general, the finding is more or less the same for both dist1-3 and st1-3.

Conclusions

It is possible to say that almost all the results supported the initial hypotheses.
So the results showed that:

a) In the ED the performed routes are significantly shorter and with less errors (forgotten targets) with respect to the performances obtained at the PC.

b) The 360° visualization influences the strategy used, with employment of more strategy with changes (expecially for men) due to more flexible planing process.

c) A gender effect have been found in both quantitative (times, routes and errors) and qualitative (heuristics and strategies) results, with higher times, fewer errors and less strategy-changes for females with respect to males subjects.

The only unexpected finding is that in the ED the time for producing a plan are longer than in the PC condition. This can happen because in the ED the survey map perspective of the environment is huge, and takes the frontal part (in front of the subject) of the circular display. So it literally took some time to visually explore the image, which was at least 10 times bigger than the one observed on the screen of the PC to the other group of subjects. Therefore, I would not say that all the time was emplyed to form a plan, but it could be that it was partially used to "process" the image, visually scan it and then move the eye-gaze from one side to the other of the survey map in order to mentally simulate the planned route. These findings could also suggest that a learning of structures took place instead of a direct learning from signals in the case of women (Olivetti Belardinelli, 1974), and this could explain longer times but less errors.

Another fact that was not expected is that a high number of subjects (6 out of 20, all females, which have been excluded from the analysis because they couldn't complete the maps) which have been tested in the VR group have reported "motion sickness" symptoms, while in the PC group these kind of symptoms have not occurred.

Anyway, it is a remarkable finding the fact that strategies and the use of heuristics are so different when a person is immersed in an environment and when he/she is performing the task on a desktop-VR. This is a very interesting fact, because most of the researches on spatial cognition are performed by means of computers, and such a significant difference cannot be ignored. If someone is interested in knowing how people use different kinds of strategies, or he/she is interested in evaluating gender differences in the application of heuristics, it is important to know that they may differ a lot according to the dimension of the screen or the level of immersivity of the environement. This is an issue that definitely should be more deeply investigated in order to have a clear definition of the features of different kind of devices, otherwise one can find results which are not reliable and biased by the tool that has been used to obtain them, and not resulted from the general cognitive functioning that was intended to be investigated.

2.4.3. Experiment 5: The use of tracking in immersive projection-based Virtual Reality

Background and motivation of the experiment

The already discussed technical differences (see chapter 1) of Visualization Systems (VSs) cause some doubts when it comes to take the difficult decision, for a scholar who want to use a Virtual Reality (VR) technology, of which, amongst the many, VS he/she should use for his/her research. The so-called “immersive Virtual Environments” (iVEs), for example, allow not only a very strong “sense of presence”, but also the complete immersion in the artificial environment, so they would be one of the best choices in the case of a scientific evaluation. These features are surely a big advantage, but there are also some drawbacks.

One of the most recognized problems in iVEs, for example, is the fact that some people are extremely sensible to the simulated optic flow inside the VS, and they experience a very unpleasant set of symptoms which are known as “Simulator Sickness”(Kennedy et al., 1992). This sickness is originated by a physiological mismatch between a) what is perceived by the visual system at each moment, and b) how proprioceptive and kinesthetic information is being processed in deep brain structures, which give information about the position of the body and body parts at any moment (Kesztyues et al., 2000).

To partially eliminate the problem, the use of Tracking System (TS) that acquires at any time the position of the moving person in a 360° projection system was thought to be a satisfactory solution, because it is supposed to diminish the mismatch between the perceptive, optical information simulating a movement (optic flow) and the proprioceptive feedback of the subject, which usually is in a “static” position.

In the previous chapter I showed how, most of the times, tools and technologies are produced without the use of user-centered guidelines or without a functional cognitive model as a working-base. In applied research, in fact, sometimes the models of functioning standing behind the human behavior are not taken into account enough as in basic research. This occurs especially in high specialized and engineering-based studies, which are focused on the product more than on the user. The risk is obviously to obtain superficial results and produce unusable tools, or start an endless chain of trials and errors in order to reach perfect product quality, ending up in a waste of time, energy, money and resources. That is why multidisciplinarity and multilevel collaborations are supported and promoted in almost every field of technology. In the case of the project of this doctoral work, besides the already discussed basic issues which have been addressed from a research point of view, another point was to show how a good interaction between basic and applied research can bring to a satisfactory goal of common interest of building good and reliable technologies which can be later used also for research. For example, relating to the SS problem and willing to evaluate the benefits of the use of a TS on cognitive processes and performances, like also to verify the correctness of the hypothesis that the use of tracking for navigation in iVEs allows better performances, we planned an experiment in the frame of ViERforES project (www.vierfores.de) which could allow us to investigate the spatial integration of the actual and artificial information processed respectively by the balancing, proprioceptive and motor system and by the visual system.

Hypotheses

The work hypotheses where basically that the use of a TS would:

a) Allow the subject to have a better performance at the cognitive task “3D Maps”, since it allows a more natural way of interaction in such a huge VS.

b) Significantly reduce the problem related to SS symptoms, because the fact of partially moving with the body could have somehow reduced the proprioceptive mismatch with the observed movement and optic flow.

If these ideas were correct, then we expected the following results:

> a) Less errors and shorter execution times in the “Tracking” condition, both for experts and for novices.
>
> b) Significantly reduced SS symptoms in the “Tracking” condition.

Methodology

Subjects: 20 subjects (10 males, 10 females) were randomly assigned to 2 different groups: “No Tracking” and “Tracking” groups. Each of the two groups was composed of 10 people (5 males and 5 females). The first group completed the 3D maps in the ED moving by means of a normal interaction device (a joypad), while the other group used the joypad plus the Tracking System described, together with the ED, in the paragraph 3.3 of the previous chapter. The task (VR-3D Maps) is the same as discussed in the previous experiment, but this time as the subject was shown the rout that he/she took right after the performance (see Fig. XXX), he/she was also asked from the experimenter: “*did you plan this in the beginning?*” The answers to this question produced the variable “askplan”.

Tests: VR-3D maps (10 test maps + 2 familiarization maps); Corsi span test (Corsi, 1972); Mini Mental Status Evaluation (MMSE, Folstein et al., 1975; German, English and Italian versions); Trail Making Test (Spinnler & Tognoni, 1987); Edinburgh's test for manual lateralization (Oldfield, 1971) and a short version of 12 items from the Raven's progressive Matrices (as suggested in Mondini et al., 2003).

Statistical analysis: in order to produce the "route length" variable, the same changes have been performed on the collected data, as discussed in the previous experiment, also on this dataset. In order to have a measure of the average behavior of the subjects about following or not their own plans, average MANOVAs have been performed on the dependent variables "Planning Time", "Execution Time", "Route Length", "Errors" and "Simulator Sickness Symptoms" (SS Symptoms), upon the between subjects variables of SEX, TRACKING and PLAN. For the post-hoc analysis and main effects comparisons, a Bonferroni correction method was used.

Results and discussion

In the following Figures, variables with ** are significant with p<0,05, while variables signed with a single * have an high eta squared values (higher than 0,20) but are not significant at a p level. Variables with no signs are not significant at any level. As it is possible to see in the Fig. 56, the results of this experiment show a significant effect of the use of tracking in the Elbe Dom: the independent variable TRACKING (p<0.05 (F(1,13)=5,594), part.eta-sq: ,757) is significant only for the variables related to times and the SS Symptoms, while the others show only a tendency, which is though not significant. In particular, the significant results show that in both planning and execution time the condition with tracking requires longer times. Additional steps, which make the route longer, do not seem to differ too much, and, surprisingly, more errors seem to be committed in the tracking than in the no tracking condition.

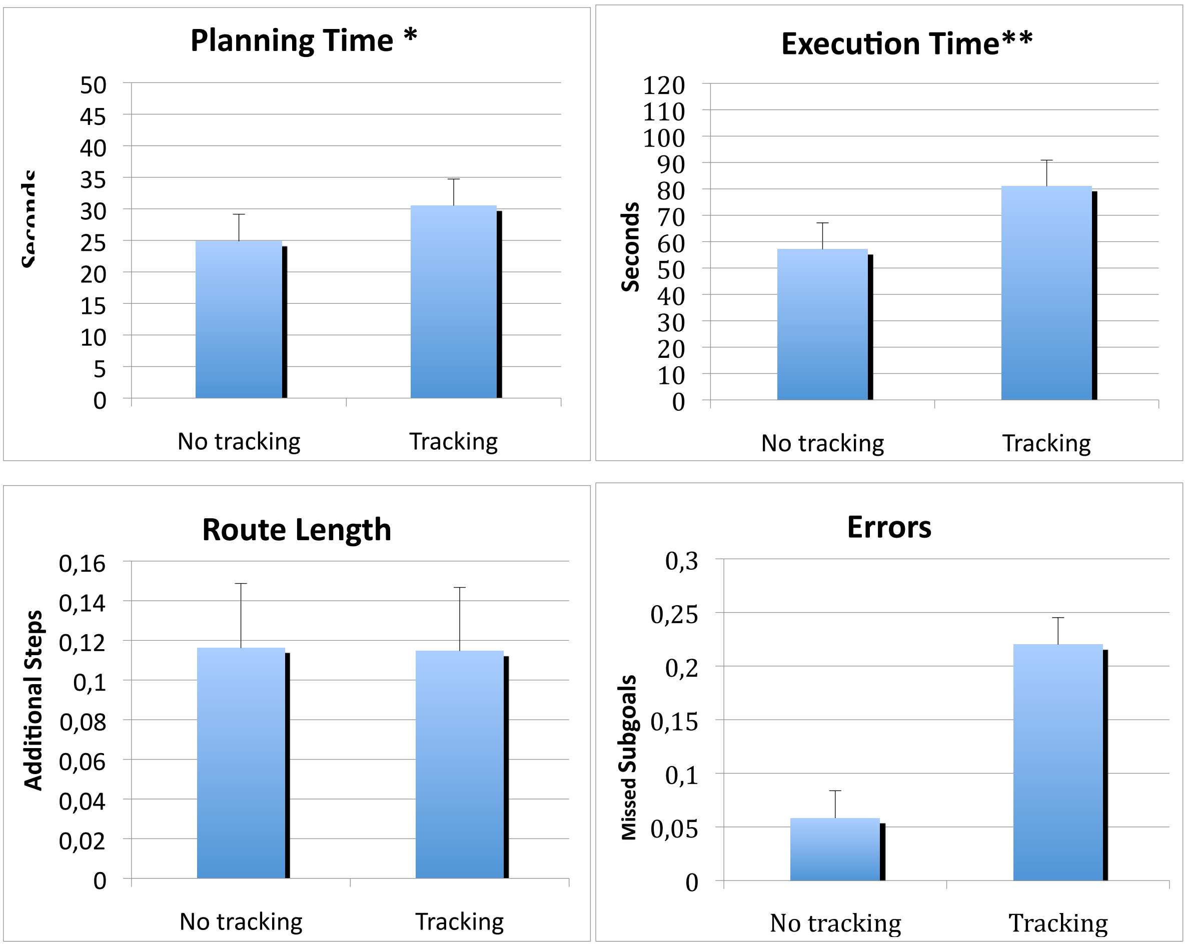

Fig. 56: Significant effects of tracking on the performance in the "3D Maps Test".

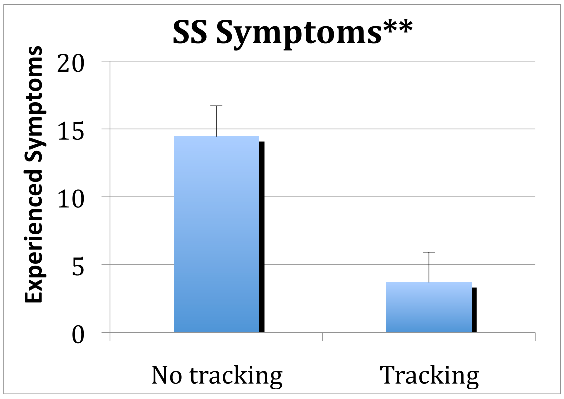

Fig. 57: Simulator Sickness Symptoms are less present in the Tracking condition.

The other significant result is that the Simulator Sickness and its symptoms are Experienced in a lower measure in the tracking condition (see Fig. 57).

This finding strongly support our second hypothesis, which states exactly that the way of interacting in the ED with a tracking system would have reduced the symptoms.

The independent variable SEX also is also significant (p<0,005 (F(1,13)=5,245), part.eta-sq: ,745), and it let us explore an interesting gender effect (see Fig. 58): women take more time to form a plan, have long execution times, perform longer routes but make fewer errors than men. This last finding somehow confirm the findings of the past experiments with the "3D Maps" test in general and the results of the experiment 4 with the "VR-3D Maps"

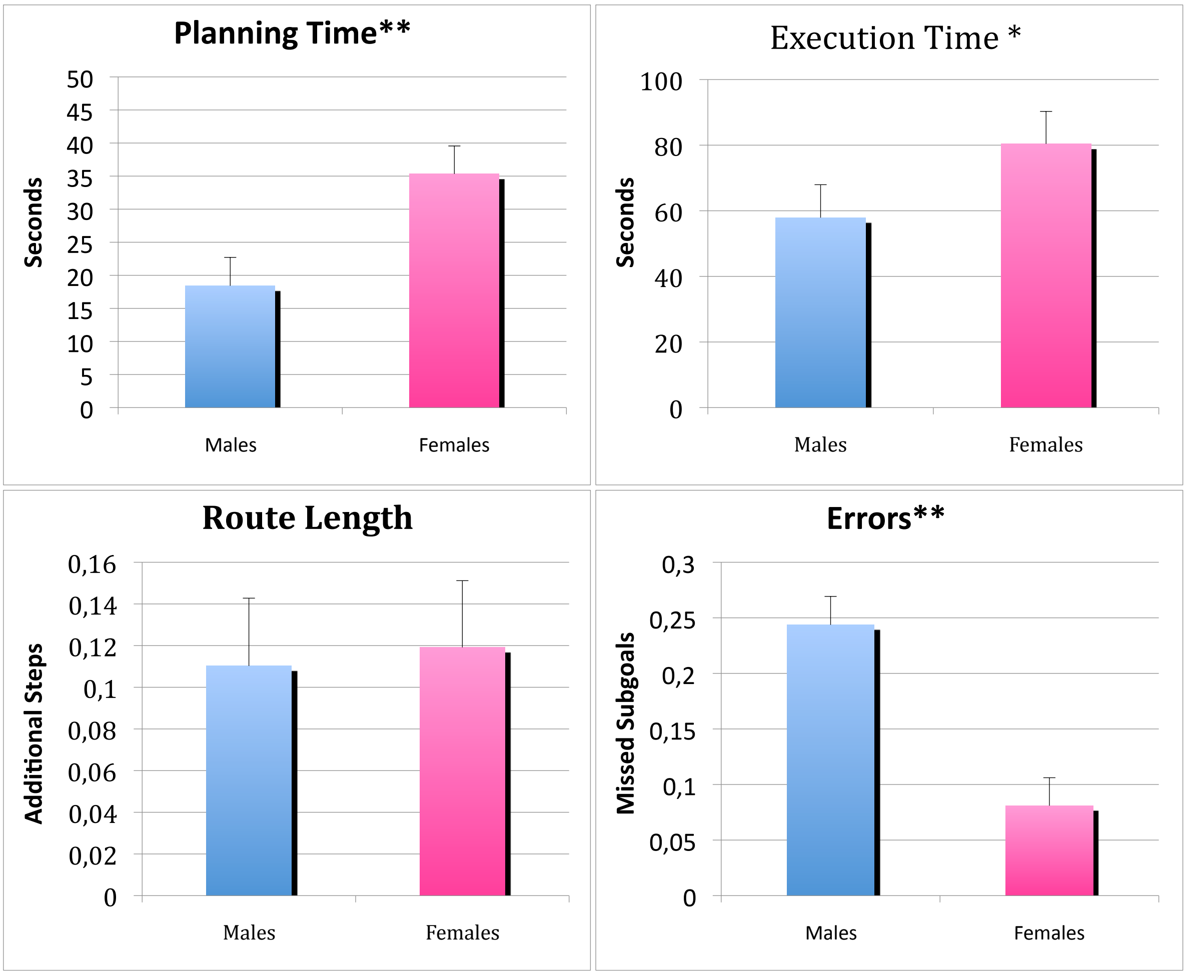

Fig. 58: Significant effects of sex on the performance in the “3D Maps Test”.

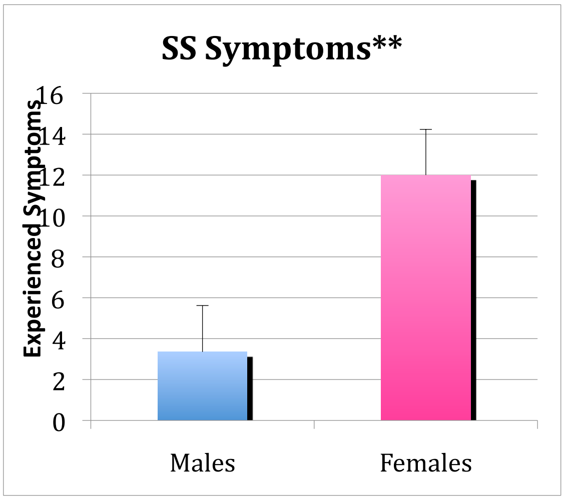

Fig. 59: Females are more affected from Simulator Sickness Symptoms than men.

Importantly, as we can see from our results on the last variable, women are more affected from SS Symptoms (see Fig. 59). In fact, as already found in the previous experiment 4 (see paragraph 2.4.2), women seem to be more sensitive to SS symptoms, as the fact that 6 females subjects had to be excluded from the analysis because they couldn’t finish the task, experiencing really bad physical and mental conditions.

These results are better understandable if we consider also another variable: the fact if subjects managed or not to follow the initial plan. To evaluate the effect of this other variable, we performed a split-file of the total number of subjects in 2 groups (no tracking, tracking) and each of them in other 2 groups (non experts, experts), and on this new set of data we performed a MANOVA for dependent variables Time, Execution Time, Route

Length and errors on the between subjects variable PLAN. The results, showed in the Fig. 60 on the significant variable PLAN (p<0,001 (F(1,13)=13,332), part.eta-sq: ,881), show that generally, when the subjects did not follow the plan, almost all the performances got slightly bad, and this becomes more evident in the tracking condition. Experts make generally more mistakes than the novices, and take longer times to perform the tasks. In particular, the experts take longer in planning and executing the task in the tracking condition when they follow the initial plan, while are slightly better in the no tracking condition. Instead, they are doing the shortest routes in the tracking condition when they follow the plan with respect to novices and the experts in with normal interaction device.

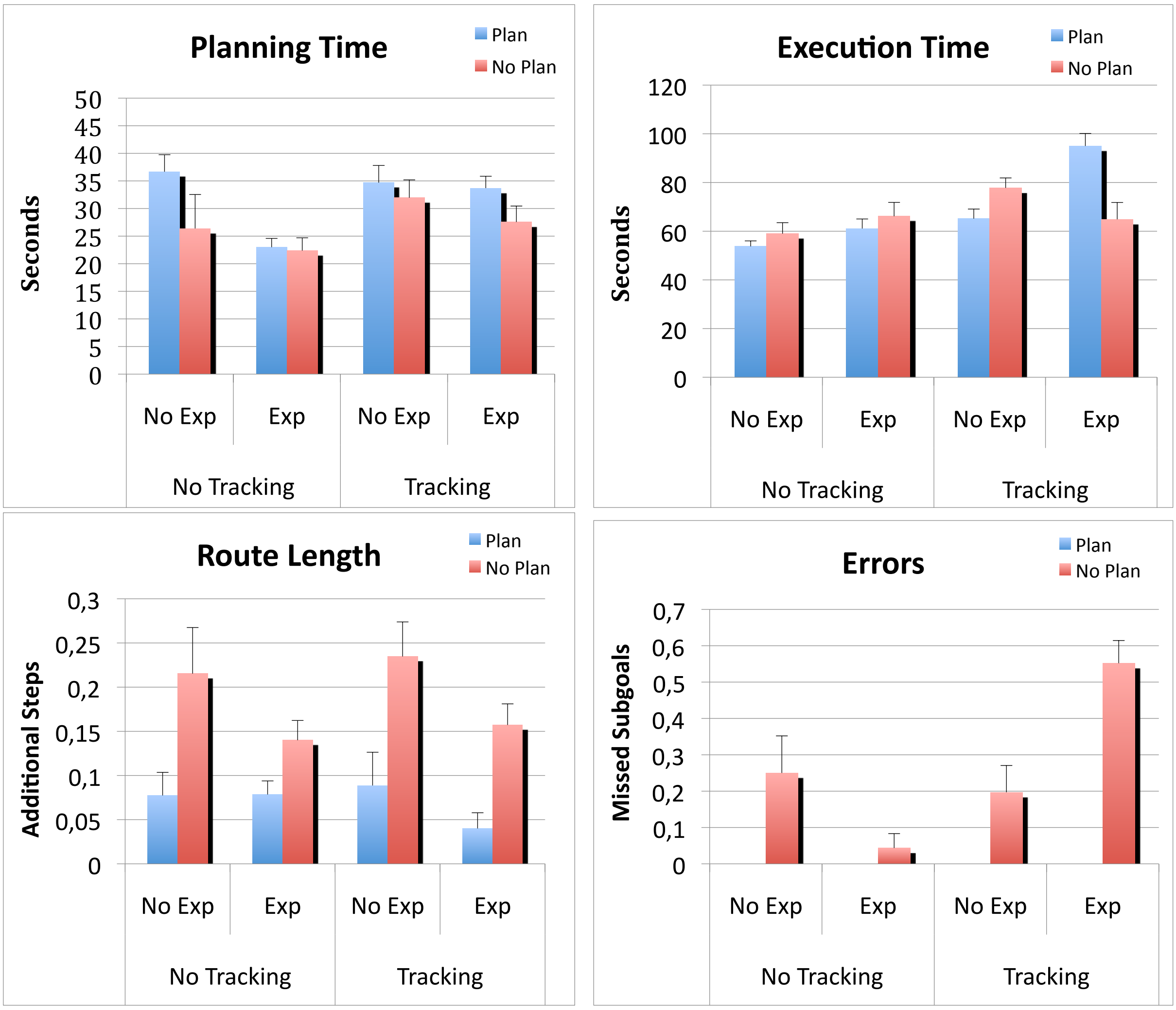

Fig. 60: The interaction between expertise ("No Exp": novices to videogames; "Exp":) and interaction modality with the performance of subjects when they followed the plan and when they did not.

Basically, the bad performances in the "Tracking" condition are due to a lack of a successful plan (or the inability to follow it). As it is possible to notice, the experts make more errors than the novices when they navigate with the tracking device. This could happen because the experts, who are used to the normal joypad, could find it a bit more difficult to navigate with a tracking system, and probably they just need a bit longer time of familiarization and training with the new device. With this way of controlling the environment, in fact, they tend to forget the plan more easily and therefore they forget more balls. In fact, the experts' impairment in the performances could come from the fact that the way of interacting with a TS looks more "natural" for the novices, but not for the expert players, who are instead used to a normal joystick and probably they need more time to familiarize with the functioning of this new device, and a little bit of training. Our findings disprove our first hypothesis, but allow us to consider some important factors, as the experience of the users and other cognitive factors (like the planning and spatial abilities) as relevant for this kind of task and interaction in such a VS.

Anyway, in the "Tracking" condition less Simulator Sickness symptoms are present (see Fig. 57), supporting the idea that interacting in a VE by means of a TS joined with a joypad helps reducing SS symptoms.

Finally, a careful analysis of all the questions of our Simulator Sickness Questionnaire allowed us to know which are the most common symptoms experienced by the subjects. As it is possible to see in the Fig. 61, the most experienced symptoms were a general difficulty in concentrating on the task, a general discomfort and dizziness, especially with closed eyes.

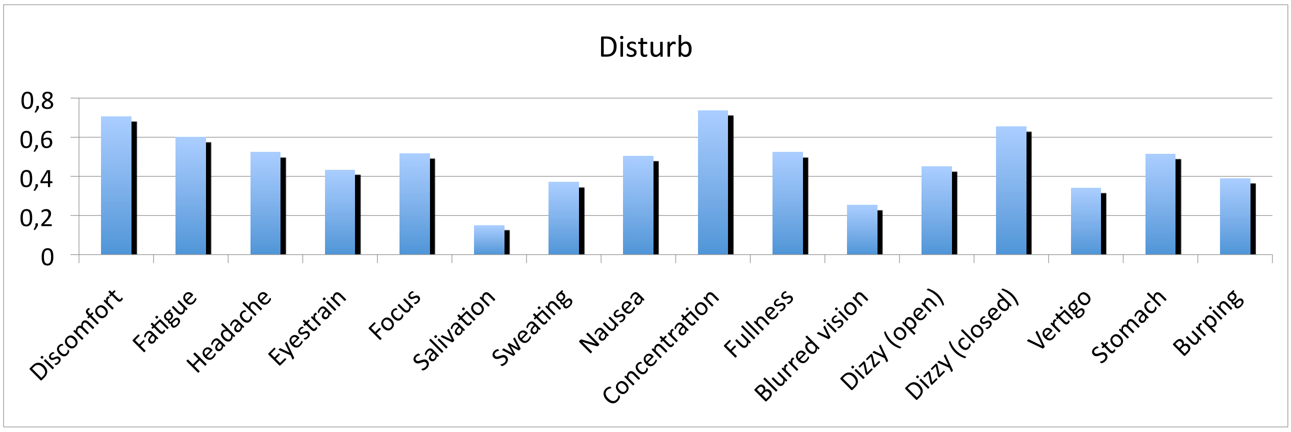

Fig. 61: all the Simulator Sickness disturbs.

Conclusions

We can therefore draw two main conclusions: 1) the idea that a Tracking System could be more easily understood by everyone and allows better performances even in a complex task was not reflected in the results. 2) With a deeper analysis of the data, we can nevertheless claim that using Tracking could be a good way of limiting the Simulator

Sickness problems and a very good way to navigate in simple environments, but not for performing complex tasks, like the one used in this experiment. To avoid this kind of problems, a small time for training on how to use the interaction device is necessary to make the tool effectively work, even for experts, actually mainly for them, as it is possible that they got used from playing videogames to interact with the normal joypad and they need more time than novices to get used to the new features offered by the Tracking System. Finally, since it looks that women are mostly affected by SS symptoms, it could be necessary a first “testing phase” in which a scenario is presented, with slow optic flow and simple textures for 1 minute of passive view and 2 minutes of active navigation (either with or without tracking) in order to register SS symptoms and evaluate if they are in the threshold range. If they are, it can be possible to complete some tasks in the VE, otherwise it would be preferable not to expose the person to such a potentially disturbing situation.

The possibility to use the Tracking allowed the subjects to actually turn left or right in order to turn left or right while navigating in the scenario. This is a good way of reducing Simulator Sickness symptoms and increasing the “natural” feeling of navigating in an environment. But there is still space for improvement of this paradigm: in the Max Planck Institute of Tübingen, for example, they have a 360° mobile tapis roulant, so that the subject can actually walk in the observed VE (usually, they use a HMD to visualize the scenarios), spontaneously deciding the speed and the direction of walking. This would completely remove the mismatch between the information that is processed either by the proprioceptive and the visual system, allowing the subject to really feel part of the VE and have the possibility to perform actions in it with his/her own body, experiencing few SS symptoms (maybe some could persist, caused just by the simulated optic flow in the scenario).

3. Conclusions, outcomes and further work

As a conclusion to the whole project, I will sum up the obtained results adding some personal remarks, and finally propose a series of improvements and suggested directions of research on VR and with VR.

After obtaining the preliminary results on the different Visualization Systems, I found two things, which drove the set-up of my successive experiments: the first was a sort of “impairment” of the performance with the VS allowing stereoscopy (especially in the CAVE, result that cannot be due to a different level of immersiveness, since also the ED is immersive, but performances in this VS actually showed the best results with respect to the others); the second was that asking the subjects to give metric estimates of the relative distances of 7 cubes on an apparently unlimited grey plane is not the best way to investigate the perception of depth in VEs. From these observations, I planned experiment 1 and started to think about how to solve the problem to produce metric estimates about distances without giving feedbacks to the subjects (which, as some authors proved, allow a highly better performance after a training; Richardson & Waller, 2005 and 2007; but here I was not interested in evaluating learning, on the contrary I wanted to investigate the basic and naïve depth perception in VEs).

With the first experiment, performed to verify if stereoscopy actually helps the evaluation of distances in VEs, I confirmed the preliminary finding that in presence of stereoscopy, more mistakes in distances estimates are made. An interesting outcomes of the results is that in particular this is true for women, who are notoriously slightly worse than men in metric judgments of distances tasks.

Hypotheses about the possible “unnaturality” of the “trick” of stereoscopy are proposed, together with the possibility of a loss of quality of the images when doubled, or in general the insufficiency of this mean to represent depth in VEs. Anyway, since some authors claim that stereoscopy allows more efficient trainings, I planned to investigate if these problems are taking place only when the subjects are forced to give a metric answer, while changing the kind of answers (including nonmetric evaluations of distances, for example) they would have taken advantage of the presence of stereoscopy, building the basis of experiment 3.

A new finding of this experiment, due to the introduction in the paradigm of a “cognitive style” test (discriminating subjects with binary spontaneous rhythm from the ones which have a spontaneous ternary one; see Olivetti Belardinelli, 1974), was also that ternary subjects, who were expected to commit less errors, actually had the worst performances, in particular in the evaluation of egocentric distances. I proposed a possible explanation for this finding considering that, being these subjects more sensible to the “structure” of the stimuli (and not to the “signal” presented on the screen, like the binaries are supposed to be: see Olivetti Belardinelli, 1994, 1978 and 1993), the fact that their actual position was not exactly the same observed on the screen, parallel to their frontal plane, produced a bigger mismatch in the case of the egocentric distances. If this explanation were true, then a direct comparison between their performances in a VE and in a RE would have showed less mistakes in the egocentric estimates in the RE.

In order to clarify this, and also to perform a direct confrontation of performances on distances evaluation in Virtual and Real Environments, I performed a second experiment, reducing the scenarios to an “inside” one without stereoscopy (since it looked to impair the performances more than help them) and comparing the answers given in the VE to the ones given about real objects in a real room (my office). Findings in this experiment 2, besides the obvious result that subjects perform a lot more underestimations in VEs than in REs, were that women underestimate more than men, making in general also more mistakes than men and that subjects with spontaneous ternary rhythm show better performances in egocentric distances in RE with respect to VE and make in general less mistakes than binaries, who very often underestimate more than ternaries, especially women. This confirmed the previous hypotheses and moreover I could notice that spontaneous rhythm styles are also related to the gender of the subjects: the group of subjects who has better performances (=less errors) is the ternary group. But this is true only for men: ternary women show the worst performances. Instead, in the binary group, the women do fewer errors, even fewer than men. I propose to explain this difference with the knowledge that in general women use more global cues (and therefore, based on the stimuli itself) in spatial cognition, while men are more analytic and pay attention to the structure of a visual scene. When women are ternaries, they find obstacles in using an unsupported processing modality, and fail more than binary women in using this. On the contrary, binary men probably tend to be faster but less precise in their answers, and only the ternaries manage to be accurate, because they follow their innate tendency to respond to the structure of the stimuli more than to the signal.

The observation that, although also in REs people make mistakes in giving numeric measures about objects’ relationships, but they are still able to move in a space and build a mental representation of it, gave the input to the third experiment, in which I implemented all the previous ideas and produced a parallel questionnaire with nonmetric judgments to join the metric questionnaire.

With this last experiment I could finally observe that stereoscopy actually provided some help in the understanding of depth in VEs, but this benefit is visible only in nonmetric evaluation of distances. In this experiment females still have slightly worse performances than men, but an interesting finding shows that females in general perform worse with stereoscopy, while men perform better (in general, either with and without stereoscopy). Interestingly, I did not find any significant difference between egocentric and allocentric estimates if considered alone, but in conjunction with stereoscopy, I could notice that in the nonmetric modality more correct egocentric answers were given.

I consider the lack of a possibility to explore the environment more or less freely a strong limit of these experiments. In fact, as I pointed out also in chapter 1, Burdea & Coiffet's definition of VR includes all the 3 "I"s, and "interaction" is still very important (as mentioned also in the same chapter) for a compelling "sense of presence", which probably would reduce the lack of geometric information (or the eventual bad quality of stereoscopy) and allow the subjects to form a better mental representation of the viewed scenario. Even though the subjects had the possibility to rotate the view as if they were moving the head, link in real environments, they could not previously "visit" the environment, so they could appreciate the objects only from this point, and this reduce a lot their way of "interacting" with the scenario, knowing how the objects look like when they are close, pass through them and so on.

An improvement for the future would surely be the creation of an interactive scenario where the subjects will be able not only to explore in a "familiarization period" but also to grab and place objects, in order to answer to nonmetric questions performing actions, for example "put the glass exactly in the middle between the plate and the bottle". This would make the experiment even more "ecologic" and would move the virtual experience closer to the one that people have in their everyday life.

An interesting experiment to perform would be the evaluation of learning curves for learning in VEs. That is, adding a feedback after the subject's answers till they reach a learning threshold and then performing another questionnaire in a similar environment to evaluate how much of the "inner metric system" of the VE has been learned and assimilated by the subjects (we know from literature that this works with "naïve" subjects; see for example Richardson & Waller, 2007). Also performing more experiments using as "evaluates" nonmetric measures (for example, time-to-walk, or "how many steps", or “walk to” paradigms) in non-immersive VEs (with and without stereoscopy) would be interesting to keep on improving our knowledge about how spatial mental representation of VEs takes place in the human cognitive system.

Another issue that I was interested to evaluate was, related to this, the issue of navigation in immersive VEs (iVEs). I performed two experiments: 1) Experiment 4, aimed to verify the actual benefits of the use of a 360° projection system (the Elbe Dom in Magdeburg, Germany) for the evaluation of navigational tasks in spatial cognition in comparison with a normal desktop-VR (the same task presented on a PC screen) and 2) Experiment 5, complementary to the first, with the intention to find a solution to the well-known problem of Simulator Sickness (SS).

Both the experiments gave interesting results: first of all, the assumed benefit of a 360° screen for the presentation of virtual scenarios in navigation tasks was evident comparing the performances obtained with the PC and in the ED. Second, even if in the ED a pretty high rate of SS was present (6 people out of 20 had to stop the experiment, because reported to feel really bad), the interesting finding is that, of these 6 subjects, all of them were female. Results show that also comparing the presence of SS symptoms in people who did not report to feel sick, the highest rate of symptoms was also for the females. A good way to reduce the symptoms seems to be the use of tracking as a modality for interacting inside the ED, more than a typical joystick, because it allows the subjects to reduce a bit the mismatch between proprioceptive information and visual perception of the optic flow, recognized to be the main cause of SS. Although the tracking helps in reducing SS symptoms, the performance within this interacting condition is significantly worse than the one with the normal joypad, and surprisingly the experts in the use of videogames make more mistakes than novices.

I conclude that a familiarization period is needed, mostly for women, which in particular should be more carefully screened with respect to the experienced symptoms before and after the familiarization period, before allowing them to spend a longer time in the ED. For what regards tracking, as I found that the most impaired with this interaction device were the experts, I suggested also a familiarization period before starting the interaction in the ED, especially for experts, since their experience with joypads of normal videogames may interfere with their performance in the task, being concentrated in the adaptation process for the use of the “new” way of interacting.

An interesting outcome of the first experiment (experiment 4), according to me, is that not only the performances in the ED were clearly better than ones in the PC, but also the use of strategies and heuristics seem to be quite different, indicating a more “ecologic” way of solving the task. If this represent a good point for the use of the ED, there is also an important consequence to this finding: whenever scholars and researchers perform this kind of task (requiring the use of strategies and heuristic for the solution of the task) on a desktop-VR, they must be aware that the results could not be entirely due to a different cognitive process, but simply biased by a small FOV screen and the almost absence of “immersivity”. Therefore, the lack of flexibility in the use of heuristics and in the application of strategies that could be found in specific studies using VEs presented on normal PC screens could be due more to the Visualization System where the 3D scenario is presented than to the subjects’ cognitive processes themselves.

Summing up, I think that VR is an extremely interesting and useful technology, which though is not developed enough to offer the particular performances needed by researchers interested in the evaluation of cognitive processes. It has been proved to be an effective tool in most of the studies on trainings, and even in rehabilitation, but I think that when it comes to research on low-level processes, like for example visual perception, attention, and so on, the quality of the images, the rendering, the frame-rate refresh and the use of the stereoscopy should be discussed extensively and carefully before deciding to perform a life-like experiment in virtual reality. To a certain extent, would be better to keep these basic experiments limited to cognitive psychology labs.

Instead, I think that higher-level cognitive processes can be successfully investigated in VEs by means of VR technologies, because the artificial scenarios offer the incredible opportunity to “simulate” situations which are compelling enough to evoke cognitive processes similar to the one that one could observe in everyday life, and do not necessary require a precise and metric knowledge of the environment, that can anyway be easily learned through interaction and numerous feedbacks with the scenario and the VS.

Anyway, the possibility to make mistakes or to perform actions without dangerous consequences, is at the same time an advance (in the case of trainings or rehabilitation), but in case we would like to evaluate, for example, the levels of panic of a certain range of people in case of emergency (with ECG registration, psicogalvanic conductance and so on), even if our virtual simulation is well done, we would never be able to observe anything similar to reality right because the subject knows that this is not real and he/she will not really risk his/her life, even in case of a wrong choice or inability to complete a task, and by the way the quality of most of the actual virtual experiences is not yet so pervasive and immersive to be multisensorially compelling. Therefore I think that there is the necessity to clearly define in which cases the use of VR is suggested and in which cases it is not appropriate.

First of all, I guess that it is true, like some authors pointed out (for example, Elneel et al., 2008; Mühlberger et al., 2007), that Virtual and Real Environments are different. Virtual Reality allows us to get in contact with something new, that is not the Reality, and not even a copy of the reality. Maybe an attempt to copy the reality, but it is not. We can take advantage of the similarities, and perform experiment "as if" were performed in natural environments, but we should be aware of the differences, as some authors warn and the results of the present work show. As a new methodology, it is clear that there is still lot of space for improvement, but the most of the efforts should be done to understand how the human perceives the VR, and keep on showing which (and to which extent) are the differences between cognitive processes in Real and Virtual Environments, more than supporting the similarities: only in this way it will be possible to draw a list of cases in which it is not advised to "substitute" experiments in the real life with the "alternate" scenarios in VR. It is important to know that perception of depth and space in VR, for example, does not work like in the real world. It is even more important to realize that giving a feedback the subject will "adapt" to the "new environment" and "learn" the metric basics to perform more correct estimates in VEs. Like in the real world, the dynamic "organism" system (that is, the perceiver) builds a representation of the external world ("environment" system) in its mind and extrapolates rules, schemes and laws of functioning by exchanging information with it in a dynamical super-system "organism-environment"": in the new "virtual environment" system, the new, complex, system will work the same way, adapting and adjusting the perceptual inputs and outputs to the new "reality". Technically, in fact, the VR is still a reality, because it exists: is what it is trying to suggest that exists *in a different form* with respect to the one that we are used to perceive in the natural world. That is why it is called "virtual".

Another remark is that, for applicative purposes, VR seems to be really effective. Trainings, learning, social communication and even rehabilitation are most of the times successful. I strongly believe that the "therapeutic game" (Gamito et al., 2011), or "serious games", has have been defined (Micheal & Cohen, 2006), have strong potentials for learning and education, but also for rehabilitation and cognitive abilities training. This, joined with the incredible possibilities of VR, sets the basic platform for alternative worlds where the main purpose is not (or not only) the pure entertainment, but they are thought to improve cognitive skills, or to rehabilitate some functions, or, again, to teach to young students (included the ones with learning disabilities), to boost the communicational capabilities of deaf or mute children, to improve socialization and wellness of disabled people and so on.

On the cognitive side, there is already work showing that playing videogames can improve some cognitive abilities, such spatial attention, spatial cognition, visuospatial planning and so on (Spence & Feng, 2010), and even reducing gender differences in spatial cogntion (Feng et al., 2007). A challenge for VR industry Is to improve the quality and realistic effects of images, as also the multisensorial feedback.

I do not have any doubt that, although someone claims that “Virtual Reality is dead” (like some users on the net[2], for example), or at least did not keep its promises, this technology will soon be something “normal”, exactly like the Personal Computer are now in every house and already 3D screens are being developed to improve visual performance in combination with home theaters that are able to produce multisource and 3D-stereo sounds. Probably in the next future nobody will play with joysticks in front of a screen anymore, but will physically “enter” into the game-world displayed all around the walls with cameras capturing and reproducing his movements inside the game, or will sit in a room and interact with holographic images of people on the other part of the planet in real time.

Concluding, VR is a seriously interesting technology that creates a “new world”, somewhat different from the “real world”, which has the potential to improve many fields of our culture, society and lives, and most of all has the double power to allow advances in research on how the brain works and to take advantage of the knowledge already obtained on cognition and neuronal functionality, to boost its own applications and become a perfectly functional Human-Computer or Human-Machine Interface.

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[2] The cited user’s blog can be found online at the URL: http://www.doolwind.com/blog/where-is-virtual-reality

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References:

Aggarwal, R., Grantcharov, T.P., Eriksen, J.R., Blirup, D., Kristiansen, V.B., Funch-Jensen & P., Darzi A., (2006). An evidence-based virtual reality training program for novice laparoscopic surgeons. Ann Surg. 2006;244:310-314.

Albert, W. S., Rensink, R. A., & Beusmans, J. M. (1999). Learning relative directions between landmarks in a desktop virtual environment. *Spatial Cognition and Computation*, *1*(2), 131–144. Springer.

Albert, W.S., Reinitz, M.T., Beusmans, J.B. and Gopal, S. (1999). The Role of Attention in Spatial Learning During Simulated Navigation, Environment and Planning A 31: 1459-1472.

Amthauer, R. (1953). Intelligenz-Struktur-Test (I-S-T). Hogrefe, Göttingen.

Amthauer, R. (1970). Intelligenz-Struktur-Test (I-S-T 70). Hogrefe, Göttingen.

Andrews, T.K., Rose F.D., Leadbetter A.G., Attree E.A. & Painter J., (1995). The use of virtual reality in the assessment of cognitive ability. In: Placencia Porrero I, Puig de la Bellacasa R, eds., The European Context for Assistive Technology: Proceedings of the 2nd TIDE Congress. Amsterdam: IOS Press.

Apfelbaum, H., Pelah, A. & Peli, E., (2007). Heading assessment by "tunnel vision" patients and control subjects standing or walking in a virtual reality environment. ACM Transactions on Applied Perception. 4(1): Article 8.

Apfelbaum, H., Pelah, A., & Peli, E. (2006). Heading assessment by “tunnel vision” patients and control subjects standing or walking in a virtual reality environment, *4*(1), 1-20.

Argyle, M. & Dean, J., (1965). Eye-contact, distance and affiliation. Sociometry 28, 3, 289,Äì304.

Armbrüster, C., Heber, I., Valvoda, J.T., Kuhlen, T., Fimm, B. & Spijkers, W., (2005). Distance estimations in a VR application: interindividual differences and interindividual stabilities from a psychological point of view. Proceedings of the HCII , 2005.

Armbrüster, C., Wolter, M., Kuhlen, T., Spijkers, W. & Fimm, B., (2008). Depth perception in virtual reality: Distance estimations in peri- and extrapersonal space. CyberPsychology & Behavior, Vol 11(1), Feb 2008. pp. 9-15.

Arthur K., Booth K.S. & Ware C., (1993). Evaluating human performance for Fishtank Virtual Reality. ACM Transactions on Information Systems 1993, 11:239-265.

Astur, R. S., St Germain, S. a, Baker, E. K., Calhoun, V., Pearlson, G. D., & Constable, R. T. (2005). fMRI hippocampal activity during a virtual radial arm maze. *Applied psychophysiology and biofeedback*, *30*(3), 307-17. doi: 10.1007/s10484-005-6385-z.

Attree, E.A., Brooks, B.M., Rose, F.D., Andrews, T.K., Leadbetter, A.G.. & Clifford, B.R., (1996). Memory processes and virtual environments: I can,Äôt remember what was there, but I can remember how I got there. Implications for people with disabilities. In: Sharkey P, ed., Proceedings of the First European Conference on Disability, Virtual Reality and Associated Technology. Maidenhead, UK: University of Reading, pp. 117-121.

Baños, R.M., Botella, C., Alca√±iz, M. & Lia√±o, V., (2004). Immersion and emotion: their impact on the sense of presence. CyberPsychology & Behavior 2004; 7:734-741.

Baños, R.M., Botella, C., Rubio, I., Quero, S., Garcia-Palacios, A. & Alcaniz, M., (2008). Presence and Emotions in Virtual Environments: The Influence of Stereoscopy CyberPsychology & Behavior. February 1, 2008, 11(1): 1-8.

Baños, R.M., Lia√±o, V., Botella, C., Alca√±iz, M., Guerrero, B. & Rey, B., (2006). Changing induced moods via virtual reality. In: IJsselsteijn WA, de Kort Y, Midden C, Eggen B, van den Hoven E, eds., Persuasive technology: lecture notes in computer science. Berlin/Heilderberg: Springer-Verlag.

Baheux, K., Yoshizawa, M., & Yoshida, Y. (2007). Simulating hemispatial neglect with virtual reality. *Journal of neuroengineering and rehabilitation*, *4*, 27. doi: 10.1186/1743-0003-4-27.

Basso, D., Bisiacchi, P. S., Cotelli, M., & Farinello, C. (2001). Planning times during Travelling Salesman,Äôs problem: Differences between closed head injury and normal subjects. Brain and Cognition, 46, 38-42.

Basso, D., Saracini, C., Lotze, M., Olivetti-Belardinelli, M., & Birbaumer, N. (2005). Repetitive TMS stimulation on virtual 3D navigation: Gender differences in frontal and parietal involvement. In: B. Hommel, G. P. H. Band, W. La Heij, & G. Wolters (a cura di), Proceedings of the XIV meeting of the ESCOP. (p. 97).

Baumann, S., Neff, C., Fetzick, S., Stangl, G., Basler, L., Vereneck, R. & Schneider, W., (2003). A virtual reality system for neurobehavioral and functional MRI studies. CyberPsychology & Behavior 6:259-266.

Beatriz Rey and Mariano AlcaÒiz (2010). Research in Neuroscience and Virtual Reality, Virtual Reality, Jae-Jin Kim (Ed.), ISBN: 978-953-307-518-1, InTech. (URL: http://www.intechopen.com/articles/show/title/research-in-neuroscience-and-virtual-reality).

Biocca F, Delaney B. (1995) Immersive virtual reality technology. In: Biocca F, Levy MR, eds., Communication in the age of virtual reality. Hillsdale, NJ: Erlbaum.

Bischof, W.R. & Boulanger, P., (2003). Spatial navigation in virtual reality environments: An EEG analysis. CyberPsychology & Behavior, Vol 6(5), Oct 2003. pp. 487-495.

Bliss, J.P., Tidwell, P.D., & Guest, M.A. (1997). The effectiveness of virtual reality for administering spatial navigation training to firefighters. Presence: Teleoperators and Virtual Environments 6:73-86.

Bosco, A., Picucci, L., Caffò, A. O., Lancioni, G. E., & Gyselinck, V. (2008). Assessing human reorientation ability inside virtual reality environments: the effects of retention interval and landmark characteristics. *Cognitive processing*, *9*(4), 299-309. doi: 10.1007/s10339-008-0210-6.

Botella, C., Ba√±os, R.M., Perpi√±a, C., et al. (1998). Virtual reality treatment of claustrophobia: a case report. Behaviour Research & Therapy 36:239-246.

Broeren, J., Sunnerhagen, K. S., & Rydmark, M. (2007). A kinematic analysis of a haptic handheld stylus in a virtual environment: a study in healthy subjects. *Journal of neuroengineering and rehabilitation*, *4*, 13. doi: 10.1186/1743-0003-4-13.

Brooks, B.M., Attree, E.A., Rose, F.D., et al. (1999). The specificity of memory enhancement during interaction with a virtual environment. Memory 7: 65-78.

Brooks, B.M., McNeil, J.E., Rose, F.D., et al. (1999). Route learning in a case of amnesia: a preliminary investigation into the efficacy of training in a virtual environment. Neuropsychological Rehabilitation 9:63-76.

Brooks, B.M., Rose, F.D., Potter, J., et al. (2004). Assessing stroke patients‚Äô prospective memory using virtual reality. Brain Injury 18:391-401.

Cadwallader, M. (1975). A behavioral model of consumer spatial decision making. Economic Geography, 51, 339-49.

Chaytor N, Schmitter-Edgecombe M, Burr R. Improving the ecological validity of executive functioning assessment. Archives of Clinical Neuropsychology 2006; 21:217-227.

Chen, C.J., Toh, S.C., & Wan, M.F., (2003). Virtual Reality: A Potential Technology for Providing Novel Perspective to Novice Driver Education in Malaysia. Proceedings of the International Conference on Information Technology: Research and Education, (CD-ROM), New Jersey: IEEE.

Connacher, H. I., Jayaram, S., & Lyons, K. W. (1997). Virtual assembly using virtual reality techniques. *Computer-Aided Design*, 28(8), 575-584. doi:10.1016/S0010-4485(96)00094-2.

Cooper, M., & Taylor, M.E. (1998). Ambisonic sound in virtual environments and applications for blind people. In: Sharkey, P., Rose, D., & Lindstr√∂m, J.-I. (eds.), Proceedings of the 2nd European Conference on Disability, Virtual Reality & Associated Technologies. Sk√∂vde, Sweden 113-118.

Corsi, P. H. (1972). *Human memory and the medial temporal region of the brain*. Università McGill di Montreal, Quebec, Canada. (unpublished doctoral thesis).

Creem-Regehr, S. H., Willemsen, P., Gooch, A. A., and Thompson, W. B. (2005). The influence of restricted viewing conditions on egocentric distance perception: Implications for real and virtual environments. Perception 34, 2, 191-204.

Crosbie, J.H., Lennon, S., Basford, J.R., McDonough, S.M., (2007). Virtual reality in stroke rehabilitation: still more virtual than real. Disabil Rehabil. 2007 Jul 30;29(14):1139-46.

Cruz-Neira C, Sandin Daniel J, DeFanti Thomas A, (1993). Surround screen projection-based virtual reality: the design and implementation of the CAVE. Proc-ACM-SIGGRAPH-93-Conf-Comput-Graphics Publ by ACM, New York, NY, USA 1993:135-142.

Cruz-Neira C, Sandin DJ, DeFanti TA, Kenyon RV, Hart JC, (1992). The CAVE: audio visual experience automatic virtual environment. Communications ACM 1992, 35:65-72.

Csikszentmihalyi M., (1990). Flow: The psychology of optimal experience. New York, HarperCollins; 1990.

Cutting J.E. & Vishton P.M., (1995). Perceiving layout: the integration, relative potency, and contextual use of different information about depth. In: Epstein W, Rogers S, eds. Handbook of perception and cognition: Vol. 5. Perception of space and motion. San Diego: Academic Press, pp. 69-117.

Cutting, J. E. (1997). How the eye measures Reality and Virtual Reality. *Behavior Research Methods, Instruments, & Computers*, *29*(1), 27-36.

Damasio A: The Feeling of What Happens: Body, Emotion and the Making of Consciousness. San Diego, CA, Harcourt Brace and Co, Inc.; 1999.

Darken, R.P., Allard, T. and Achille, L.B. (1998). Spatial Orientation andWayfinding in Large-Scale Virtual Spaces: An Introduction, Presence 7: 101-107.

Das, D.A., Grimmer, J.A., Sparnon, A.L., McRae, S.E. & Thomas, B.H., (2005). The efficacy of playing a virtual reality game in modulating pain for children with acute burn injuries: A randomized controlled trial. BMC Pediatr. 2005; 5: 1.

Dauster B, Steinberg AP, Vassiliou MC, et al. (2005) Validity of the MISTELS simulator for laparoscopy training in urology. J Endourol 19:541-545.

De la Rosa, S., Moraglia, G., & Schneider, B. a. (2008). The magnitude of binocular disparity modulates search time for targets defined by a conjunction of depth and colour. *Canadian journal of experimental psychology = Revue canadienne de psychologie expérimentale*, *62*(3), 150-5. doi:10.1037/1196-1961.62.3.150

Demiralp, Ç, Jackson, C.D., Karelitz, D.B., Zhang, S., Laidlaw, D.H., (2006). CAVE and Fishtank Virtual-Reality Displays: A Qualitative and Quantitative Comparison. IEEE Transactions on Visualization and Computer Graphics, vol. 12, no. 3, pp. 323-330, May/June 2006, doi:10.1109/TVCG.2006.42.

Deutsch, Judith, E., Borbely, M., Filler, J., & Huhn, K. (2011). Use of a Low-Cost, Commercially available Gaming Console (Wii) for Rehabilitation of an Adolescent with Cerebral Palsy. *Physical Therapy*, *88*(10), 1196-1207. doi: 10.1007/s12565-011-0107-9.

Dietrich, E., (2000). *Cognitive Dynamics: Conceptual and Representational Change in Humans and Machines*. Editor: Arthur B. Markman. Publisher: Lawrence Erlbaum Associates. Place of Publication: Mahwah, NJ. Publication Year: 2000. Pages: 388.

Dong, H., Pelah, A., Cameron, J., & Lasenby, J. (2008). The perceptual influences on gait transition of step parameters and optic flow in virtual environment locomotion simulators. *APGV August 9–10*.(Vol. 1, pp. 143-146). Los Angeles, California: Association for Computing Machinery, Inc.

Durgin, F. H., Pelah, A., Fox, L. F., Lewis, J., Kane, R., & Walley, K. A. (2005). Self motion perception during locomotor recalibration: More than meets the eye. Journal of Experimental Psychology: Human Perception and Performance, 31, 398–419.

Ebert, A., Deller, M., Steffen, D., Heintz, M., Gmbh, D., Visualization, C. C. H.-centered, et al. (2009). "Where Did I Put That?" – Effectiveness of Kinesthetic Memory in Immersive Virtual Environments. *Access*, 179-188.

Edmond CV, Wiet GJ, Bolger B (1998) Surgical simulation in otology. Otolaryngol Clin North Am 31:369-381.

Elkind, J.S., Rubin, E., Rosenthal, S., et al. (2001). A simulated reality scenario compared with the computerized Wisconsin Card Sorting test: an analysis of preliminary results. CyberPsychology & Behavior 4:489-496.

Emmelkamp, P.M., Krijn, M., Hulsbosch, A.M., et al. (2002). Virtual reality treatment versus exposure in vivo: a comparative evaluation in acrophobia. Behaviour Research & Therapy 40:509-516.
environment, Human Factors, 1997, 39, 526-531.

Farias ST, Harrell E, Neumann C, Houtz A. The relationship between neuropsychological performance and daily functioning in individuals with Alzheimer‚Äôs disease: ecological validity of neuropsychological tests. Archives of Clinical Neuropsychology 2003; 18:655-672.

Feng, J., Spence, I., & Pratt, J. (2007). Playing an action video game reduces gender differences in spatial cognition. Psychological Science, 18, 850–855.

Fischmeister, F. P. S., & Bauer, H. (2006). Neural correlates of monocular and binocular depth cues based on natural images: a LORETA analysis. *Vision research*, *46*(20), 3373-80. doi:10.1016/j.visres.2006.04.026

Flannery, K. a, & Walles, R. (2003). How does schema theory apply to real versus virtual memories? *Cyberpsychology & behavior : the impact of the Internet, multimedia and virtual reality on behavior and society*, *6*(2), 151-9. doi: 10.1089/109493103321640347.

Fröehlich, T. (1997). Das Virtuelle Ozeanarium, Zeitschrift Thema Forschung. Darmstadt: Technische Universitat Darmstadt, pp. 50-57.

Freeman J, Avons SE, Davidoff J, Pearson DE., (1997). Effects of stereo and motion manipulations on measured presence in stereoscopic displays. Perception 1997; 26(suppl.):42.

Fried M, Satava R (2001) Metrics for objective assessment of errors: Endoscopic Sinus Surgery Simulator (ES3). Surgical Simulation Metrics Workshop, Montefiore Hospital, NYC, December 15, 2001. From Computer-Simulated Environments. Journal of Experimental Psychology: Applied 2000, Vol. 6, No. 4, 307-321.

Gallagher, A.G., McClure, N., McGuigan, J., et al. (1999). Virtual reality training in laparoscopic surgery: a preliminary assessment of minimally invasive surgical trainer virtual reality (MIST VR). Endoscopy 31:310-313.

Gamito, P., Oliveira, J., & Morais, D. (2007). Serious Games for Serious Problems : from Ludicus to Therapeuticus. *Virtual Reality*, (1971).

Garcia-Palacios, A., Hoffman, H., Carlin, A., et al. (2002). Virtual reality in the treatment of spider phobia: a controlled study. Behavior Research and Therapy 40:983-993.

Goldberg, S. (1994). Training dismounted soldiers in a distributed interactive virtual environment. U.S. Army Research Institute Newsletter 14:9-12.

Goldberg, S. L., & Knerr, B. W. (1997). Collective training in virtual environments: Exploring performance requirements for dismounted soldier simulation. In R.J. Seidel & P.R. Chatelier (Eds.), Virtual reality, training's future? New York: Plenum Press.

Gould NF, Holmes MK, Fantie BD, Luckenbaugh DA, Pine DS, Gould TD, et al. Performance on a virtual reality spatial memory navigation task in depressed patients. American Journal of Psychiatry 2007; 164: 516-519.

Gregg, L., Tarrier, N., (2007). Virtual reality in mental health. Social Psychiatry and Psychiatric Epidemiology. 2007, Vol. 42, No. 5: 343.

Hamamé, C. M., Cosmelli, D., Henriquez, R., & Aboitiz, F. (2011). Neural Mechanisms of Human Perceptual Learning: Electrophysiological Evidence for a Two-Stage Process. (M. H. Herzog, Ed.)*PLoS ONE*, *6*(4), 1-13. doi:10.1371/journal.pone.0019221

Hayhoe, M. & Ballard, D., (2005). Eye movements in natural behavior. Trends in Cognitive Sciences 2005, April Vol.9 No.4 pp. 188-194.

He, Z. J., & Nakayama, K. (1995). Visual attention to surfaces in three-dimensional space. *Proceedings of the National Academy of Sciences of the United States of America*, *92*(24), 11155-9.

Heeter, C. (1992). Being there: The subjective experience of presence. Presence, 1(2), 262-271.

Heilig, M. (1962). Sensorama. Patent online (URL: http://www.freepatentsonline.com/3050870.html)

Henderson, A., Korner-Bitensky, N. & Levin, M., (2007). Virtual reality in stroke rehabilitation: a systematic review of its effectiveness for upper limb motor recovery. Top Stroke Rehabil. 2007 Mar-Apr;14(2):52-61.

Hendrix C, Barfield W., (1996). Presence within virtual environments as a function of visual display parameters. Presence: Teleoperators & Virtual Environments 1996;5:274-289.

Henry, D., & Furness, T. (1993). Spatial perception in virtual environ- ments: Evaluating an architectural application. In IEEE Virtual Reality Annual International Symposium, Seattle (pp. 33–40). New York: IEEE.

Hodges, L.F., Rothbaum, B.O., Kooper, R., et al. (1995). Virtual environments for treating the fear of heights. IEEE Computer 28:27-34.

Hue, P., Delannay, B., & Berland, J.-C. (1997). Virtual reality training simulator for long time flight. In: Seidel, R.J., & Chantelier, P.R. (eds.), Virtual reality, training,Äôs future? New York: Plenum Press, pp. 69-76.

Hunt, E., & Waller, D. (1999). Navigation and wayfinding: A review. (ONR technical report N00014-96-0380). Arlington, VA: Office of Naval Research.

Iachini, T., & Ruggiero, G. (2006). Egocentric and allocentric spatial frames of reference: a direct measure. *Cognitive Processing*, *7*(S1), 126-127. doi:10.1007/s10339-006-0100-8.

Iachini, T., Ruggiero, G., Ruotolo, F., Pizza, R. (2008). Age and gender differences in some components of spatial cognition. Cap. 16, in H. T. Benninghouse et al. (Eds), Women and Aging: New Research. Nova Science Publishers: NY.

IJsselsteijn WA, de Ridder H, Freeman J, Avons SE. (2000) Presence: concept, determinants and measurement. Proceedings of the SPIE 3959, 520-529.

Interrante, V., Anderson, L., & Ries, B. (2006). Distance perception in immersive virtual environments, revisited. In IEEE Virtual Reality 2006 (pp. 3–10). New York: IEEE.

Jacob, T. (2002). Bionic Man. *EMBO Reports*, *3*(9), 821-821. doi: 10.1093/embo-reports/kvf183.

Jacobson J, Redfern MS, Furman JF, Whitney SL, Sparto PJ, Wilson JB, Hodges LF, (2001). Balance NAVE: a virtual reality facility for research and rehabilitation of balance disorders. In In: Proceedings of the ACM symposium on virtual reality software and technology: 2001; Banff, Alberta, Canada ACM Press; 2001:103-109.

John, N.W, (2002). Using stereoscopy for medical virtual reality. Stud Health Technol Inform 2002;85:214–220.

Johnson-Laird, P.N. (1983). Mental Models: Towards a Cognitive Science of Language, Inference, and Consciousness. Cambridge: Cambridge University Press.

Kahana, M. J., Sekuler, R., Caplan, J. B., Kirschen, M., & Madsen, J. R. (1999). Human theta oscillations exhibit task dependence during virtual maze navigation. Nature, 399, 781-784.

Keshner, E.A., (2004). Virtual reality and physical rehabilitation: a new toy or a new research and rehabilitation tool? Journal of NeuroEngineering and Rehabilitation 2004, 1:8.

Knapp, J. M. (1999). The visual perception of egocentric distance in virtual environments. Dissertation Abstracts International, 61(09), 5034B.

Knapp, J.M., & Loomis, J.M. (2004). Limited field of view of head mounted displays is not the cause of distance underestimation in virtual environments. Presence, 13, 572-577.

Knerr, B.W., Breaux, R., Goldberg, S.L. et al. (2002). National defense. In: Stanney, K.M. (ed.) Handbook of virtual environments. Mahwah, NJ: Erlbaum, pp. 857-872.

Kozak, J. J., Hancock, P. A., Arthur, E. J., Chrysler, S. T., (1993). Transfer of training from virtual reality. Ergonomics, Vol 36(7), Jul 1993. pp. 777-784.

Lachman, R., Butterfield, E.C. & Lachman, J.L., (1979). Cognitive Psychology and Information Processing: An Introduction. Publisher: Lawrence Erlbaum Associates. Hillsdale, NJ., 1979. Pages: 573.

Lampton DR, McDonald DP, Singer M, Bliss JP., (1995). Distance estimation in virtual environments. Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting 1995; 1268-1272.

Lawler, E. L., Lenstra, J. K., Rinnooy Kan, A. H. G., & Shmoys, D. B. (a cura di), (1985). The Traveling Salesman Problem. New York: Wiley.

Lee, L.M., Ku, J.H., Jang, D.P., et al. (2002). Virtual reality system for treatment of the fear of public speaking using image-based rendering and moving pictures. CyberPsychology & Behavior 5:191-195.

Lehky, S. R., & Sereno, A. B. (2007). Comparison of shape encoding in primate dorsal and ventral visual pathways. *Journal of neurophysiology*, *97*(1), 307-19. doi:10.1152/jn.00168.2006

Leroy, L., Fuchs, P., Paljic, A., Moreau, G., Nantes, E. C., & Irstv, C. (2008). Study of stereoscopic shape perception for virtual design. *Methods*, 144-151.

Lin, J.J.W., Abi-Rached, H., Lahav, M., (2004). Virtual guiding avatar: An effective procedure to reduce simulator sickness in virtual environments. Proceedings of CHI 2004 2004:24-29.

Lintern, G., Roscoe, S.N., Koonce, J.M., et al. (1990). Display principles, control dynamics and environmental factors in pilot training and transfer. Human Factors 32:299-317.

Lo Priore, C., Castelnuovo, G. & Liccione, D., (2003). Experience with V-STORE: Considerations on presence in virtual environments for effective neuropsychological rehabilitation of executive functions. CyberPsychology & Behavior, 2003, 6, 281-287.

Loftin RB & Kenney P., (1995). Training the Hubble space telescope Aight team. IEEE Comput Graphics Appl 1995;15:31-7.

Loftin,R.B., Savely, R. T., Benedetti, R., Culbert, C., Pusch, L., Jones, R., Lucas, R., Muratore, J., Menninger, M., Engelbert, M., Kenney, P., Nguyen, L.,Saito, T. & Voss, M., (1997).Virtual environment technology in training: Results from the Hubble space telescope mission in 1993. In R.J. Seidel & P. R .Chantelier (Eds), Virtual Reality: Training‚Äôs Future. New York: Plenum.

Lombard, M., (1995). Direct responses to people on the screen‚Äîtelevision and personal-space. Communication Research 22, 3, 288-324.

Loomis, J. M., & Knapp, J. M. (2003). Visual perception of egocentric distance in real and virtual environments. In L. J. Hettinger and M. W. Haas (Eds.), Virtual and adaptive environments (pp. 21–46). Mahwah, NJ: Erlbaum

Loomis, J. M., Blascovich, J. J., & Beall, a C. (1999). Immersive virtual environment technology as a basic research tool in psychology. *Behavior research methods, instruments, & computers : a journal of the Psychonomic Society, Inc*, *31*(4), 557-64.

Lumbreras, M., & Sanchez, J. (2000). Usability and cognitive impact of the interaction with 3D virtual interactive acoustic environments by blind children. In: Sharkey, P., Cesarani, A., Pugnetti, L. et al. (eds.), Proceedings of the 3rd International Conference on Disability, Virtual Reality & Associated Technologies. Alghero, Sardinia, pp. 129-136.

Magee, L.E., (1997). Virtual Reality Simulator (VRS) for Training Ship Handling Skills. In R.J. Seidel and P.R. Chatelier (Eds), Virtual Reality, Training‚Äôs Future? Defence Research Series, Volume 6, Plenum Press: New York. pp19-29.

Mahoney, D.P. (1997). Defensive driving. Computer Graphics World 20:71.

Maltby, N., Kirsch, I., Mayers, M., et al. (2002). Virtual Reality Exposure Therapy for the treatment of fear of flying: a controlled investigation. Journal of Consulting & Clinical Psychology 70:1112-1118.

Martin JA, Regehr G, Reznick R, et al. (1997) Objective Structured Assessment of Technical Skill (OSATS) for surgical residents. Br J Surg 84:273-278.

Matheis RJ, Schultheis MT, Tiersky LA, Deluca J, Millis SR, Rizzo A. (2007). Is learning and memory different in a virtual environment? Clinical Neuropsychology 2007; 21:146-161.

Matheis, R.J., Schultheis, M.T., & Rizzo, A.A. (2003). Learning and memory in a virtual office environment. In: Burdea, G., Thalmann, D., & Lewis, J.A. (eds.), Proceedings of the 2nd International Workshop in Virtual Rehabilitation. Piscataway, NJ: Rutgers University, 48-54.

McCloy, R., & Stone, R., (2001). Science, medicine, and the future. Virtual reality in surgery. British Medical Journal. 323:912-915.

McGeorge, P., Phillips, L.H., Crawford, J.R., et al. (2001). Using virtual environments in the assessment of executive dysfunction. Presence: Teleoperators & Virtual Environments 10:375-383.

Medendorp, W.P., Goltz, H.C., Vilis, T. & Crawford, J.D., (2003). Gaze-centered Updating of visual space in human parietal cortex. Journal of Neuroscience, 23, 6209-6214, 2003.

Mellet, E., Briscogne, S., Tzourio-Mazoyer, N., Ghaem, O., Petit, L., Zago, L., et al. (2000). Neural correlates of topographic mental exploration: The impact of route versus survey perspective learning. Neuroimage, 12(5), 588-600.

Merians AS, Jack D, Boian R, Tremaine M, Burdea GC, Adamovich SV, Recce M, Poizner H. (2002). Virtual reality-augmented rehabilitation for patients following stroke. Phys Ther 2002, 82:898-915.

Merriam EP, Colby CL, Thulborn KR, Luna B, Olson CR, Weeney JA: Stimulus-response incompatibility activates cortex proximate to three eye fields. Neuroimage 2001;13:794-800.

Messing, R., & Durgin, F. H. (2005). Distance perception and the visual horizon in head-mounted displays. ACM Transactions on Applied Per- ception, 2, 234–250.

Mihalik, J. P., Kohli, L. & Whitton, M. C., (2008). Do the physical characteristics of a virtual reality device contraindicate its use for balance assessment? Journal of Sport Rehabilitation, Vol 17(1), Feb 2008. pp. 38-49.

Miller GA, Galanter E & Pribram KH., (1960). Plans and the Structure of Behavior. New York, NY: Holt.

Moffat, S. D., Zonderman, A. B., & Resnick, S. M. (2001). Age differences in spatial memory in a virtual environment navigation task. *Neurobiology of Aging*, *22*, 787-796.

Mohler, B. J., Creem-Regehr, S. H., & Thompson, W. B. (2006, July). The influence of feedback on egocentric distance judgments in real and virtual environments. In ACM SIGGRAPH Symposium on Applied Perception in Graphics and Visualization (pp. 9–14).

Mondini, S., Mapelli, D., Vestri, A., & Bisiacchi, P. (2003). *Esame neuropsicologico breve*. Milano: Raffaello Cortina Editore.

Morganti F. (2004). Virtual interaction in cognitive neuropsychology. Studies in Health Technology and Informatics 2004, 99:55-70. (URL: http://www.cybertherapy.info/pages/book3.htm" http://www.cybertherapy.info/pages/book3.htm).

Morganti, F. & Gaggioli, Andrea (2007): A virtual reality extended neuropsychological assessment for topographical disorientation: a feasibility study. In Journal of NeuroEngineering and Rehabilitation, 4 (26).

Morganti, F., Carassa, A. & Geminiani, G., (2007). Planning optimal paths: A simple assessment of survey spatial knowledge in virtual environments. Computers in Human Behavior Volume 23, Issue 4, July 2007, Pages 1982-1996.

Morris, R.G., Kotitsa, M., Bramham, J., et al. (2002). Virtual reality investigation of strategy formation, rule breaking and prospective memory in patients with focal prefrontal neurosurgical lesions. In: Sharkey, P., L√°nyi, C.S., & Standen, P. (eds.), Proceedings of the 4th International Conference on Disability, Virtual Reality & Associated Technologies. Veszpr√©m, Hungary, pp. 101-108.

Morris, R.G., Parslow, D., Fleminger, S., Brooks, B., Giametro,V. & Rose, F.D., (2002). Functional magnetic resonance imagining investigation of allocentric spatial memory tested using virtual reality in patients with anoxic hippocampal damage. In: Sharkey, P., L√°nyi, C.S., & Standen, P. (eds.), Proceedings of the 4th International Conference on Disability, Virtual Reality & Associated Technologies. Veszpr√©m, Hungary, pp. 87-92.

Mossio, M., Vidal, M., & Berthoz, A. (2008). Traveled distances: new insights into the role of optic flow. *Vision research*, *48*(2), 289-303. doi:10.1016/j.visres.2007.11.015

Mou, W., Biocca, F., Owen, C. B., Tang, A., Xiao, F., & Lim, L. (2004). Frames of reference in mobile augmented reality displays. Journal of Experimental Psychology: Applied, 10, 238-244.

Nagata S., (1993). How to reinforce perception of depth in single two-dimensional pictures. In: Ellis S, ed. Pictorial communication in virtual and real environments. London: Taylor & Francis, pp. 527-550.

Nakayama, K. & Silverman, G. H. (1986). Serial and parallel processing of visual feature conjunctions. *Nature*, *320*(6059), 264–265.

Nakayama, K., Shimojo, S., & Silverman, G. H. (1989). Stereoscopic depth: its relation to image segmentation, grouping, and the recognition of occluded objects. *Perception*, *18*(1), 55–68.

North, M.M., North, S.M., & Coble, J.R. (1996). Effectiveness of virtual environment desensitization in the treatment of agoraphobia. Presence, Teleoperators, and Virtual Environments 5:127,Äì132.

Nyberg, L., Lundin-Olsson, L., Sondell, B., Backman, A., Holmlund, K., Eriksson, S., Stenvall, M., Rosendahl, E., Maxhall, M. & Bucht, G., (2006). Using a Virtual Reality System to Study Balance and Walking in a Virtual Outdoor Environment: A Pilot Study. CyberPsychology & Behavior, Vol 9(4), Aug 2006. pp. 388-395.

Oddsson, L.I., Karlsson, R., Konrad, J., Ince, S., Williams, S.R., Zemkova, E., (2007). A rehabilitation tool for functional balance using altered gravity and virtual reality. J Neuroeng Rehabil 2007, 4:25.

Paillard J (1991) Motor and representational framing of space. In: Paillard J (ed) Brain and space. Oxford University Press, Oxford

Pani JR, Dupree D (1994) Spatial reference system in the comprehension of rotational motion. Perception 23:929–946.

Parslow DM, Morris RG, Fleminger S, Rahman Q, Abrahams S, Recce M. Allocentric spatial memory in humans with hippocampal lesions. Acta Psychologica 2005; 118:123-147.

Parsons TD, Larson P, Kratz K, Thiebaux M, Bluestein B, Buckwalter JG, et al., (2004). Sex differences in mental rotation and spatial rotation in a virtual environment. Neuropsychologia 2004; 42:555-562.

Parsons, T.D., & Rizzo, A.A. (2008). Initial Validation of a Virtual Environment for Assessment of Memory Functioning: Virtual Reality Cognitive Performance Assessment Test. Cyberpsychology and Behavior, 11, 17-25.

Parsons, T.D., Bowerly, T., Buckwalter, J.G., & Rizzo, A.A. (2007). A controlled clinical comparison of attention performance in children with ADHD in a virtual reality classroom compared to standard neuropsychological methods. Child Neuropsychology 2007, 13: 363-381.

Pelah, A., & Koenderink, J. J. (2007). Editorial: Walking in Real and Virtual Environments. *ACM Transactions on Applied Perception*, *4*(1), 1-es. doi: 10.1145/1227134.1227135.

Pertaub, D.P., Slater, M. & Barker, C., (2002). An experiment on public speaking anxiety in response to three different types of virtual audience. Presence-Teleoperators and Virtual Environments 11, 1, 68-78.

Peruch P, Vercher JL, Gauthier GM. Acquisition of spatial knowledge through visual exploration of simulated environments. Ecological Psychology 1995; 7:1-20.

Phelps A, Fritchle A, Hoffman H. Passive vs. active virtual reality learning: The effects on short- and longterm memory of anatomical structures. Studies in Health Technology & Informatics 2004; 98:298-300.

Pierce, C. a. (2004). Cautionary Note on Reporting Eta-Squared Values from Multifactor ANOVA Designs. Educational and Psychological Measurement, 64(6), 916-924. doi:10.1177/0013164404264848.

Plumert, J. M., Kearney, J. K., Cremer, J. F.,&Recker, K. (2005). Distance perception in real and virtual environments. ACM Transactions on Applied Perception, 2, 216–233.

Pravettoni, G., Leotta, S. N. & Lucchiari, C., (2008). The eye caught in the Net: A study on attention and motivation in virtual environment exploration. European Journal of Cognitive Psychology, Vol 20(5), Sep 2008. pp. 955-966.

Priore, C., Castelnuovo, G., & Liccione, D. (2002). Virtual environments in cognitive rehabilitation of executive functions. *International Conference on Disability, Virtual Reality& Associated Technologies* (pp. 165-172). Veszprém, Hungary: ICDVRAT/University of Reading, UK.

Proctor, M.D., Bauer, M. & Lucario, T., (2007). Helicopter Flight Training through Serious Aviation Gaming, The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology, 2007 Volume 4, Number 3, July.

Proctor, M.D., Panko, M. and Donovan, S. (2004) Considerations for Training Team Awareness and Task Performance Through PC-Gamer Simulated Multiship Helicopter Operations. The International Journal of Aviation Psychology, 14(2), 191-205.

Pugnetti L, Mendozzi L, Attree E, Barbieri E, Brooks BM, Cazzullo CL, et al. (1998) Probing memory and executive functions with virtual reality: Past and present studies. CyberPsychology & Behavior 1998; 1:151-162.

Pugnetti, L., Mendozzi, L., Barberi, E., Rose, F. D., & Attree, E. A. (1996). Nervous system correlates of virtual reality experience. *1st European Conference on Disability, Virtual Reality& Associated Technology* (pp. 239-246). Maidenhead, UK: ECDVRAT and University of Reading, UK.

Reason, J., & Brand, J. (1975). Motion sickness. London: Academic Press.

Regian, J.W., Shebilske, W.L. & Monk, J.M., (1992). Virtual reality: An instructional medium for visual spatial tasks. Journal of Communication, 1992, 42, 136-149.

Reves, B. & Nass, C., (2000). Perceptual bandwith. Communications of the Acm 43, 3, 65-70.

Richardson, A. R., & Waller, D. (2005). The effect of feedback training on distance estimation in virtual environments. Applied Cognitive Psychol- ogy, 19, 1089–1108.

Richardson, A. R., & Waller, D. (2007). Interaction with an immersive virtual environment corrects users' distance estimates. Human Factors, 49, 507–517.

Richardson, A.R., Montello, D.R. and Hegarty, M. (1999). Spatial Knowledge Acquisition from Maps, and from Navigation in Real and Virtual Environments, Memory and Cognition 27: 741-750.

Riva, G., & Davide, F. (eds.). (2001). Communications through virtual technologies: identity, community and technology in the communication age. Amsterdam: IOS Press. (URL: www.emergingcommunication. com/ volume1.html).

Riva, G., & Waterworth, J.A. (2003). Presence and the self: a cognitive neuroscience approach. Presence-Connect (URL: http://presence. cs.ucl.ac.uk/presenceconnect/articles/Apr2003/jwworthApr72003114532/jwworthApr.html).

Riva, G., Davide, F., & IJsselsteijn, W.A. (eds.). (2003). Being there: concepts, effects and measurements of user presence in synthetic environments. Amsterdam: IOS Press. (URL: www.emergingcommunication.com/ volume5.html).

Rizzo, A.A., Buckwalter, J.G. & Van der Zaag, C. (2002). Virtual environment applications for neuropsychological assessment and rehabilitation. In: Stanney, K. (ed.), Handbook of virtual environments. Mahwah, NJ: Earlbaum, pp. 1027-1064.

Rosahl, S. K., Gharabaghi, A., Hubbe, U., Shahidi, R., D, P., & Samii, M. (2006). Virtual Reality Augmentation in Skull Base Surgery. *Skull Base*, *1*(212), 59-66. doi:10.1055/s-2006-931620.

Rose, F. D., Attree, E. A., Brooks, B. M., Parslow, D. M. & Penn, P. R., (2000). Training in virtual environments: transfer to real world tasks and equivalence to real task training. Ergonomics, Volume 43, Issue 4 April 2000 , pages 494-511.

Rosen MJ, (1999). Telerehabilitation. NeuroRehabilitation 12 (1). Special Topic Issue on Technology in Neurorehabilitation 1999.

Rouw, R., Kosslyn, S. M., & Hamel, R. (1997). Detecting high-level and low-level properties in visual images and visual percepts. *Cognition*, *63*(2), 209-26.

Sadasivan, S., Greenstein J.S., Gramopadhye, A.K. & Duchowski, A.T., (2005). Use of eye movements as feedforward training for a synthetic aircraft inspection task. April 2005 CHI '05: Proceedings of the SIGCHI conference on Human factors in computing systems.

Sahm, C. S., Creem-Regehr, S. H., Thompson, W. B., & Willemsen, P. (2005). Throwing versus walking as indicators of distance perception in similar real and virtual environments. ACM Transactions on Applied Perception, 2, 35-45.

Salzman, M., Dede, C., Loften, R.B., and Chen, J., The Design and Evaluation of Virtual Reality-based Learning Environments, Presence: Teleoperators and Virtual Environments 8 (3), 293-316.

Sandin DJ, Margolis T, Dawe G, Leigh J, DeFanti TA (2001). The VarrierTM auto-stereographic display. SPIE 2001, 4297:. WA: SPIE.

Sanne M.B.I. Botden, Sonja N. Buzink, Marlies P. Schijven, & Jack J. Jakimowicz World J Surg. (2007). Augmented versus Virtual Reality Laparoscopic Simulation: What Is the Difference?: A Comparison of the ProMIS Augmented Reality Laparoscopic Simulator versus LapSim Virtual Reality Laparoscopic Simulator April; 31(4): 764-772. Published online 2007 March 8.

Santrock, J. W. (2003). *Psychology* (7th ed.). Singapore: McGraw-Hill.

Saracini, C., Basso, D., Olivetti Belardinelli, M. (2008). Repetitive TMS stimulation on virtual 3D navigation: Gender differences in frontal and parietal involvement. 20th IAPS Conference proceedings, Rome.

Saracini, C., Basso, D., Olivetti-Belardinelli, M., & Birbaumer, N. (IN PREPARATION). 3D Maps: a tool for wayfinding and planning evaluation.

Satava, R. M., (2008). Historical Review of Surgical Simulation, Personal Perspective World J Surg (2008) 32:141-148.

Schneider, S.M. & Hood, L.E., (2007). Virtual Reality: A Distraction Intervention for Chemotherapy. Oncol Nurs Forum. 2007 January ; 34(1): 39-46.

Seidel, R. J., & Chatelier, P. R. (1997). Virtual reality, training's future?: Perspectives on virtual reality and related emerging technologies. New York: Plenum Press.

Seymour NE, Gallagher AG, Roman SA, et al. (2002) Virtual reality training improves operating room performance: results of a randomized, double-blinded study. Ann Surg 236:458-463.

Shallice, T., & Burgess, P. W., (1991a). Deficits in strategy application following frontal lobe damage in man. Brain, 114, 727-741.

Shallice, T., & Burgess, P.W., (1991b). Higher order cognitive impairments and frontal lobe lesions in man. In: Levin, H.S., Eisenberg, H.M., & Benton, A.L. (eds.),Frontal lobe function and dysfunction. Oxford: Oxford University Press, pp. 125-138.

Shannon, C.E. (1948). "A Mathematical Theory of Communication", Bell System Technical Journal, 27, pp. 379–423 & 623–656, July & October, 1948.

Shelton, A. L., & Gabrieli, J. D. E. (2002). Neural correlates of encoding space from route and survey perspectives. Journal of Neuroscience, 22, 2711-2717.

Shelton, A. L., & Gabrieli, J. D. E. (2004). Neural correlates of individual differences in spatial learning strategies. Neuropsychology, 18, 442-449.

Shelton, A. L., & McNamara, T. P. (2001). Systems of spatial reference in human memory. Cognitive Psychology, 43, 274-310.

Shelton, A. L., & McNamara, T. P. (2004). Orientation and perspective dependence in route and survey learning. Journal of Experimental Psychology: Learning, Memory, and Cognition, 30, 158-170.

Shepard, R. N., & Metzler, J. (1971, February 19). Mental rotation of three-dimensional objects. Science, 171, 701-703.

Sheridan TB., (1992). Musings on telepresence and virtual presence. Presence: Teleoperators & Virtual Environments 1992; 1:120-125.

Sheridan TB., (1996). Further musings on the psychophysics of presence. Presence: Teleoperators & Virtual Environments 1996; 5:241-246.

Sherman W & Craig A: Understanding virtual reality: Interface, application, and design California: Morgan Kaufmann; 2002.

Siegel, A. W., & White, S. H. (1975). The development of spatial representations of large-scale environments. In H. W. Reese (a cura di), Advances in child development and behavior. (vol. 10, pp. 9-55). NewYork: Academic Press.

Sinai, M. J., Krebs, W. K., Darken, R. P., Rowland, J. H., & McCarley, J. S. (1999). Egocentric distance perception in a virtual environment using a perceptual matching task. Proceedings of the 43rd Annual Meeting Human Factors and Ergonomics Society, 43, 1256–1260.

Skelton, R.W., Bukach, C.M., Laurance, H.E., et al. (2000). Humans with traumatic brain injuries show place-learning deficits in computer-generated virtual space. Journal of Clinical & Experimental Neuropsychology 22:157-175.

Slater M, (2002). Course Notes on Understanding Virtual Environments: Immersion, Presence and Performance. San Antonio, TX, ACM - Siggraph; 2002.

Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): speculations on the role of presence in virtual environments. Presence 6:603-617.

Smith, J. D., & Graham T. C. N. (2006). Eye Tracking in Advanced Interface Design. ACE 06, 2006 June 14-16, Hollywood, California, USA.

Sprague, N. & Ballard, D., (2003). Eye movements for reward maximization. In Advances in Neural Information Processing Systems (Vol. 16), MIT Press.

Standen, P.J. & Brown, D.J, (2005). Virtual Reality in the Rehabilitation of People with Intellectual Disabilities: Review. Cyberpsychology & Behavior, 2005 Volume 8, Number 3.

Stanford Encyclopedia of Philosophy (URL: http://plato.stanford.edu/entries/connectionism/).

Stanney KM: Handbook of Virtual Environments: Design, Implementation, and Applications New Jersey: Erlbaum Assoc; 2002.

Stanton, D., Wilson, P., Foreman, N. et al. (2000). Virtual environments as spatial training aids for children and adults with physical disabilities. Presented at the 3rd International Conference on Disability, Virtual Reality and Associated Technologies, Sardinia.

Stone, R.J. (2002). Applications of virtual environments: An overview. In: Stanney, K.M. (ed.), Handbook of virtual environments. Mahwah, NJ: Erlbaum, pp. 827-856.

Subramanian, S., Knaut, L.A., Beaudoin, C., McFadyen, B.J., Feldman, A.G. & Levin, M.F., (2007). Virtual reality environments for post-stroke arm rehabilitation. J Neuroengineering Rehabil. 2007; 4: 20. Published online 2007 June 22. doi: 10.1186/1743-0003-4-20.

Sutherland LM, Middleton PF, Anthony A, Hamdorf J, Cregan P, Scott D, Maddern GJ., (2006). Surgical simulation: a systematic review. Ann Surg. 2006 Mar;243(3):291-300.

Sutton, R. & Barto, A., (1998). Reinforcement Learning, MIT.

Szentágotai, A., Opriş, D., & David, D. (2010). Virtual Reality in Evidence - Based Psychotherapy. In J.-J. K. (Ed.) (Ed.), *Virtual Reality* (pp. 445-468).

Takatalo, J., Nyman, G. & Laaksonen, L., (2008). Components of human experience in virtual environments. Computers in Human Behavior Volume 24, Issue 1, January 2008, Pages 1-15.

Terzopoulos, D. & Rabie, T.F. (1997) Animat vision: Active vision in artificial animals. Videre: J. Comput. Vision Res. 1, 2-19.

Thompson, W. B., Willemsen, P., Gooch, A. A., Creem-Regehr, S. H., Loomis, J. M., & Beall, A. C. (2004). Does the quality of the computer graphics matter when judging distances in visually immersive environments? Presence: Teleoperators & Virtual Environments, 13, 560–571.

Thompson, W.B., Willemsen, P., Gooch, A.A., Creem-Regehr, S.H., Loomis, J.M., & Beall, A.C. (2004). Does the quality of the computer graphics matter when judging distances in visually immersive environments? Presence, 13, 560-571.

Through a Computer-Simulated Environment. Environment and Behavior 28: 647-664.

Tidwell M, Johnston RS, Melville D, Furness TA (1995). The virtual retinal display – a retinal scanning imaging system. In Proceedings of Virtual Reality World '95 Heidelberg: Springer-Verlag; 1995:325-333.

Tlauka, M., & Wilson, P. N. (1996). Orientation-free representations from navigation through a computer-simulated environment. Environment and Behavior, 28, 647-664.

Vincelli, F., Anolli, L., Bouchard, S., et al. (2003). Experiential cognitive therapy in the treatment of panic disorders with agoraphobia: a controlled study. CyberPsychology & Behavior 6:312-318.

Visual thesaurus (November 2004) is created by the Cognitive Science Laboratory at Princeton University. Available on line: http://www.visualthesaurus.com/online/index.html.

Waller, D., (2000). Individual Differences in Spatial Learning.

Waller, D., Hunt, E., & Knapp, D. (1998). The transfer of spatial knowledge in virtual environment training. Presence: Teleoperators and Virtual Environments, 7, 129,Äì143.

Wang, M., & Reid, D. (2010). Virtual Reality in Pediatric Neurorehabilitation: Attention Deficit Hyperactivity Disorder, Autism and Cerebral Palsy. *Neuroepidemiology*, *36*(1), 2-18. doi: 10.1159/000320847.

Wann, J. P., Rushton, S., & Mon-Williams, M. (1995). Natural problems for stereoscopic depth perception in virtual environments. *Vision research*, *35*(19), 2731-6.

Ware C, Arthur K, Booth KS (1993). Fish tank virtual reality. In INTERCHI '93 Conf Proceedings Edited by: Ashlund S, Mullet K, Henderson A, Hollnagel E, White T. NY: ACM Press; 1993:37-42.

Waterworth, J.A., & Waterworth, E.L. (2003). The meaning of presence. Presence-Connect (URL: http://presence.cs.ucl.ac.uk/presenceconnect/articles/Feb2003/jwworthFeb1020031217/jwworthFeb. html).

Weiss P, Rand D, Katz N, Kizony R: Video capture virtual reality as a flexible and effective rehabilitation tool. Journal of Neuro-Engineering and Rehabilitation 2004, 1(1):12.

Weiss PL, Bialik P, Kizony K (2003). Virtual reality provides leisure time opportunities for young adults with physical and intellectual disabilities. Cyberpsychol Behav 2003, 6:335-342.

Wilcox, L.M. ,Allison, Robert, S., Elfassy, S. & Grelik, C., Personal space in virtual reality. ACM Transactions on Applied Perception, 3 (4):412{428, October 2006.

Wilkie, R.M., Wann, J.P. & Allison, R.S., (2008). Active gaze, visual look-ahead, and locomotor control. Journal of Experimental Psychology: Human Perception and Performance, Vol 34(5), Oct 2008. pp. 1150-1164.

Willemsen, P., & Gooch, A. (2002). Perceived egocentric distances in real, image-based, and traditional virtual environments. Proceedings of IEEE Virtual Reality 2002 (pp. 275–276). New York: IEEE.

Willemsen, P., Colton, M.B., Creem-Regehr,S.H. & Thompson, W.B., (2004). The effects of head-mounted display mechanics on distance judgments in virtual environments. Proceedings of the 1st Symposium on Applied Perception in Graphics and Visualization, August 7–8, (Los Angeles, CA), 35–48.

Wilson, B.A., Alderman, N., Burgess, P.W., et al. (1996). Behavioural Assessment of the Dysexecutive Syndrome Test (BADS). Bury St. Edmunds: Thames Valley Test Company.

Wilson, P. (1993). Nearly there. Special Children 68: 28-30.

Wilson, P. N., Foreman, N., & Tlauka, M. (1997). Transfer of spatial information from a virtual to a real environment. Human Factors, 39, 526-531.

Wilson, P.N., Foreman, N., Gillet, R., et al. (1997). Active versus passive processing of spatial information in a computer simulated environment. Ecological Psychology 9:207-222.

Winograd T. & Flores F., (1986). Understanding Computers and Cognition: A New Foundation for Design. Norwood, NJ, Ablex Publishing Corporation; 1986.

Witmer, B. G., & Kline, P. (1998). Judging perceived and traversed distance in virtual environments. Presence: Teleoperators & Virtual Environments, 7, 144–167. Received

Witmer, B. G., & Sadowski, W. J. (1998). Nonvisually guided locomotion to a previously viewed target in real and virtual environments. Human Factors, 40, 478-488.

Wolbers T, Weiller C, Buchel C., (2004). Neural foundations of emerging route knowledge in complex spatial environments. Brain Research Cognitive Brain Research 2004; 21:401,Äì11.

Wraga, M., Creem-Regehr, S. H., & Proffitt, D. R. (2004). Spatial updating of virtual displays during self and display rotation. Memory & Cognition, 32(3), 399,Äì415.

Yan, N., Wang, J., & Lv, Y. (2008). Designing a Brain-computer Interface Device for Neurofeedback Using Virtual Environments. *Engineering*, *28*(3), 167-172.

Yarbus, A. (1967) Eye Movements and Vision, Plenum Press.

You, S. H. (2005). Cortical reorganization induced by virtual reality therapy in a child with hemiparetic cerebral palsy. *Developmental Medicine and Child Neurology*, *47*(09), 628. doi: 10.1017/S0012162205001234.

Zhang, X., Furnas, G.W., 2005a. mCVEs: using cross-scale collaboration to support user interaction with multiscale structures. Presence, Teleoperators and Virtual Environments 14 (1), 31-46.