Sede Amministrativa: Università degli Studi di Padova

Dipartimento di Psicologia Generale

SCUOLA DI DOTTORATO DI RICERCA IN: SCIENZE PSICOLOGICHE

CICLO: XXVIII°

Confluence: Contributions from Embodiment, Physiological Computing and Subliminal Perception to New Forms of Human-Computer Interaction

Direttore della Scuola: Ch.mo Prof. Francesca Peressotti

Supervisore: Ch.mo Prof. Luciano Gamberini

Dottorando: Paolo Negri

RIASSUNTO

Il presente lavoro è parte di quel campo di ricerca che prende il nome di Human-Computer Confluence (HCC) e che si prefigge di indagare l'emergente relazione simbiotica tra umani e computer. L'idea di simbiosi tra uomo e computer non è nuova, infatti risale al 1960 quando Licklider ha preso in prestito dalla biologia la nozione di simbiosi tra diversi organismi allo scopo di descrivere una nuova possibile relazione tra uomo e computer (Licklider, 1960). Licklider ha immaginato una collaborazione nella quale l'uomo definisce gli obiettivi, formula le ipotesi, determina i criteri ed esegue le valutazioni, e i computer realizzano il lavoro routinario. Lo scopo dell'autore era quello di immaginare una diade nella quale i computer e il cervello umano fossero cosi strettamente accoppiati in una relazione reciprocamente vantaggiosa da ricordare il modo in cui l'insetto Blastophaga grossorum e l'albero di fico sono uniti l'uno all'altro da una cooperazione produttiva. L'interesse verso la simbiosi tra uomo e macchina si è recentemente rinnovato. Questo rinnovamento è testimoniato sia dall'emergere di workshop internazionali, sia dal recente arricchimento della letteratura scientifica su questo tema, sia infine dall'attenzione e dai cospicui finanziamenti che la Commissione Europea sta dedicando a progetti legati a questo argomento.

Il presente lavoro si prefigge lo scopo di analizzare e comprendere alcuni aspetti che, a diversi livelli, possono contribuire a stabilire una relazione simbiotica, in particolare, nel campo dei sistemi di esplorazione dell'informazione. A questo scopo, sono stati condotti alcuni esperimenti per indagare:

- L'importanza per i sistemi simbiotici di una interazione "embodied" all'interno di ambienti di "realtà mista" altamente immersivi.

- La User experience (UX) e la performance di apprendimento degli utenti mentre interagiscono con dataset molto grandi all'interno di un ambiente immersivo, adattivo ed equipaggiato di tecnologie capaci di misurare lo stato psicofisiologico dell'utente.
- L'uso di una tecnica di stimolazione subliminale per influenzare il comportamento di scelta dell'utente in un ambiente virtuale.

Il lavoro inizia con una rassegna dei contributi teorici sui sistemi simbiotici, a partire dall'origine dell'idea (Licklider, 1960) per arrivare sino alle più recenti definizioni concepite anche sulla base dei recenti avanzamenti tecnologici. Dopo una rassegna di lavori che testimonia il rinnovato interesse verso l'argomento, il lavoro continua offrendo una discussione riguardante i contributi teorici che altri modelli di HCI danno alla teoria dei sistemi simbiotici. In particolare, sono presi in considerazione e discussi i contributi di Telepresence, Persuasive technologies, Embodied interaction, Affective e Physiological computing.

Il primo studio realizzato si prefiggeva lo scopo di misurare e comparare sia la UX che la performance associate a diversi modi di interagire con oggetti virtuali in un ambiente di realtà mista. In particolare è stato comparato il modo più comune di dare comandi ad un computer, cioè attraverso la tastiera e il mouse, con una interazione "embodied" che utilizza gesti naturali e movimenti del corpo. I risultati hanno mostrato che, nonostante la performance (in termini di tempo di esecuzione del compito) fosse migliore con la tastiera e il mouse, la UX era migliore con il sistema di interazione "embodied".

Il secondo studio si prefiggeva di indagare la performance di apprendimento e la UX durante l'interazione con un dataset di informazioni neuroscientifiche all'interno di un ambiente di realtà mista. Il sistema era equipaggiato di tecnologia indossabile per misurare lo stato psicofisiologico dell'utente durante la sua interazione. Lo scopo era di rendere il sistema "adattivo" ossia capace di eseguire in tempo reale alcune modifiche dell'informazione mostrata in accordo allo stato dell'utente per supportare il suo compi-

to. I risultati hanno mostrato che il sistema era in grado di facilitare il compito dell'utente, portando a migliori performance d'apprendimento e ad una migliore UX.
Il terzo studio si prefiggeva di indagare l'efficacia del "cueing" subliminale nell'influenzare il comportamento di selezione dei partecipanti in un compito di scelta forzata tra oggetti in un ambiente virtuale in 3D raffigurante uno scenario realistico. I risultati hanno mostrato che il "cueing" subliminale ha un effetto sul comportamento di scelta, dimostrando la possibilità del suo utilizzo in ambienti di realtà virtuale. I risultati evidenziano anche alcune caratteristiche peculiari del "cueing" subliminale, come il rapido dissolvimento del suo effetto. Questi risultati dovrebbero essere presi in considerazione da chi si occupa di design di nuove interfacce capaci di utilizzare gli stimoli subliminali come un canale di comunicazione aggiuntivo tra il computer e l'utente. Nella conclusione i risultati degli studi sono discussi e valutati.

SUMMARY

The present work is part of that research field that has been called Human-Computer Confluence (HCC) and that aims at investigating the emerging symbiotic relationship between humans and computers. The idea of human-computer symbiosis is not novel, indeed it dates back to 1960 when Licklider borrowed from biology the notion of symbiosis between different organisms to depict a new vision of the relationship between humans and computers (Licklider, 1960). Licklider envisioned a partnership in which men set the goals, formulate the hypotheses, determine the criteria, and perform evaluations, and computers do the routinizable work. The purpose of the author was to envision a dyad in which computing machines and human brain were so tightly coupled in a mutually beneficial relationship to remember the way in which the insect Blastophaga grossorum and a fig tree relate to each other in a fruitful cooperation. The interest in symbiotic interaction has been recently renewed. This is witnessed both by the emergence of dedicated international workshops and by the recent enrichment of the scientific literature on this subject, and also by the attention and substantial funding that the European Commission is dedicating to projects related to this topic.

The present work aims at analyzing and understanding some aspects that, at different levels, can contribute to a symbiotic relationship, in particular in the field of information exploration systems. To this end, some experiments have been conducted to investigate:

- The relevance to symbiotic relationships of an embodied interaction within an immersive mixed-reality environment.
- The User experience (UX) and learning performance while the user interacts with large datasets within an immersive, adaptive environment and while the system was equipped with sensing technologies to compute the user's psychophysiological state.
- The use of a subliminal technique to bias the user's selection behavior in a 3D virtual environment.

The work starts with an overview of theoretical efforts on symbiotic systems, from the origin of the idea (Licklider, 1960) to the more recent definitions informed by the recent advances in technology. After a review of research testifying the recent renewed interest in the topic, the work continues offering a discussion about theoretical contributions from other frameworks to the symbiotic systems theory. In particular, contributions from Telepresence, Persuasive technologies, Embodied interaction, Affective and Physiological computing have been considered and discussed.

The first study aimed at measuring and comparing both UX and performance related to different ways to interact with virtual objects in a mixed-reality environment. In particular, we compared the most common way to input commands to a computer, that is, through the keyboard and mouse with an embodied interaction exploiting natural gestures and body movements. Results showed that, despite the performance (in term of task execution time) was greater with the keyboard and mouse, the UX was better with the embodied interaction system.

The second study aimed at investigating the learning performance and the UX during the interaction with a neuroscience dataset within a mixed-reality environment. Important, the system was endowed with wearable sensing technology to compute the psychophysiological state of the user during his/her interaction. The purpose was to make the system adaptive, namely, capable to perform in real time some adjustments of information displayed according to the user's state in order to support his/her task. Results showed that the system was able to facilitate the user's task, leading to better learning performance and UX.

The third study aimed at investigating the efficacy of the subliminal cueing in biasing the participants' selection behavior in a forced-choice task between objects in a 3D virtual environment (VE) representing a realistic scenario. Results showed a significant effect of subliminal cueing on the selection behavior demonstrating the feasibility of subliminal cueing in VEs. The results also highlighted some peculiar characteristics of the subliminal cueing, like the short duration of its effect. These findings are relevant and suitable to inform the design of novel interfaces that exploit subliminal stimuli as an additional communication channel between the computer and the user. In the conclusion the results of the studies are discussed and evaluated.

INDEX

1 CHAPTER ONE

1.1 Human-Computer Confluence

Nowadays, we are witnessing an accelerating process of dissemination of technological devices in everyday-life environments and objects. Computing devices are increasingly smaller, embedded in everyday objects becoming more and more "invisible". Information communication technologies (ICT) are increasingly wireless and miniaturized in such a way that they can be easily embedded in tools, accessories, furniture, and in any part of the everyday environment of users. Computers are increasingly "confluent" with humans and their environments in a way that they can radically change the style of how humans perceive, think, interact, learn, work and live. Technological advancements are making the relationship between men and computing machines increasingly "symbiotic", and these circumstances rise the interest in understanding the way in which this new relationship can impact how we behave and socialize as individuals and also as members of social groups. This research interest has been called Human-computer confluence: "Human computer confluence (HCC) is an ambitious research program studying how the emerging symbiotic relation between humans and computing devices can enable radically new forms of sensing, perception, interaction, and understanding" (Viaud-Delmon, Gaggioli, Ferscha, & Dunne, 2012, p. 42).

The symbiosis between man and computer is taking shape not only through the ubiquitous presence of technological devices, but also because technologies are ever more "embodied", that is, capable to tailor their services to the person and their context of use and, consequently, ever more "persuasive". Technologies are even more suitable to impact the "sense of presence", and the scientific community are envisioning a world in which technologies will be ever more capable to understand intentions, emotions and cognitive states of the user. These advancements are setting a more reciprocal and deep relationship between humans and computers that has been in part originally envisioned by Licklider (1960) and to which different qualities of new technologies contribute. With the present work we aim at delineating the main characteristics of this new type of human-computer interaction (HCI) in which technologies are increasingly confluent with users and their context of use starting from the foundational conception provided by Licklider and describing the contributions of different HCI's frameworks. We will focus in particular on the contribution coming from Embodied Interaction, Affective and Physiological Computing and, finally, from Subliminal Perception. We will not neglect the contribution of Telepresence and Persuasive Technologies.

1.2 Towards a Symbiosis between Humans and Computers

Origin of the Idea.

In the 60s Licklider borrowed from biology the notion of symbiosis between different organisms to depict a new vision of the relationship between human and computer (Licklider, 1960). The purpose of the author was to envision a dyad in which computing machines and human brain were so tightly coupled in a mutually beneficial relationship to remember the way in which the insect Blastophaga grossorum and a fig tree relate to each other in a fruitful cooperation. Licklider envisioned a partnership in which men set the goals, formulate the hypotheses, determine the criteria, and perform evaluations, and computers do the routinizable work. This vision differs from both the idea of "Mechanically Extended Man" (North, 1954), later known as "Augmented Human" (Engelbart, 2001), and from the idea of "Artificial Intelligence". In the Augmented Human, the machine was a mere extension of human abilities, or, in the words of Licklider, "the mechanical parts of the systems were mere extensions, first of the human arm, then of the human eye" (Licklider, 1960, p. 4). On the other hand, the human was in charge with providing the initiative, the direction, the integration and the criterion, in short, the human was the problem solver. Conversely, in the Artificial Intelligence the principal problem solver is the computer. According to Licklider, the aim of symbiosis is to let computers cooperate with men in the decision-making by enabling them to go beyond the role of processors of data according to preformulated procedures. To this purpose, two requirements need to be satisfied: computers need to be brought into the process of “thinking”, moreover, this “thinking” on the part of the computer must occur in real time. The final result is a cooperation that should look like to that in which we think together with a colleague whose skills complement ours. Relative to computers, the humans’ nervous system allows many parallel and simultaneous operations. Relative to humans, computers can perform only few elementary operations at a time but much faster. Humans can reprogram themselves according to novel information; traditional computers cannot do it. Computer are more accurate and less flexible compared to humans. The comparison between humans and computers capabilities highlights that humans can perform activities that are impossible for computers, and computers can perform readily activities that are very difficult or very time-consuming for humans.

Licklider stated that, when we are engaged in a scientific work, about 85 per cent of our “thinking” time is spent on clerical and repetitive tasks, like searching information, calculating, transforming data and so on. In other words, all those tasks that need to be accomplished to prepare the decision-making and that can be performed more effectively by computers than by humans. It is evident that a cooperation in a symbiotic relationship capable to integrate strengths of both humans and computers should give to computers all those clerical and repetitive activities that are very time-consuming for humans, and should give to humans those activities that are impossible or difficult for computers. These non-routinizable activities consists of setting the goals, formulating the hypotheses, determining the criteria, and performing evaluations.

Recent renewed interest in Human-Computer Symbiosis.

The interest in symbiotic interaction between human and computer has been recently renewed. This is witnessed both by the emergence of dedicated international workshops (i.e., International Workshop on Symbiotic Interaction), and also by the attention and substantial funding that the European Commission is dedicating to projects related to this topic. For instance, it is worth mentioning the EU FET (Future and Emerging Technologies) Proactive Initiative on "Symbiosis between humans and computers" coordinated as part of the Objective ICT-2013.2.1 "Robotics, Cognitive Systems & Smart Spaces, Symbiotic Interaction". This initiative, in the FP7 (EU 7th

Framework Programme for Research), aims at a deeper understanding of human behavior during interaction with ICT (Information and Communication Technology), going beyond conventional approaches. As reported in the website of the European Commission “foundational research on symbiotic relations between humans and machines will aim at the design of new interactive technologies based on new theories and models of human cognition and emotion, non-rational decision-making, social behavior and spatial and temporal perception and processing. RTD (Research and Technological Development) will also investigate the influence of such technologies on human behavior and methods to promote positive co-evolution and co-adaptation of symbiotic systems” (“Special Initiative: Symbiotic human-machine interaction” n.d., para. 4).

The Proactive Initiative on "Symbiosis between humans and computers" has already funded some projects which aim at the design of symbiotic technologies. In the field of human-robot interaction, the BioMot (Smart Wearable Robots with Bioinspired Sensory-Motor Skills) project aims at improving the compliance between humans and wearable robotic exoskeletons in order to lead to a more symbiotic gait behavior (Moreno et al., 2014). Similarly, the SYMBITRON (Symbiotic man-machine interactions in wearable exoskeletons to enhance mobility for paraplegics) project aims at developing new bioinspired exoskeletons capable to complement the remaining walking ability in spinal cord injured patients (http://cordis.europa.eu/project/rcn/110314_en.html).

In the same human-robot interaction field, the EASEL (Expressive Agents for Symbiotic Education and Learning) project aims at creating a new generation of robots capable to interact with humans in a more symbiotic way. The challenge is to design robotic-based tutoring systems with the capacity to extract usable knowledge from the interaction with learners and consequently adapt their behavior across encounters and within encounters (http://easel.upf.edu/project).

In the information retrieval field, the MindSee (Symbiotic Mind Computer Interaction for Information Seeking) project aims at creating a symbiotic system for the retrieval and exploration of scientific literature, based on a reciprocal adaptation between user and computer. This coadaptation is based on the capacity of the system to predict the user’s search intentions and to understand the user's affective states, and to adapt in real time both the information seeking output and the graphic characteristics of the interface. The capacity of the system to understand user's intentions and emotions will be based on coupling of psychophysiological measures (i.e., electroencephalogram and peripheral measures) with behavioral data (Gamberini et al., 2015).

The renewed interest in human-computer symbiosis is also evident from recent enrichment of the literature on this subject.

In the 2004 a researcher of the MIT (Roy, 2004) suggested the chance to augment human skills by an order of '10 x'. The human abilities that the MIT Media Laboratory aspires to improve are: (1) memory. Computers can store an unlimited amount of information therefore they can facilitate human access to very large datasets improving human's cognitive abilities. (2) Expression. The human's expressing activities can be augmented by technological devices that translate human's intentions of actions into physical actions; (3) Listening. Computers can improve human's ability to listen through audio browsing environments allowing human for more effective listening. (4) Learning and understanding. Computers can enabling humans to understand situations in new ways. (5) Physical skills. Robots and bionic technologies can extend, improve or restore the humans' physical ability. (6) Awareness. Through networks of sensors and wearable devices, computers can extend humans' awareness of environments. This approach to the human-computer symbiosis leads us back to the idea of Augmented Human" (Engelbart, 2001) but is also based on the conception of computers as learning systems beyond instruction and programming (i.e., computers that can learn from humans through interactions).

In (Schalk, 2008), the author observed that, while the ongoing technical advance of computers provides the basis for a huge increase of user's efficiency, a bottleneck needs to be overcome. The author referred to the limited capacities of input and output of the human's body that impact on the communication between users and computers. A theoretical and practical possibility to establish a direct communication between the brain and the computer has been discussed, and both decoding information from the brain and sending information into the brain have been considered.

In (van Erp, Veltman, & Grootjen, 2010), authors proposed that user interfaces should go from being user-friendly to being user-centric acquiring the capacity to understand and anticipate the user's intentions. In particular they applied the concept of user-system symbiosis to brain-based interfaces. A central role in the proposal of these authors is played by the concept of "operator model". The operator model is a representation containing a variety of information both about the user (e.g., preferences, capacities and affective processes) and about the task (e.g., task load). The operator model is needed to implement useful adaptation to the specific user, and the operator model is constantly updated by data coming from the user engaged in the active task. Data sources are, for instance, emotions from voice, facial expressions, gestures and physiological measures like electroencephalogram (EEG).

In a recent theoretical work (Jacucci, Spagnolli, Freeman, & Gamberini, 2014, p. 9), authors stated that a symbiotic interaction "can be achieved by combining computation, sensing technology, and interaction design to achieve deep perception, awareness, and understanding between humans and computers."

Authors conceived symbiotic interactions as defined by three key dimensions: understanding, transparency and goals. The dimension of understanding refers to the depth to which the computer can understand the user through sensing technologies. There may be no sensing or sensing only the location of the user or the computer may recognize some user's activities (e.g. walking, running). Deeper understanding refers to situations in which computers can monitor the cognition of users, or can understand natural language or the user's emotions. Along the dimension of transparency, the system may be a "black box" preventing the user to understand what it is doing, or it may be transparent and configurable. The system is reciprocal to the extent that the system can access and use resources of the user (e.g., individual characteristics, history, cognitive and affective processes, etc.). As for the dimension of goals, the relationship between the user and the system may pursue a single, common goal or, alternatively, it may pursue a variety of independent goals of different actors.

Authors also presented an interesting taxonomy based on the three key dimensions of symbiotic interaction using concrete systems as examples (Figure 1).

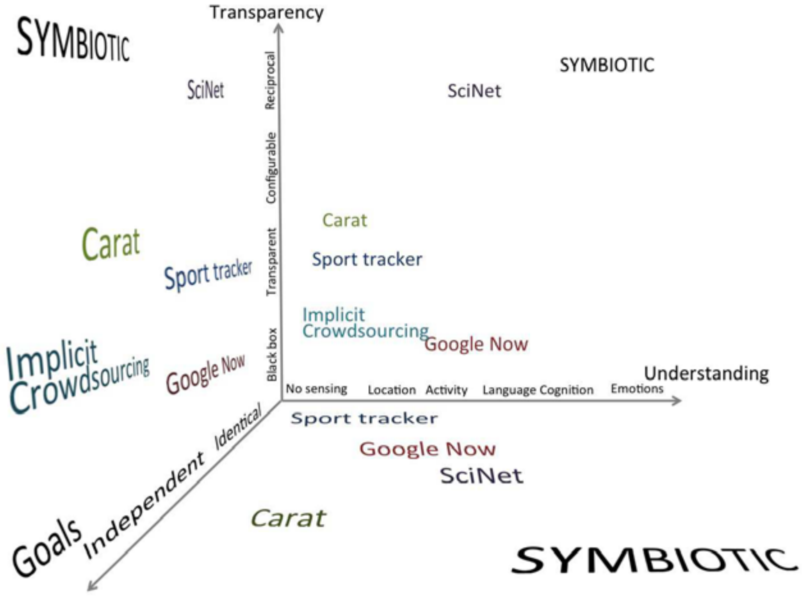


Fig. 1. Taxonomy of symbiotic relationship adapted from (Jacucci et al., 2014). Authors used some concrete systems as examples, in particular: Google Now, Carat (Athukorala et al., 2014), implicit crowdsourcing, SciNet (Ruotsalo et al., 2013), and sport trackers.

For instance, Google Now, an intelligent personal assistant developed by Google, works as a black box, to pursue the user's goal, and has an understanding that includes physical location and activity of the user. SciNet is an interactive information retrieval system with a user interface that allows active engagement of users in directing the search (Ruotsalo et al., 2013). Compared to Google Now, SciNet is higher in the transparency dimension. Carat is an app used to manage phone batteries (Athukorala et al., 2014). In this case there are two independent goals: the first is to help the user to save battery, the second is related to the fact that, when using Carat, users crowdsource data automatically that is used to predict how much battery time is saved in the whole community of users by updating or closing other apps. Carat is also a quite transparent system with a quite low understanding of the user. Implicit crowdsourcing may have several independent goals and works as a black box due to the fact that the user might not even know that other goals are pursued.

The more the technology can be placed in the corners of the quadrants, the more symbiotic is the relationship.

Since that of symbiotic systems is a multidisciplinary field, studies investigated the topic from points of view that are even very different from each other. Some works have tackled with the human-robot interaction, like in Micera et al. (2015) in which the objectives of the NEBIAS (NEurocontrolled BIdirectional Artificial upper limb and hand prosthesis) project are outlined. The aim is to develop a neuro-controlled hand prothesis that amputees can feel like a natural hand.

In other studies, the efforts are more strictly focused on improving the algorithms like in Shimoda et al. (2015) in which researchers discussed and tested a robot joint stiffness tuning algorithm for exoskeleton robots. In another study (Andolina & Forlizzi, 2014), efforts focused to improve the efficiency when humans interact with swarms of collaborative biologically inspired robots. In Hore, Tyrvainen, Pyykko, and Glowacka (2014) authors proposed an image retrieval system based on an algorithm that, compared to the traditional ones, is more heavily based on user's research intent.

In the field of mobile internet, Åman, Liikkanen, Jacucci, and Hinkka (2014) proposed OUT-Media, a location-based music discover application with the aim of supporting a symbiotic interaction between public spaces and media content.

Other works have focused attention on a more technical side. For instance, a research group recently conceived a novel tactile glove endowed with effectors that deliver tactile feedback while the user moves in a certain space of interaction (Hsieh, Jylhä, & Jacucci, 2014).

Several works have focused on design solutions of searching interfaces (e.g., Serim, 2014) and information retrieval systems (e.g., Bandyopadhyay, Ruotsalo, Ukkonen, & Jacucci, 2014).

Theoretical contribution from other frameworks.

In this section we begin to review some frameworks that, in various ways, provide a contribution to the theory of confluence and symbiotic systems. A first approach is that of mixed-initiative interaction (Horvitz, 1999). The author proposed a new way to improve human-computer interaction consisting in a coupling of automated services provided by an interface agent with direct manipulation of objects by the user. When the system infers that the user needs assistance in problem solving or navigation, the interface agent can initiate a dialogue with the aim to help the user. In mixed-initiative interaction the user's problems are solved in an interactive way in which both the user and the system are supposed to be active, and this characteristic is precisely what makes this approach relevant to symbiotic systems. However, this approach has been essentially used to assist the user in office tools environments. Moreover, some efforts by the user are often required to correct irrelevant dialogues promoted by the system.

Other relevant frameworks are those highlighting the human-computer interdependence, in particular, Telepresence, Persuasive Technology, Affective and Physiological Computing. Critical contributions come also from human-centred frameworks, in particular we refer to Embodied Interaction, UbiComp and Tangible bits.

We decided to briefly address the contribution of Telepresence and Persuasive Technology in next two subsections. Embodied interaction, UbiComp and Tangible bits will be extensively addressed in chapter 2 due to their relevance to our first study. In chapter 3 we will extensively addressed Affective and Physiological Computing because they are relevant to the second study. In chapter 4, with our third study, we will show how Subliminal perception may be of interest for symbiotic systems.

Telepresence.

Telepresence or presence can be defined as the "sense of being there", that is the subjective experience of being in the mediated environment (Witmer & Singer, 1998). In other words, presence is the sense of being in the environment that is supported by digital resources. In (Lombard & Ditton, 1997) authors referred to presence as transportation: "Three distinct types of transportation can be identified: "You are there," in which the user is transported to another place; "It is here," in which another place and the objects within it are transported to the user; and "We are together," in which two (or more) communicators are transported together to a place that they share" (Lombard & Ditton, 1997, p. 0). The concept of presence has to be distinguished from that of "immersion". When the construct of presence has been used in the virtual reality field, Slater and Wilbur (1997) defined presence as a "state of consciousness (of the user) that may be concomitant with immersion, and is related to a sense of being in a place" (Slater & Wilbur, 1997, p. 1). Authors instead defined immersion as a set of characteristic of the virtual reality technology that determine the extent to which the mediated environment saturates the user's perception excluding the real world. Authors listed some features of virtual reality technology that contribute to immersion and that can be objectively assessed. Among these, the extent to which the display can deliver an extensive surrounding to the user excluding visual stimuli of the external world, and the vividness of the virtual environment (Slater & Wilbur, 1997).

The experience of presence comprises both the components of spatial presence and social presence. Spatial presence can be defined as the "feeling of being in a specific spatial context, and intuitively and spontaneously knowing where one is with respect to the immediate surround" (Riecke, & von der Heyde, 2002, p. 1). Social presence can be defined as "a sense of being with another" in the environment mediated by technology (Biocca, Harms, & Burgoon, 2003).

There are several models of presence. Some of them (for a review see Spagnolli, Bracken, & Orso, 2014) assume a separation between real and digital, and do not account for those physical resources that are parts of the user's experience even in the mediated environment like, for instance, the body of the user himself, or input devices. Other models of presence (e.g. Spagnolli & Gamberini, 2005) consider presence as a hybrid experience resulting from an interplay between digital and non-digital objects. The sense of being in a mediated environment is an experience to which also physical resources contribute. Presence is a concept relevant to human-computer symbiosis because it refers to the interdependence between the resources that take part to the system, and captures the intimacy of the relationship between the user and technological parts of the system (Jacucci, Spagnolli, Freeman, & Gamberini, 2014). Presence overlaps with symbiosis to the extent to which the symbiosis defines a relationship between humans and machines in which machines adapt to humans. In this sense, using design strategies to intensify the symbiosis, namely the interdependence between users and computers, also means increasing the sense of presence (Jacucci, Spagnolli, Freeman, & Gamberini, 2014).

Persuasive Technology.

The term persuasive technology has been coined by B.J. Fogg to refer to technology that is designed to support users in changing their attitudes or behaviors (Fogg, 2002). Persuasive technologies exploit psychological theories of persuasion, and computers can persuade both in quality of tools, as medium or as a social actor (Fig. 2.).

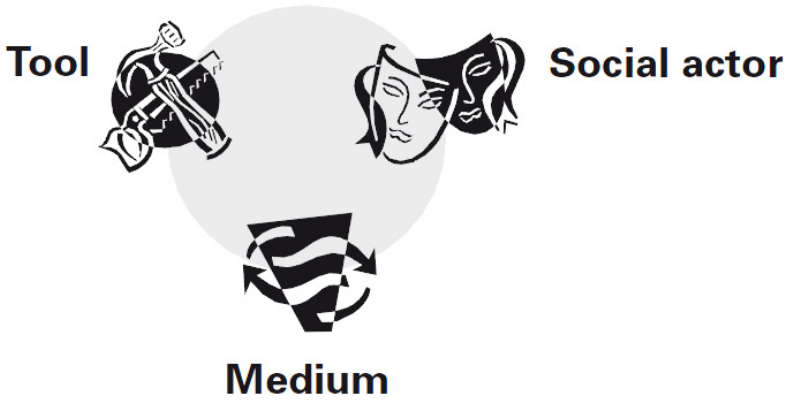


Fig. 2. Technology can influence in different ways depending on its role. (Adapted from Fogg, 2002).

Computers as tools can be persuasive because they increase the capacity of users, for instance they can perform calculations and measurements that motivate users. They make easier the desired behavior, or they guide people in the execution of a process. In quality of medium, computers can be persuasive because they can provide experience, for instance they can provide alternative experiences that can give motivation (e.g. within virtual environments). In quality of social actor, computers can persuade because they create relationships and, for instance, they can provide positive reinforcements. They also can serve as a model of an attitude or behavior to be obtained, or they can provide social support (Fogg., 2002).
Technologies can promote new attitudes and behaviors in several domains of application, for instance in the safety field (e.g., Chittaro 2012), in health and wellness (e.g., Japuntich et al.,

2006; Consolvo, Klasnja, McDonald, & Landay, 2009), and in pro-environmental projects (e.g., Spagnolli et al., 2011; Gamberini et al., 2012).

The theory of persuasive technology is relevant to a symbiotic systems framework for at least two reasons. First of all, like any technology, even symbiotic technologies have an intrinsic persuasive power determined by their affordances. To date, the concept of affordance has been referred to those features of the technical device that invite a certain action promoting the usability of the device itself. Some authors (Jacucci et al. 2014) envisioned that, in a future, affordances could be used for persuasive purposes. Secondly, symbiotic systems have an additional persuasive power associated with their capacity to implicitly direct the users' choices when they reconfigure their output to adapt to the users. This characteristic of symbiotic systems poses some ethical concerns mainly related to the users' agency. In fact, implicitly directing the users' decisions, the symbiosis configures a situation in which users' behaviors seem to be affected by information not entering the users' awareness, resulting in a hidden persuasion. In the persuasive technology field, Smidt (2012) argues that the voluntariness of behavioral changes is a fundamental requirement that must be preserved. According to this, we think that symbiotic systems rise an ethical discussion that, with its peculiarities, will not be very different from that on persuasive technologies.

2 CHAPTER TWO

2.1 Contributions from Embodied Interaction

Jacucci and collaborators (2014) stated that, in symbiotic interaction, an important aspect needs to be implemented, they referred to the transparency. This concept leads us back to a Human-centred framework which gives a critical contribution to the definition of human-computer symbiosis: the concept of Embodied interaction as it has been conceived by Dourish (Dourish, 2001). According to Dourish, computation should be embodied in the sense of manifested “in the world, real-time and real-space, here and now” (Dourish, 2001, p. 235). Therefore, computation should be embodied, that is, explicitly represented, in a transparent way considering both the physical and the broader context (i.e., social, cultural, organizational and interactional) in which the interaction takes place. Embodiment refers to the property of being in the everyday world, and it does not simply refer to the physical presence, it also extends to social aspect of the everyday world. A technological device could be embodied not simply in the physical environment, but also in the same sense that makes embodied a conversation. Conversation is embodied in the way that it happens in the world, engaging people that are embodied and connected by relationships that are, in turn, embodied in a web of relationships and social rules. Therefore, speaking of embodied interaction means speaking about a phenomenon, the interaction, that is embodied both in the physical world and in social practices and purposes.

The Dourish’s vision is rooted in two related proposals, the Weiser’s Ubiquitous Computing (Weiser, 1991) and the Ishii’s Tangible Bits (Ishii & Ullmer, 1997). Weiser founded his UbiComp vision on two considerations. Firstly, he observed that technologies that collect the greatest consensus and success are those that disappear because they are embedded into the background; secondly, Weiser considered the continuous reduction in the size and cost of computation technologies. Taken together, these two circumstances pushed Weiser to envision a situation in which our everyday environments can be infused with embedded, "invisible" computational power allowing technologies to be useful to users in completely new ways.

The Ishii's more recent proposal of Tangible bits (Ishii & Ullmer, 1997) is based on the observation that with traditional GUI (Graphical User Interface) users act in two different dimensions, that of bits and that of atoms, the first referring to the computational world, the latter to the physical world. The currently most widespread way of interacting with the digital world provided from the use of traditional GUIs is based on a "desktop metaphor". In this situation, the interface simulates a desktop on a bit-mapped screen. However, this metaphor establishes a gap between bits and atoms, that is, between the cyberspace and the physical world. Therefore, the most part of interacting systems does not use those natural abilities that users, as organisms inside the physical world, have developed, like grasping and manipulating. The Ishii's proposal is an attempt to bridge the gap between digital and physical worlds by coupling bits with physical objects. By doing this, interacting systems allow users to exploit those human skills (grasp and manipulate objects) that users are naturally predisposed to use, and the aim is to make interactions more natural and "transparent", that is, intuitive and easier.

With the aim of comparing the interaction with virtual objects using the traditional desktop metaphor with an embodied way to interact involving natural gesture, we conducted the Study 1.

2.2 EXPERIMENT 1: Comparing Input Sensors in an Immersive Mixed-Reality Environment for Human-Computer Symbiosis

Introduction.

In a recent study (Betella et al., 2014) participants had to interact with a large neuroscience dataset either using a common desktop PC, or using an immersive mixed-reality environment. In the first condition, participants explored the information by using a user interface based on the common desktop metaphor, in the second condition they used a novel interface exploiting natural gestures and body movements. Learning performances were analyzed and participants that used natural gestures in the mixed-reality environment showed better performance compared to participants that explored the same dataset with a normal desktop PC. These findings seem to suggest that learning is favored from the embodied interaction when large datasets need to be explored.

The aim of the present study is to take a step forward by measuring and comparing both user experience (UX) and performance related to three different ways to interact with virtual objects in a mixed-reality environment. In particular, we compared the common interaction via keyboard and mouse with two types of embodied interaction in a mixed-reality environment created with the eXperience Induction Machine (XIM) (Bernardet et al., 2010). The XIM is an immersive environment endowed with effectors (loudspeakers and projectors) and sensors (for a detailed description see the section "Setting and equipment") conceived with the purpose of studying and evaluating the human-artifact interaction in condition of good ecological validity (Bernardet et al., 2010). This mixed-reality environment has been inspired by the ADA project, that is a large-scale public exhibit for the Swiss Expo.02 national exhibition (Eng et al., 2002). The study evaluates the interface of BrainX^3 (Arsiwalla et al., 2015; Betella et al., 2014), an application designed for exploration of neuroscience datasets that has been develop using the XIM framework. As for the embodied interaction, two motion-sensing input devices were selected, the Microsoft Kinect360, and the next version released by Microsoft, the KinectOne. In the XIM, visualization and interaction were controlled by the XIM-engine (Omedas et al., 2014). The XIM-engine was in charge of interpreting the input of sensors (e.g., the Kinect) and change the visualization accordingly.

Therefore, with the present study, we compared both performance and UX inside the XIM using the BrainX^3 interface, when subjects used for interacting respectively the Kinect360, or the KinectOne or the keyboard and the mouse. Important, for this study we conceived the interaction by means of the Kinect360 requiring the use of the mouse. The mouse had to be keep in the right hand. Conversely, the interaction by means of the KinectOne did not require the mouse and any other physical artifact.

Subjects were asked to perform some tasks within the XIM using one input system. Then they had to repeat the same tasks with a second and a third input system. As for the UX, we measured it using two questionnaires, and our hypothesis was that subjects would express better evaluations of the interaction via the Kinect360 and via the KinectOne compared with the keyboard and the mouse. Our hypotheses rooted in the idea that gestural input systems, precisely because they are natural systems, would reduce the abstraction of input actions and also the subjects' effort needed to input commands. Indeed, gestural inputs (e.g. taking a step backward to zoom-out the visual content) were designed to easily suggest their meaning, namely the action they allow to perform. In general, with gestural inputs the user is not asked to learn an abstract association between a specific action (e.g., pressing a specific keyboard key) and a specific consequent response by the system. Moreover, we hypothesized that subjects would express better evaluations of the interaction via the KinectOne compared with the Kinect360. This hypothesis was based on the fact that, in our opinion, subjects would experience the use of the KinectOne as more natural and simple due to the fact that, in our study, the Kinect360 required the use of a mouse, while the KinectOne did not.

Finally, we measured the performance in terms of task execution time, and we hypothesized that users would perform faster with the keyboard and the mouse due to the fact that they were very accustomed to use them.

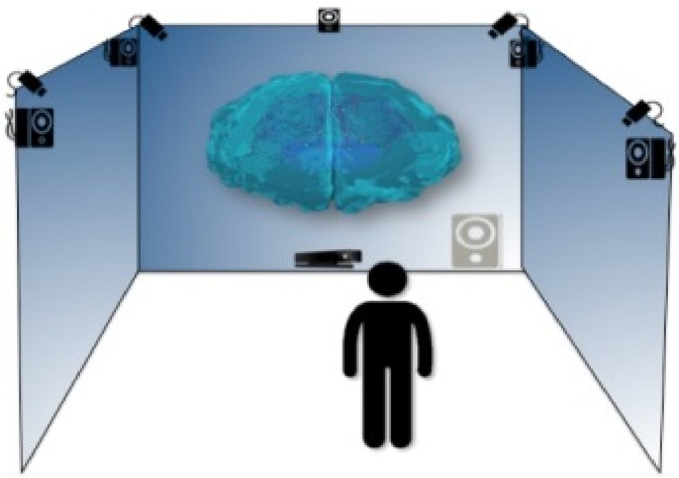


Fig. 3. The eXperience Induction Machine (XIM) (adapted from Negri et al., 2015)

Method.

Participants.

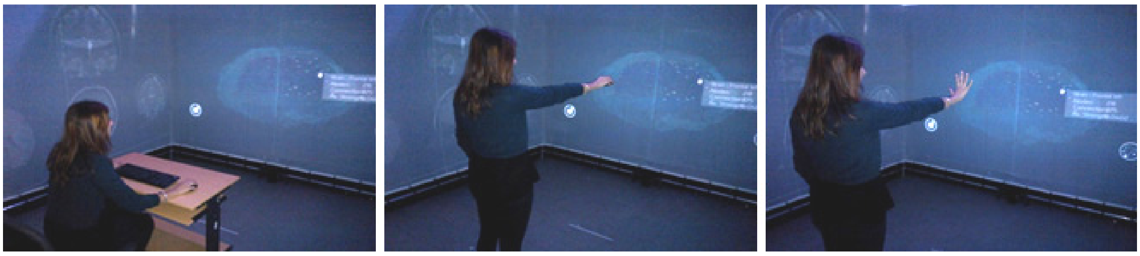
Twelve undergraduate/graduate students of the University of Padua were recruited for this study (9 males and 3 females; mean age = 23.91; SD = 2.43; range 20-28). All participants had normal or corrected-to-normal vision and gave their informed consent.

Design.

Participants were asked to perform a series of ten tasks within the XIM. The input system was varied in a within-subjects design, that is, all the subjects used all three input systems, and the order of the input systems was counterbalanced across subjects.

Setting and equipment.

During the whole experiment, the participant was the only person that remained within the XIM, and the experimenters monitored the participant through a video-camera and recorded the whole experimental session through other four video-cameras that were installed inside the XIM (Figure 3). The participant was instructed through pre-recorded vocal commands. In the key-board and mouse condition, the participant could move the pointer on the XIM's screen by means of the mouse. Moreover, he/she could select a button of the interface or a cerebral area by pressing the left button of the mouse (in the next session the software will be presented). In the two Kinect conditions, the participant could control the pointer on the XIM's screen by moving the right hand with the arm stretched (Figure 4). Between the two Kinect there was only one difference, that is the way to select cerebral areas or buttons. In fact, with the KinectOne, the participant had to close and then open the right hand, instead with the Kinect360 he/she had to press the left button of the mouse he/she kept in the right hand. Another important difference in the way the participant had to interact with the interface regarded the zooming actions. In the keyboard and mouse condition, the participant had to perform the zoom in and the zoom out by using two keyboard keys, instead in the two Kinect conditions he/she had to step forward or backward respectively.



Keyboard and mouse Kinect360 and mouse KinectOne

Fig. 4. The three experimental conditions: (1) keyboard and mouse; (2) Kinect360 (in this condition the participant was required to keep a mouse in the right hand and to use its left button to select some part in the interface); (3) KinectOne.

Three PCs were employed in the experiment. A first PC was dedicated to the three projectors that allowed the interface to be displayed on the three XIM's screens. A second PC was used for the two Kinect, and a third PC was utilized for the four video-cameras used to videorecord the participant during the experiment while interacting with the interface.

The interface.

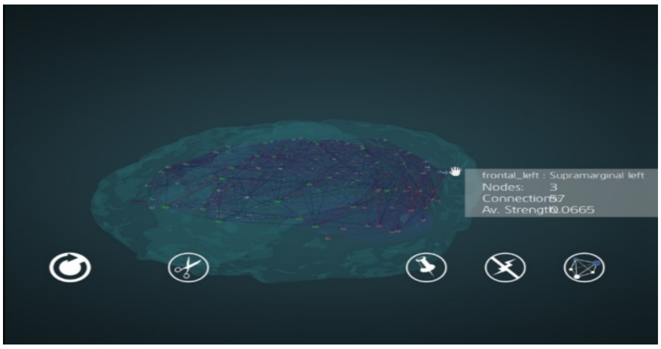


Fig. 5. The interface (adapted from Negri et al., 2015)

The XIM's interface used in the experiment was designed to allow the interaction with a neuroscience dataset displayed by the BrainX[3] application. The interface consisted of three parts, and each part was projected on a different panel, the frontal one and two lateral ones. In Figure 5 the frontal panel of the XIM is represented. In this panel the connectome, that is the 3D model of the human brain was displayed. In the lower part of this screen, five buttons were presented. Starting from the lower right, the complexity button was always displayed, and by clicking on it, the participant could increase or decrease the complexity level of the connectome. The three central buttons were displayed whenever the pointer was placed on any area of the brain. The inject activity button was used to visualize the neural activity of a cerebral area; the bookmark button was used to highlight any cerebral area; the remove button was used to remove any action previously performed on a cerebral area. Finally, in the lower left, the reset button was always displayed, and by clicking on it the connectome went backs to the starting position.

The right screen displayed the information about the cerebral area on which the pointer was currently located, while the left screen offered four representations of the brain, three were related to the different planes of view (sagittal, coronary and transverse), and one representation (that one on the top center) was a 3D representation of the brain. In all the representations, the current position of the participant inside the brain was constantly displayed. For a full description of the interface see Betella et al. (2014).

Tasks.

The participant was asked to perform 10 tasks inside the XIM: (1) Multiple pointing. The participant had to place the pointer above three cerebral areas highlighted by the researcher with a laser pointer in a predefined, fixed sequence. (2) Using the bookmark button. The participant had to select a specific area, grab the corresponding circle, drag it on the Bookmark button and then release it. (3) Performing a horizontal leftward rotation. The participant had to horizontally rotate the brain until a specific cerebral area (highlighted by the researcher), which was initially located laterally to the right, came to be located in the central area of the frontal panel. (4) Performing a horizontal rightward rotation. The participant had to horizontally rotate the brain until a specific cerebral area (highlighted by the researcher), which was initially located laterally to the left, came to be located in the central area of the frontal panel. (5) Performing a vertical downward rotation. The participant had to vertically rotate the brain until a specific cerebral area (highlighted by the researcher), which was initially located in a rostral position within the brain, came to be positioned in the central area of the frontal panel. (6) Performing a vertical upward rotation. The participant had to vertically rotate the brain until a specific cerebral area (highlighted by the researcher), which was initially located in an inferior position within the brain, came to be positioned in the central area of the frontal panel. (7) Zooming in. The participant had to increase the size of the connectome till it reached its maximum. (8) Zooming out. The participant had to reduce the size of the connectome till it reached its minimum. (9) Using the inject activity button. The participant had to visualize the neural activity of a cerebral area by grabbing the corresponding circle and dropping it on the Inject Activity button. (10) Using the remove button. The participant had to remove the neural activity of a cerebral area by grabbing the corresponding circle and dropping it on the Remove button.

According to the number of movements that were required to complete the task, the 10 tasks differed in complexity.

Measures.

Task execution time. The time required to the participant to complete each task was measured and considered as a measure of performance.

Video recording. The whole experimental session was recorded in order to perform video analysis of the participants while executing the tasks with each input system.

Task-related questionnaire. At the end of each task, a first UX questionnaire was administered for the purpose of measuring the UX for each combination of input system and task. The questionnaire consisted in six items, and the participant was asked to express his/her agreement using a 5-point Likert scale. The items were the following: (1) The execution of the commands is easy; (2) The execution of the commands is pleasant; (3) The meaning of the command is intuitively associated with its function; (4) The system responds promptly to the command; (5) The execution of the command is complicated; (6) The cursor/brain on the display moves smoothly.

Device-related questionnaire. At the end of the experiment, a second UX questionnaire was administered for the purpose of comparing the UX related to the use of the three input systems. The questionnaire consisted in the following 7 items: (1) Which system is easier to use? (2) Which system is more pleasant to use? (3) Which movement was the most difficult to perform with the Kinect360? (4) Which movement was the most difficult to perform with the KinectOne? (5) Which movement was the most difficult to perform with the Keyboard? (6) Which system seemed smoother? (7) What would you change in general?

Procedure.

The experimental procedure started with the filling in the informed consent that contained a release note for the video-recorded material. After that, the participant entered the XIM. The participant was informed that he/she would have to complete various tasks which required to interact with the connectome by using the three input systems. Afterwards, the participant was asked to reach the starting position, namely, a desktop positioned at the center of the XIM (in the keyboard and mouse condition) or a white line on the floor at the center of the XIM (in the two Kinect conditions). For each task, pre-recorded instructions were presented to the participant and this latter could ask to repeat them when needed. The instructions related to the same task could be slightly different in accordance to the input system. When the task required it, one experimenter was in charge of highlighting the specific cerebral area on which the task had to be executed by using a laser pointer. No time limit was set to complete the task and, after each task, the participant could take a short break and was asked to fill in the task-related questionnaire. After all the 10 tasks were completed with one input system, the participant started anew with the subsequent input system. Therefore, overall, the same task series was repeated three times. The order of conditions (i.e., the order of use of the input systems) was counterbalanced. The experimenters monitored the participant while performing the tasks from outside the XIM, and at the end of the whole experiment participants were asked to fill in the device-related questionnaire. The testing session lasted about one hour.

Results.

Task execution time.

As for the task execution time, in order to see if the input system utilized had an effect on the performance, we performed a repeated-measures ANOVA with input system (three levels) and task (ten levels) as within-participants factors. This analysis revealed a main effect of the task, $F(9,99) = 11.63$, $p < .001$, $\eta^2_p = .51$, indicating that, regardless of the input system, the ten tasks differed in the time needed to accomplish them. This result showed that the task series included tasks of varying difficulty.

Table 1. Marginal Means, Standard Errors and *p*-value of Time (in seconds) on Task, by Type of Sensor. * refers to the comparison between Keyboard/Mouse and Kinect360, ** between Keyboard/Mouse and KinectOne, and *** between Kinect360 and KinectOne. In the *p*-value column only statistically significant comparisons are reported. (Adapted from Negri et al., 2014).

Task	Keyboard/Mouse (n=12)	Kinect 360 (n=12)	KinectOne (n=12)	*p*-value
	M (SE)	*M (SE)*	*M (SE)*	
Multiple pointing	6.37 (0.31)	16.28 (1.21)	17.94 (3.12)	* < .001 ** = .009
Bookmark button	4.97 (0.20)	12.54 (1.74)	10.11 (0.67)	* = .003 ** < .001
Horizontal leftward rotation	9.74 (1.29)	11.67 (1.53)	11.37 (1.78)	-
Horizontal rightward rotation	7.91 (0.90)	12.10 (2.79)	11.23 (2.04)	-
Vertical downward rotation	3.82 (0.37)	10.87 (1.20)	15.36 (2.79)	* < .001 ** = .004
Vertical upward rotation	3.70 (0.39)	12.33 (1.04)	9.30 (1.35)	* < .001 ** = .001
Zoom-in	11.39 (0.17)	25.39 (2.56)	12.95 (0.43)	* = .001 ** = .034 *** = .001
Zoom-out	10.69 (0.29)	15.21 (0.84)	27.12 (3.14)	* = .002 ** = .001 *** = .003
Inject activity button	4.89 (0.16)	11.12 (0.84)	11.90 (2.79)	* < .001
Remove button	4.31 (0.11)	10.44 (1.02)	8.78 (0.68)	* < .001 ** < .001

The same analysis revealed also a main effect of the input system, $F(2,22) = 72.99$, $p < .001$, $\eta^2_p = .869$, indicating that, regardless of the specific task, the mean time needed by the participants in order to complete a task differed with the three input systems. The pairwise comparisons showed that when using the keyboard/mouse (*M* = 6.78, *SD* = 1.03) participants completed their tasks faster than with both the Kinect360 (*M* = 13.80, *SD* = 1.96; $p < .001$, *d* = 4.48) and the KinectOne (*M* = 13.60, *SD* = 2.88; $p < .001$, *d* = 3.15). No significant differences emerged between the Kinect360 and the KinectOne.

Moreover, a two-way interaction between input system and task emerged, $F(18,198) = 5.94$, $p < .001$, $\eta^2_p = .35$, indicating that the three input systems performed differently with regard to the execution time depending on the task. We therefore compared the performance task by task, and we found that where there was a difference it was in favor of the keyboard/mouse condition. Between the two Kinect conditions there was generally no difference except in the zoom-in task where participants were faster when they used the KinectOne than when they used the Kinect360, and in the zoom-out task where we found the opposite result. The pairwise comparisons are summarized in Table 1.

Video analysis.

We performed a video analysis on the recorded experimental session to identify the occurrence of "action breakdowns" (Gamberini et al., 2013), that is observable interruptions in the course of an action not due to system failures (e.g. rotation interruptions). From the video analysis three type of breakdowns emerged during the task execution: (1) rotation interruptions: the gesture with the right arm was executed incorrectly causing the interruption of the action; (2) zoom-in interruptions: the subject moved outside of the field within which the Kinect could detect his/her body; in these situations the interface stopped working until the subject came back inside the area tracked by the Kinect; (3) cursor accuracy: the subject was not able to maintain the cursor stationary or stable while performing an action.

Table 2. N. of participants experiencing each type of breakdown per condition (adapted from Negri et al., 2014).

	Keyboard/Mouse	Kinect360	KinectOne
Rotation interruptions	1	5	2
Zoom-in interruption	0	4	0
Cursor accuracy	1	8	1

Table 2 shows that a higher number of subjects experienced action breakdowns when they utilized the Kinect360 as input system. Instead, when they used the KinectOne and Keyboard/mouse, they experienced a lower number of breakdowns. Therefore, using the Kinect360 subjects encountered difficulties mainly under the following circumstances: (a) involuntary movements interpreted by the system as commands; (b) difficulties in recognizing the participant if outside of the tracking area (too close or too far from the Kinect); (c) difficulties in recognizing gestures if not performed properly.

Questionnaires.

Task-related questionnaire. First of all, we recoded negative items so that higher scores corresponded to a positive evaluation. The Kronback's alpha of the questionnaire in the three conditions was high (keyboard/mouse $\alpha = .97$; Kinect360 $\alpha = .98$; KinectOne $\alpha = .98$), showing consistency between the items. In order to see if the input system utilized had an effect on the UX, we performed a repeated-measures ANOVA with the input system (three levels), task (ten levels), and question (six levels) as within-participants factors.

The analysis revealed the main effect of the input system, $F(2,22) = 3.80$, $p = .04$, $\eta^2_p = .257$. However, the pairwise comparisons did not show any significant differences between input systems.

From the ANOVA also the main effect of the task emerged, $F(3.663, 40.291) = 4.132$, $p = .008$, $\eta^2_p = .27$, indicating that, regardless of the input device or the specific question, the ten tasks differed in their overall evaluation.

Table 3. Marginal Means, Standard Errors and *p*-value of User experience scores by Task and Type of Sensor (data from Task-related questionnaire). * refers to the comparison between Keyboard/Mouse and Kinect360, ** between Keyboard/Mouse and KinectOne, and *** between Kinect360 and KinectOne. In the *p*-value column only statistically significant comparisons are reported (adapted from Negri et al., 2014).

Task	Keyboard/Mouse (n=12)	Kinect 360 (n=12)	KinectOne (n=12)	*p*-value
	M (SE)	*M (SE)*	*M (SE)*	
Multiple pointing	4.33 (0.18)	3.33 (0.18)	3.81 (0.27)	* = .001
Bookmark button	4.40 (0.15)	3.51 (0.19)	3.82 (0.25)	* = .002
Horizontal leftward rotation	3.98 (0.24)	4.01 (0.20)	4.00 (0.20)	-
Horizontal rightward rotation	4.01 (0.22)	4.08 (0.19)	4.10 (0.19)	-
Vertical downward rotation	4.29 (0.16)	3.99 (0.21)	3.71 (0.26)	** = .030
Vertical upward rotation	4.36 (0.14)	3.93 (0.22)	4.00 (0.20)	-
Zoom-in	4.33 (0.13)	4.32 (0.17)	4.40 (0.16)	-
Zoom-out	4.24 (0.11)	4.35 (0.15)	4.22 (0.18)	-
Inject activity button	4.26 (0.19)	3.85 (0.23)	4.10 (0.22)	-
Remove button	4.36 (0.18)	3.79 (0.24)	4.22 (0.19)	* = .034 *** = .009

A two-way interaction between input system and task emerged, $F(18,198) = 4.687$, $p < .001$, $\eta^2_p = .30$, indicating that the three input systems differed in the overall evaluation depending on the task. However, the pairwise comparisons revealed a difference between input systems only in four tasks out of ten, and it was in favor of the keyboard/mouse condition at the expenses of the Kinect360 condition. The pairwise comparisons are summarized in Table 3.

The ANOVA also revealed a two-way interaction between the input system and the questionnaire items, $F(4.069,44.758) = 6.88$, $p < .001$, $\eta^2_p = .385$, indicating that, regardless of the task, participants evaluated the UX differently when using different input systems depending of the specific question. The pairwise comparisons are summarized in Table 4.

Table 4. Marginal Means and Standard Errors of User Experience scores, by question and Type of Sensor. (data from Task-related questionnaire). * refers to the comparison between Keyboard/Mouse and Kinect360, ** between Keyboard/Mouse and KinectOne, and *** between Kinect360 and KinectOne. In the *p*-value column only statistically significant comparisons are reported (adapted from Negri et al., 2014).

Item	Keyboard/Mouse (n=12)	Kinect 360 (n=12)	KinectOne (n=12)	*p*-value
	M (SE)	*M (SE)*	*M (SE)*	
The execution of the commands is easy	4.70 (0.12)	4.13 (0.16)	4.30 (0.16)	* = .017
The execution of the commands is pleasant	3.71 (0.17)	3.83 (0.27)	4.18 (0.24)	-
The meaning of the command is intuitively associated with its function	4.12 (0.15)	4.22 (0.18)	4.31 (0.21)	-
The system responds promptly to the command	4.27 (0.19)	3.72 (0.20)	3.70 (0.20)	* = .005 ** = .017
The execution of the command is complicated	1.34 (0.14)	1.95 (0.17)	1.97 (0.19)	* = .014 ** = .014
The cursor/brain on the display moves smoothly	4.09 (0.28)	3.52 (0.21)	3.71 (0.25)	* = .025

Device-related questionnaire. As for the question “which system is easier to use”, the majority of participants (83%) evaluated the keyboard/mouse as the easiest. A small number of participants (17%) evaluated the KinectOne as the easiest system to use. None of the participants considered the Kinect360 as the easiest system to use.

Noteworthy, in answering the question “which system is more pleasant to use” the majority of participants (58,4%) evaluated the KinectOne as the more pleasant. A third of the participants (33,3%) evaluated the keyboard/mouse as the more pleasant. Only one (8.3%) participant considered the Kinect360 as the more pleasant.

As for the questions “which movement was the most difficult to perform with the Kinect360 (or the KinectOne or the Keyboard/mouse)”, a lower number of issues have been observed in the keyboard/mouse condition. In fact, for this condition 9 participants out of 12 responded “none”, whereas for the Kinects conditions they indicated a variety of problems (e.g. selecting a node, horizontal rotation). Noteworthy, for the Kinect360, 5 participants out of 12 responded “cursor accuracy”. Finally, in answering the question “which system seemed smoother” all participants evaluated the Keyboard/mouse as the smoother.

Discussion.

With the present study, we aimed at comparing three types of input system when participants interacted with a neuroscience tool called $BrainX^3$ within the XIM, namely an immersive mixed-reality environment. In particular, we compared the most common way to input commands to a computer, that is through the keyboard and a mouse with two embodied input systems. As for the embodied systems, we used two motion-sensing input devices, the widely used Microsoft Kinect360, and the subsequent version released by Microsoft, the KinectOne. These devices allowed a type of interaction with the system interface based on body movements and natural gestures. Specifically, the interaction by means of the KinectOne did not require the use of any physical artifact, and all the actions could be performed through the body. Instead, we conceived the interaction by means of the Kinect360 requiring the use of a mouse to be kept in the right hand. Therefore, this latter condition (Kinect360 and mouse) was a hybrid condition between that one based on the “desktop metaphor” (keyboard and mouse) and the completely embodied and gestural condition (KinectOne).

Therefore, in the present study we measured both performance and UX of participants while they were engaged with 10 tasks that required them to interact with the 3D model of the human brain by using the aforementioned input systems.

As for the UX, we hypothesized that participants would evaluate better the interaction through the two Kinect, and especially that one exploiting only natural gestures (KinectOne condition) compared to the interaction via the keyboard and mouse. As for the performance, we measured it in terms of task execution time, and results showed that participants were faster in completing the tasks when they used the keyboard and mouse compared to both the other input systems.

This result can be partially attributed to the fact that participants were highly familiar with the use of the keyboard and mouse. The same cannot be said for the two gestural input systems.
Regarding the results about the UX, the task related questionnaire did not show differences between input systems in the evaluation of participants in the majority of tasks. Some differences emerged but they regarded the comparison between the keyboard/mouse condition and the Kinect360, and they were in favor of the former. Noteworthy, overall, participants did not evaluate better the keyboard/mouse compared to the KinecOne. This result is particularly interesting if we consider that participants were more familiar with the keyboard/mouse. In addition, in the device related questionnaire the majority of participants evaluated the KinectOne as the more pleasant input system to use. Despite the time that participants needed to complete the tasks was greater when they used the KinectOne, they nonetheless evaluated this input system as the more pleasant during the whole experiment. This result partially supports our hypothesis that participants would judge better the fully embodied interaction. However, we should also consider the possibility that participants favored the KinectOne over the keyboard/mouse in part due to a "novelty effect", namely because it was a quite novel way to interact and hence able to elicit a greater engagement. Finally, the video analysis showed that the number of participants that encountered difficulties during the execution of the tasks was higher in the Kinect360 condition, and there were no differences between the keyboard/mouse and the KinectOne. This result could in part explain the worst evaluation in term of UX that participants expressed in relation to the Kinect360.

Overall, the results of the present study seem to suggest that, in an immersive mixed-reality environment as the XIM, an embodied input system that does not require the use of any physical artifact is preferred to the common input system based on the use of keyboard and mouse even if participants performed better with this latter. In this regard, in the present study, we did not put in place any training, but future research might consider the opportunity to implement it in order to make the participants more familiar with the new input system. In this way, it might be possible to reduce the likelihood that the traditional system results in better performances not because it is the best system per se, but only because participants have a greater expertise level in using it.

Ethical concerns.

In the present study we identified some ethical concerns mainly related to the video recording of the participant during the whole experimental session, and to the use of this video recordings for research purposes. Moreover, during the experiment we also collected the task execution times and the answers to the questionnaires items. We addressed these ethical issues by informing the participant about the experimental procedure, the data we would collected and the purposes of the study. We used an informed consent with an information note that contained all the afore-mentioned information (appendix 1), and a specific release note for the video-recorded material.

My contribution.

My personal contribution to the realization of this study concerns the conception of the experimental design, the data collection, the data analysis and the interpretation of the results. These data were presented in a paper published in the proceedings of Symbiotic2015 (Negri et al., 2015).

3 CHAPTER THREE

3.1 Contributions from Affective and Physiological Computing

A research field relevant to symbiotic interaction is Affective Computing. Affective Computing is an interdisciplinary field involving computer science, engineering, psychology, neuroscience and more, that aims to endow computers with emotional skills. Affective Computing has been defined by Rosalind Picard as “computing that relates to, arises from, or deliberately influences emotions.” (Picard, 2000, p. 3). Affective Computing considers at least four general abilities to be provided to computers: emotion recognition, emotion expression, feeling emotions, having emotional intelligence.

In the last decades, research highlighted the essential role that emotions play in many psychological processes as attention (Izard, 1993), perception and memory (LeDoux, 1996), and social interaction (Salovey & Mayer, 1990). As for social interaction, it has been demonstrated (e.g., Reeves & Nass, 1996) that people interact with computers as if they were social entities. This is also evident when users admit to swearing at computers (Mori, 1999). Exactly like emotions take naturally part of interaction between humans, they also hallmark interaction between humans and computers, and this gives reason to equip computers with emotional abilities.

Undoubtedly, emotions impact health. The effect that psychological stress exerts on physical health conditions is well-known (e.g., Cohen, Tyrrell, & Smith, 1991; Barefoot, Dahlstrom, & Williams, 1983).

Relevant, emotions also impact functions thought as purely rational like decision making (Damasio, 1994) and problem solving (Isen, Daubman, & Nowicki, 1987). As demonstrated by the well-known Damasio’s studies with frontal lobe patients, a lack of emotions also impairs the decision making. Isen and colleagues (1987) demonstrated that when inducing positive emotions the creative problem solving improves.

For all these reasons the effort to equip computers with emotional intelligence seems to be a necessary step in order to deepen the mutual relationship between men and machines. And precisely for this reason, the Affective computing is relevant to build more symbiotic relationships (Jacucci et al., 2014).

Generally, the Affective Computing research focuses either on developing virtual agents endowed with the capacity to express emotions (Ball & Breese, 2000; Rosis, Pelachaud, Poggi, Carofiglio, & Carolis, 2003), or in detecting user's affective states to use as input to the system. Usually, the process of detecting affective states makes use of physiological measures, including brain signals and peripheral nervous system activities like electrodermal activity (EDA), heart rate (HR), facial electromyography (fEMG), blood volume pressure (BVP).

Affective states represent a fundamental aspect to consider when we want to build a representation of the user's state. A symbiotic system needs to be "aware" of the emotions that the user feels during his interaction in order to make, in real time, those changes that seem suitable to optimize the user's affective state.

However, the affective component is just one of the components that a symbiotic system should consider in order to make computers able to achieve a wider knowledge of the user. Besides the emotional component, the system needs to be able to account at least some features related to the cognitive state of the user. For instance, during his interaction with the system the user could be tired and distracted, or very attentive; he could be very attentive to some part of information or be cognitively overloaded. According to these cognitive states, a symbiotic system needs to be able to "react" through making those changes that seem to be required in order to assist the user. The capacity to monitor the user's affective and cognitive state is a key ability also to achieve a more reciprocal and symmetric relationship between humans and computers that is required to realize a symbiotic relationship (Jacucci, 2014). The need to go beyond the knowledge of the affective state, going towards an understanding of the cognitive components, pushes us towards the concept of physiological computing.

Physiological computing represents an "innovative mode of HCI where system interaction is achieved by monitoring, analyzing and responding to covert psychophysiological activity from the user in real-time" (Fairclough, 2009, p. 133). Physiological computing aims at monitoring both the user's affective states (e.g., Kapoor, Burleson, & Picard, 2007) and/or cognitive states (e.g., Wilson, 2003) and is constructed around a biocybernetic loop. Physiological data of the user are collected and classified to inform an adaptive controller which, in turn, is responsible for implementing adaptive actions in the interface (Fairclough, 2009). Recently, Fairclough (2015) made the proposal of a first- and second-order adaptation that is particularly relevant to symbiotic systems. The first-order adaptation consists in a loop that starts with monitoring the user's state. The loop ends with the implementation of adaptive actions. This first-order adaptation clearly requires a set of rules that combine each user's state to at least one adaptive action. However, the same user's state could be faced with a multiplicity of alternative actions. For instance, the frustration of the user can be faced with an offer of help or, alternatively, with the suggestion of a break, and so on. Therefore, the first-order adaptation is characterized by a certain level of improvisation, that is, the system performs default adaptive actions. The second-order adaptation consists in detecting those changes in the user's state that are direct consequence of adaptive actions, and allows the system to collect information about the user and his preferences across repeated interactions with him. This second-order adaptation makes the system capable to tailor the adaptive repertoire of actions to the specific user, represents a phase of reciprocal coupling and, in the long term, it leads to a co-evolution of the system and the user.

3.2 Related work

A key challenge of the biocybernetic loop is the capacity to monitor the user's state or intention, from which the ability to translate physiological data into appropriate adaptive actions depends. In this respect, many works have been published. All these investigations are particularly interesting because they "brought out of the lab" some psychophysiological measures, representing an important step towards those ecological conditions that we encounter in case of concrete use in real tasks. For instance, in the field of information seeking in complex scenarios, a recent study (Pluchino, Gamberini, Barral, & Minelle, 2014) investigated the possibility of using the pupil behavior of users as implicit input to improve the interaction between information retrieval systems and users. In particular, the study investigated the relationship between semantic processing of words and pupil behavior through a semantic priming experiment in which the semantic association between words was manipulated. Results showed faster pupil dilation in trials in which words were semantically associated. In another study (Golenia, Wenzel, & Blankertz, 2015) authors built a demo application to deal with those conditions in which users, when searching images on the web, are confronted with irrelevant results due to ambiguous queries. The demo used EEG and eye-tracking data to disambiguate the possible interpretation of an ambiguous query. Results showed that from these data is possible to predict the right subcategory of searching results, namely, those results that are relevant to the subcategory that the user has previously chosen. In another work (Nicolae, Acqualagna, & Blankertz, 2015) an experimental paradigm has been designed to detect brain activity related to three different type of cognitive tasks: memory, language, visual imagery. Results showed that, from event-related potentials of brain activity, is feasible to monitor and recognize the depth of cognitive processing. In another study (Wenzel, Moreira, Lungu, Bogojeski, & Blankertz, 2015) EEG data were used to estimate whether a particular stimulus was relevant for the user's search intent. Both linguistic and abstract stimuli were used, and it is noteworthy that stimuli were more complex compared to those commonly used in brain-computer interfacing, and neural processes related to their recognition occurred with different latencies after the stimulus onset. Despite different latencies, results showed the feasibility of detecting the relevance of the stimulus to the search intent of the user from EEG data. The classification were better when the EEG data were aligned to the user's response compared to when they were aligned to the stimulus-onset. In the neuroaesthetic field, other authors (Babiloni et al., 2015) collected EEG and eye-tracking data when participants were visiting an arts gallery displaying Titian paintings. Results showed that within the first few seconds from the initial exposition of the participant to the painting, the neural and ocular correlates of (un)pleasantness were generated. In another interesting study (Di Flumeri et al., 2015), researchers used the EEG data to estimate the mental workload during an ecological Air Traffic Management (ATM) task. During the task, participants also rated their subjective mental workload. Results showed that the EEG-based mental workload index highly correlated with the subjective evaluation, and was able to discriminate between tasks associated with different difficulty levels. Other works focused on developing new methods of brain-computer interfacing (BCI) to direct brain-robot interface (e.g. Rutkowski, Shimizu, Kodama, Jurica, & Cichocki, 2015).

3.3 EXPERIMENT 2: User Experience and Learning Performance with an Adaptive System

Introduction.

The aim of the present study was to evaluate the XIM system (Omedas et al., 2014) while participants utilized it to explore a neuroscience dataset. In this experiment the input system used in the XIM was an embodied system exploiting body movements and natural gestures without requiring the use of any physical artifact. In particular, since the results of the study 1 seemed to suggest that the KinectOne was the most appreciated system to input commands, it has been selected as input system in the present study. However, this time the XIM system analyzed both explicit (i.e., body movements) and implicit (i.e., pupil dilation, skin conductance and heart rate) input signals from participants. The participant wore sensing devices (Fig. 8) that captured physiological signals, and the XIM system used these physiological measures to build a representation of the participant himself in psychological terms.

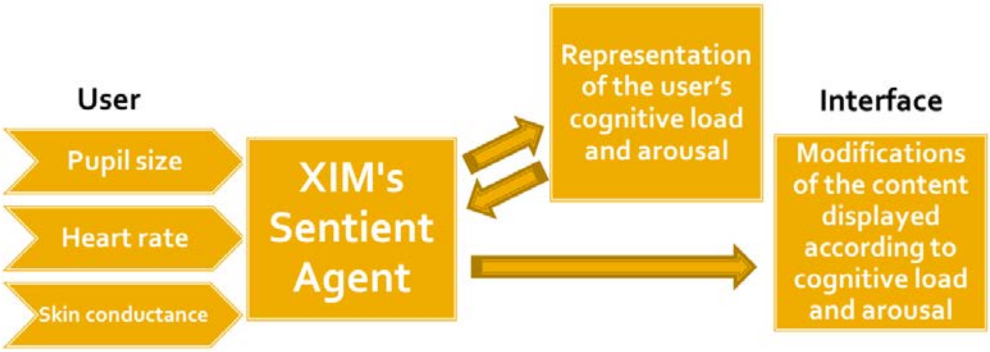


Fig. 6. The XIM's sentient agent used the physiological signals to build a representation of the user in terms of cognitive load and arousal. Then the sentient agent produced some adaptations of the information displayed according to the cognitive load and arousal of the user in order to support him/her during the exploration of the dataset.

In particular, the XIM system was endowed with a new component, the sentient agent (Figure 6), that, using physiological measures, represented in real time the participant's state in terms of arousal and cognitive load and, according to this representation, it applied some modifications to the information displayed on the three XIM's screens in order to support the participant during the interaction. We refer to these modifications as the confluent features (Table 5). Therefore, in order to improve the interaction, the XIM system processed implicit physiological information that were acquired employing different wearable devices (i.e., an eye-tracking helmet, a smart T-shirt and a custom glove were utilized to record respectively pupil size, heart rate and skin conductance). As for the pupil size, it has been reported that highly demanding cognitive tasks in terms of memory load are linked to an increment in pupil size (e.g., Beatty & Kahneman, 1966). Several studies showed that the mental workload increases the pupil size (e.g., Bailey & Iqbal, 2008; Chen, Epps, & Chen, 2013). The increment of pupil size also relates to emotional states (e.g., Hess & Polt, 1960). As for the heart rate, in general, it has been considered as an index of stress. In fact, the heart rate increases in response to psychological stressors (e.g., Ulrich-Lai, & Herman, 2009). Moreover, heart rate has been also linked to cognitive workload (e.g., Brookings, Wilson, & Swain, 1996; Veltman & Gaillard, 1996). As for the skin conductance, this measure is particularly suited to serve as an objective indicator of arousal (e.g., Lang, 1995). In fact, while the vast majority of peripheral measures are affected by both branches of the autonomic nervous system (e.g. heart rate, pulse volume, etc.), the skin conductance is probably the purest indicator of sympathetic activity (Cacioppo, Tassinary, & Berntson, 2007).

According to the level of cognitive load and arousal, once every 30 seconds, the XIM's sentient agent could apply a specific confluent feature that modified the interaction in order to support the participant. As it is shown in table 5, according to the participant's arousal the sentient agent could modify the pointer speed, the navigation speed and the sonification inside the XIM. Specifically, when the participant's arousal was high (in comparison with a baseline level that was computed as the mean value of a period of sixty seconds before the beginning of each phase) the sentient agent could decrease the pointer and navigation speed, and vice versa, when the arousal was low it could increase the pointer and navigation speed. The sonification inside the XIM was associated with the arousal level in a way that was supposed to contribute to raise the arousal when it was too low and lower it when it was too high.

According to the participant's cognitive load the sentient agent could mark one of the areas with a low visit rate. Specifically, when the participant's cognitive load was higher than the baseline level the sentient agent could mark an area with fewer visits with a slow pulsation of its nodes. When the cognitive load was very high the sentient agent could use a fast pulsation of the nodes. Alternatively, when the cognitive load was high the sentient agent could decide to refocus the camera by positioning the user close to one of the areas with fewer visits. Finally, when both arousal and cognitive load were very high the sentient agent could bring back the connectome to its initial position.

The XIM system endowed with the sentient agent became an adaptive system (e.g., Benyon, 1993).

Table 5. Confluent features of the XIM system.

User's state	Modifications
Arousal	Pointer speed
Arousal	Navigation speed: The system increases or decreases the rotation and zoom speed
Arousal	Sonification: The system changes the pitch of the background sound
Cognitive load	Low saliency: The system marks one of the areas with a low visit rate with a slow pulsation of the nodes
Cognitive load	High saliency: The system marks one of the areas with a low visit rate with a fast pulsation of the nodes and by changing their colour

Cognitive load	Refocus on an area: The system refocuses the camera by positioning the user close to one of the areas with fewer visits
Arousal and Cognitive load	Reset camera to the initial view: The system resets the 3D model of the brain to its initial position

Our aim was to evaluate the effectiveness of an adaptive system in supporting a better user experience and a greater learning performance while the participant interacted with a large dataset in a mixed-reality environment. In particular, we compared the UX and the learning performance of participants randomly assigned to three different conditions. Only in one of the experimental conditions the confluent features were properly activated in order to support the participant. We hypothesized that in this condition the participants' learning performance and UX would be better compared to both the control conditions in which the confluent features were not properly implemented.

Method.

Participants.

Thirty-six undergraduate/graduate students of the University of Padua were recruited for this study (13 males and 23 female; mean age = 23.27; SD = 2.08). All participants had normal or corrected-to-normal vision and gave their informed consent.

Design.

Participants were asked to perform a series of tasks within the XIM that required them to explore the connectome, to find specific cerebral areas and to learn information. The symbiotic level of the system was varied in a between-subjects design, that is, participants were randomly assigned to one out of three conditions: confluent, fake-confluent and no-confluent. In the confluent condition the confluent features were properly activated and the system tried to adapt the information displayed according to the participant's state in order to facilitate his/her task. In the fake-confluent condition the system collected the physiological data from the participant but carried out modifications of the information displayed in a random way. Finally, in the no confluent condition the system collected the physiological data but did not perform any modification of the information displayed.

Setting and equipment.

The experiment took place at the Department of Psychology of the University of Padua. The experimental room was divided into two separate areas: the internal space of the XIM and the backstage from which the experimenters monitored the participant (Figure 7).

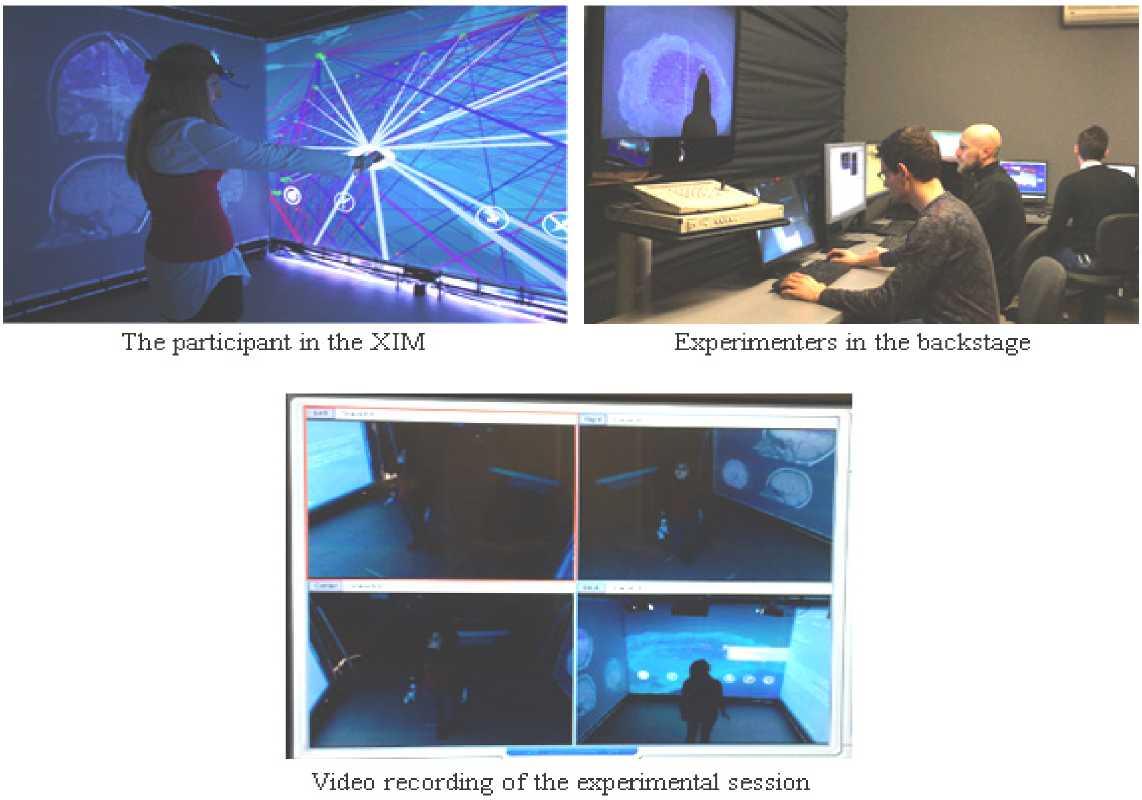


Fig. 7. The participant in the internal space of the XIM; experimenters in the backstage; video recording of the experimental session through four video cameras

As in Study 1, the XIM comprised three output panels (and projectors) arranged in a horseshoe configuration (i.e. a left panel, a frontal panel and a right panel) which displayed the connectome, that is the 3D model of the human brain.

The input system (i.e. KinectOne) that was needed to recognize users' gestures was located in the lower center of the central panel. Four different cameras were placed on different points to allow the recording of the experimental sessions for the subsequent video-analyses. A fifth (directional) camera allowed to monitor the participants during the experimental session.

The backstage contained the hardware needed to run the BrainX[3] (Arsiwalla et al., 2015; Betella et al., 2014) along with the machines to record the physiological signals. Four PCs were utilized in the experiment. A display machine was connected to the three projectors which displayed the interface on the three XIM's panels. A second computer (sensor machine) collected the physiological measures. A third machine was utilized to control the eye-tracker. A fourth PC was connected to the four cameras in order to record the experimental sessions.

The participants wore three physiological sensors (Figure 8), namely an eye-tracking helmet, a smart t-shirt and a custom glove. The eye-tracker provided the data on pupil dilation and eye movements. The smart t-shirt allowed the recording of both the respiratory rate and the ECG (electrocardiogram) from which the heart-rate was derived. Finally, the custom glove that was worn by the participants on their left hand recorded the electrodermal activity and finger movements.

Fig. 8. A participant wearing the sensors: the eye-tracking helmet; the smart t-shirt for respiratory rate and heart rate; the glove for the electrodermal activity.

The gestural input system consisted of a KinectOne placed in the lower center of the frontal XIM panel, and allowed the participants to interact with the system by performing different gestures and movements, mainly with the right arm and the right hand (the gesture required to interact with the system were the same as the Study 1).

The interface.

Fig. 9. The three parts of the XIM's interface projected on the three panels: in the left panel, multiple representation of the cerebral area currently examined; in the central panel, the connectome; in the right panel, information about the cerebral area on which the cursor is located.

The XIM's interface used in the experiment was the same as the study 1, and allowed the interaction with a neuroscience dataset displayed by the BrainX[3] application. The interface consisted of three parts, and each part was projected on a different panel, the frontal one and two lateral ones. In Figure 9 the three parts of the interface are represented. In the central screen the connectome, that is the 3D model of the human brain, was displayed. In the lower part of this screen, the five buttons required to interact with the information were presented: the reset button, the remove button, the bookmark button, the inject activity button and the complexity button (the functions of these buttons have already been described in chapter 2; see Figure 5). The right screen displayed the information about the cerebral area on which the pointer was currently located, while the left screen offered four representations of the brain, three were related to the different planes of view (sagittal, coronary and transverse), and one representation (that one on the top center) was a 3D representation of the brain. In all the representations, the current position of the participant inside the brain was constantly displayed.

Tasks.

The first phase in which the participant had to interact with the XIM was the training phase. During this phase, the participant was instructed on the way to perform the gestures required to interact with the 3D model of the brain. Therefore, the participant was asked to reach the starting position within the XIM, marked by a white line on the floor, and to listen carefully to a set of pre-recorded audio instructions. The instructions contained information on each possible command. After a command and the relative gestures were explained in detail, the participant was asked to execute it. This procedure was repeated until the participants performed properly each command once. In particular the participant was asked to perform the following tasks: (1) Zooming in. The participant had to increase the size of the connectome. (2) Zooming out. The participant had to reduce the size of the connectome. (3) Cursor control: the participant had to move the pointer on the screen. (4) Performing a vertical upwards rotation. The participant had to vertically rotate the brain from bottom to top. (5) Performing a vertical downwards rotation. The participant had to vertically rotate the brain from top to bottom. (6) Performing a horizontal rightward rotation. The participant had to horizontally rotate the brain from left to right. (7) Performing a horizontal leftward rotation. The participant had to horizontally rotate the brain from right to left. (8) Using the bookmark button. The participant had to select a cerebral area, grab the corresponding circle, drag it on the Bookmark button and then release it.

During the following practice phase, the participant was asked to practice the command he/she just learned.

The experiment consisted in three main task session. During the first session, the free exploration, the participant was asked to freely explore the neuroscience dataset and to learn as much information as possible about the contents explored. The participant was also encouraged to pay attention to all three of the panel of the XIM, given that each panel displayed different kinds of information. In the second task session, the participant was asked to perform three different searching tasks. He/she was asked to find three specific cerebral areas (i.e. Pars Triangularis, Cuneus, Parahippocampal) and to find which cerebral lobes were connected to these target areas. In the third task session, the participant was asked to perform other three searching tasks. He/she was asked to find other three cerebral areas (i.e. Pars Opercularis, Postcentral, and the Superior Parietal) and to learn as much information as possible regarding these target areas (e.g. function, neighboring areas, connections, etc.).

Measures

Learning performance. In order to measure the learning performance of participants associated to the three task session, ad hoc questionnaires were utilized. Overall, we used four questionnaires: a pre-test questionnaire (appendix 2) was administered before the first task session (free exploration) to evaluate the participants' prior knowledge about neuroanatomy; the post-test1 questionnaire (appendix 3) was administered after the first task session (free exploration), and this questionnaire contained both three questions that were also presented in the pre-test and other three questions that were not previously presented; after the second task session (first 3 searching tasks) the post-test2 questionnaire (appendix 4) was administered; finally, after the third task session (the second 3 searching tasks) the post-test3 questionnaire (appendix 5) was administered. All questionnaire consisted of both open-ended and multiple-choice questions.

User experience. In order to measure various dimensions of the UX of participants while they interacted with the XIM interface, we administered several UX questionnaires: an ad hoc wearability questionnaire (appendix 13) to measure the UX concerning the wearing of sensing devices (eye-tracking helmet, smart t-shirt and custom glove); the Witmer and Singer presence questionnaire (Witmer & Singer, 1998; appendix 10) to measure the sense of presence; an edited version of the IMI (intrinsic motivation inventory) questionnaire (McAuley, Duncan, & Tammen, 1989; appendix 11) to measure the intrinsic motivation to use the XIM; the NASA-TLX (Hart, 2006; appendix 12) to measure the workload; an acceptance questionnaire (Spagnolli, Guardigli, Orso, Varotto, & Gamberini, 2014; appendix 8) to measure whether the system was accepted by the participants consistently as a tool to support their activity, objective and performance; an ad hoc confluence questionnaire (appendix 6) to measure whether the XIM system was perceived as confluent; an ad hoc credibility questionnaire (appendix 9) to measure whether the system was perceived as credible; a UX questionnaire (appendix 7) to measure other dimensions of the participants' UX.

We performed a video analysis of the video recordings of participants while interacting with the XIM's interface during the experimental sessions. This analysis aimed at understanding what kinds of issues emerged during the interaction with the XIM system.

Physiological measures. During the experimental sessions we collected the pupil size and the heart rate of participants. We considered the pupil dilation as an index of the cognitive load level. In fact, in literature the relationship between pupil dilation and cognitive load has been reported, in particular, it has been shown that cognitive workload increases the pupil size (e.g. Kahneman, 1973). We utilized the heart rate as an index of the stress level. In fact, it has been demonstrated that heart beat increases in response to psychological stressors (e.g., Ulrich-Lai, & Herman, 2009).

Procedure.

The experimental procedure started with the filling in the informed consent that contained a release note for the video-recorded material. After that, the participant was asked to fill in the pre-test questionnaire required to evaluate the participant's prior knowledge about neuroanatomy. Moreover, some other information were collected (e.g., English proficiency level, frequency of use of videogames, etc). These latter information were collected to investigate possible confounds. Then, the participant entered the XIM, where a researcher helped him/her to wear the sensing devices (i.e., eye-tracking helmet, smart t-shirt and glove). Hence, the eye tracker was calibrated with a 9-point calibration procedure. The participant was asked to look at nine dots that appeared one at a time on the frontal panel of the XIM while keeping the head as still as possible.

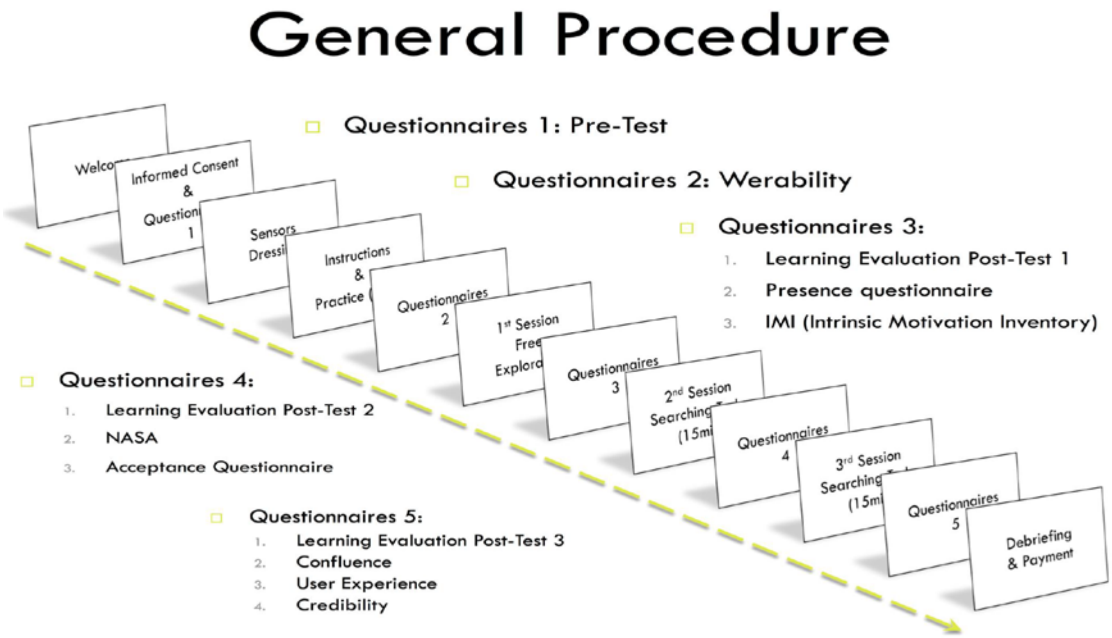


Fig. 10. The experimental procedure

Then, the participant was asked to reach the starting position inside the XIM that was marked by a white line on the floor, and received pre-recorded audio instructions on the way to interact with the XIM interface through the gestures. The audio instructions contained information about each possible command, and after a single command was explained, the participant was asked to perform it and eventually to repeat it till it was properly executed once. After all instruction about gestures were delivered, an additional period of five minutes was left to the participant to practice the command he/she just learned. After this phase, the wearability questionnaire was administered. Followed the first task session, where the participant was asked to freely explore the neuroscience dataset and to learn as much information as possible about the contents he/she explored. The instructions about the task to be performed in this (and also in subsequent) phase were pre-recorded and delivered at the beginning of the experimental phase. This first task session lasted 15 minutes. At the end of this phase, the participant was asked to fill in the post-test1 questionnaire, the presence questionnaire (Witmer & Singer, 1998), and the IMI questionnaire (McAuley, Duncan, & Tammen, 1989). Afterwards, the second task session started, and the participant was required to find three specific cerebral areas (i.e. Pars Triangularis, Cuneus, Parahippocampal) and to learn which cerebral lobes were connected to these areas. After the task instructions were delivered, one minute was left before the beginning of the task in order for the system to compute a baseline level for the physiological signals. An experimenter was responsible for communicating to the participant when to start and when to stop the task. Five minutes were left for each searching task (i.e., for each cerebral area). At the end of this second task session, the participant was asked to fill in the post-test2 questionnaire, the acceptance questionnaire (Spagnolli, Guardigli, Orso, Varotto, & Gamberini, 2014) and the NASA-TLX (Hart, 2006). Followed the third task session, and the participant was asked to find other three cerebral areas (i.e. Pars Opercularis, Postcentral, and the Superior Parietal) and to learn as much information as possible about these areas (e.g. function, neighboring areas, connections, etc.). Like in the previous task session, five minutes were left for each searching task (i.e., for each cerebral area). At the end of this task session, the participant was asked to fill in the post-test3 questionnaire, the credibility questionnaire, the user experience questionnaire and the confluence questionnaire. Afterwards, the participant was invited to take off the sensing devices and he/she was fully debriefed about the experiment. Overall, the experiment lasted about two hours and half.

Results.

Learning performance.

The learning performance was considered to evaluate potential differences between conditions in the level of information learning achieved by participants while performing the tasks. In other words, this analyses tested in which way the XIM confluent features (that are properly active in the confluence condition only) could support users in accomplish the various tasks.

After the first task session, the free exploration, participants were administered the post-test1 questionnaire that contained three questions that were present also in the pre-test. Moreover, three new questions were added. We performed a repeated measures ANOVA on the scores obtained at the questionnaires with the time (two levels: Pre-Test, Post-Test1) as within-participant factor and the condition (three levels: no-confluence, confluence, fake confluence) as between-participants factor. The main effect of time only approached the significance level, $F(1,33) = 4.07$, $p = .052$, $\eta^2_p = .11$, and the main effect of condition did not emerged. No interaction between condition and time was found $F(2,33) = 3.05$, $p = .061$, $\eta^2_p = .16$.

We performed a univariate ANOVA on the scores obtained at the three new questions, with the condition (three levels: no-confluence, confluence, fake confluence) as between-participants factor. The main effect of condition emerged, $F(2,33) = 3.77$, $p = .033$, $\eta^2_p = .19$, however the pairwise comparisons did not highlight differences between conditions.

We performed a MANOVA considering as dependent variable the scores obtained at multiple-choice and open-ended questions after the second as well as after the third task sessions.

The analysis revealed, at multivariate level, the main effect of condition Wilks' Lambda = .453, $F(8,60) = 3.64$, $p = .02$, $\eta^2_p = .33$. At univariate level, the main effect of condition emerged, F(2,33) = 10.83, p < .001, η2p = .40, pertaining the scores at the three open-ended questions administered after the second task session. Pairwise comparisons showed a difference between the confluence condition ($M = 3.62$) and both other conditions ($M = 2.04$, $p = .04$, and $M = .81$, $p < .001$). The analysis also revealed the main effect of condition regarding the score at the three open-ended questions administered after the third task session, $F(2,33) = 4.92$, $p = .013$, η^2_p =

.23. Pairwise comparisons showed that the learning outcome in the confluence condition (*M* = 6.45) outperformed the outcome in the no-confluence condition (*M* = 3.10, *p* = .012). At univariate level, no differences emerged concerning the multiple-choice questions in both the second and third task session.

Video analysis.

We performed a video analysis of the video recordings of participants while interacting with the XIM's interface during the experimental sessions. This analysis aimed at understanding what kinds of issues emerged during the interaction with the XIM system. In particular, three different types of occurrences were considered while reviewing the recordings: (1) errors made by the participants while executing a particular command or trying to accomplish a specific goal; (2) repetitions; (3) action breakdowns (Gamberini et al., 2013), that is observable interruptions in the course of an action not due to system failures. The occurrence of the different types of issue in the three conditions is reported in Table 6. The number of errors and repetitions in the confluence condition is lower compared to both the other conditions. Moreover, the confluence condition showed a higher number of breakdowns, along with the fake confluence condition, in comparisons to the no-confluence condition.

Table 6. Occurrence of errors, repetitions and action breakdowns observed during the interaction with the XIM inferface per condition

	NO-CONFLUENCE (n = 12)	**FAKE CONFLUENCE** (n = 12)	**CONFLUENCE** (n = 12)
Errors	43	37	23
Repetitions	4	8	2
Breakdowns	4	29	22
Total	51	74	47

The video analysis revealed the following six kinds of error: (1) rotation error. The participant was clearly trying to perform a rotation of the brain but failed either because he/she did not properly close the right hand in the first place or because he/she opened it shortly after the beginning of the rotation; (2) grab & release error. The participant tried to bookmark an area but he/she released the node outside of the target button; (3) undesired rotation. The participant unwittingly closed the right hand and lowers the right arm; consequently, the brain rotates downward until the hand was opened again; (4) undesired selection. The participant unwittingly closed and opened the right hand, mistakenly selecting a node or a button as a consequence; (5) undesired zoom-in and zoom-out. The participant stood slightly closer/farther from the frontal screen compared to the neutral position, and consequently he/she unwittingly performed the zoom-in/out command; (6) text exit error. The participant opened/moved the right hand while reading the text on the right screen, and consequently the text disappeared.

The aforementioned errors were mainly due to unwitting or incorrect movements which resulted in the execution of undesired commands. The analysis revealed that a lower number of errors occurred in the confluence condition. This result might be attributed to the fact that in the confluent condition the system often reduced the interaction speed, hence the participants may have been facilitated in the execution of precise movements. The video analysis revealed that the action breakdowns occurred in correspondence of some adaptations of the information displayed that the system performed in relation to the arousal and cognitive load of the participant. In particular, action breakdown emerged in correspondence of the following four kinds of adaptation: (1) complexity increase/decrease. The system decided to adapt the information on the central screen by increasing/decreasing the visual complexity of the connectome just when the participant was pursuing a specific goal. (2) Camera reset. The system decided to resets the camera (that is the point of view of the participant on connectome). (3) Spatial cueing. The system increased the visual saliency of a single node or group of nodes in the connectome just when the participant was looking for a different area. (4) Camera refocus. The system changed the point of view of the participant on the connectome by placing him/her close to an area/lobe with a low visit rate when he/she was freely exploring the brain. Therefore, the action breakdowns were mainly due to some adaptations of the interface produced by the system and related to the confluent features. Sometimes, the adaptations forced participants to re-map the interaction space.

User experience.

Confluence questionnaire. We performed a MANOVA on the mean values of the confluence questionnaire items. The mean values and standard deviations of answers are listed in Table 7. The analysis revealed, at multivariate level, the main effect of condition, Wilks' Lambda = .072, $F(28,40) = 3.91$, $p = .001$, $\eta^2_p = .73$. At univariate level some items showed a difference in the mean values across conditions. Considering the following items, the confluent condition showed higher scores compared to one or both other conditions: "I felt the system was taking into ac-

Table 7. Mean values and standard deviations of answers to confluence items per condition. * = comparisons confluence Vs. no-confluence conditions; * = comparisons confluence Vs. fake confluence conditions. Answers were on a 6-point Likert scale.

Confluence questionnaire	NO-CONFLUENCE (n = 12)		FAKE CONFLUENCE (n = 12)		CONFLUENCE (n = 12)	
ITEMS	*M*	*SD*	*M*	*SD*	*M*	*SD*
1. Overall I am satisfied with the system	4,33	1,15	4,25	1,06	4,08	0,79
I felt the system…						
2. …was taking into account my previous actions on it	**2,75***	**1,48**	**3,42**	**1,44**	**4,17***	**0,94**
3. …responded like it knew what I wanted	3,00	1,28	3,42	1,24	3,58	0,79
4. …was responding to more than my explicit requests	2,67	1,15	3,08	1,16	3,17	1,19
5. …responded meaningfully	**4,33***	**0,98**	**3,58**	**1,08**	**3,00***	**1,21**
6. …anticipated what I was going to do next	**2,42***	**1,38**	**2,67***	**0,98**	**3,83****	**0,83**
7. …was an extension of my body	2,92	1,24	3,58	1,31	3,42	1,51
8 …was an extension of my brain	2,25	0,87	3,42	1,31	2,92	1,08
9 …was sensitive to my feelings	**1,33***	**0,49**	**1,08***	**0,29**	**3,08****	**1,31**

10 …helped me to refine my goals and objectives	2,50	1,51	3,50*	1,17	1,92*	1,00
11 …and I understood each other	**1,92***	**1,00**	**2,25***	**1,48**	**4,25****	**0,75**
12 …was useful	4,25	0,87	4,17	1,03	4,42	0,79
13 …made my task easier	4,00	1,13	4,00	1,13	3,58	1,31
14 …enabled me to discover something relevant	4,50	1,17	5,00	0,60	3,92	1,17

count my previous actions on it", $F(2,33) = 3.50$, $p = .042$, $\eta^2_p = .17$; "I felt the system was anticipated what I was going to do next", $F(2,33) = 5.76$, $p = .007$, $\eta^2_p = .26$); "I felt the system was sensitive to my feelings", $F(2,33) = 20.90$, $p < .001$, $\eta^2_p = .56$; "I felt the system and I understood each other", $F(2,33) = 15.22$, $p < .001$, $\eta^2_p = .48$. Pairwise comparisons qualified these differences across conditions. Regarding the following items the confluence condition showed higher mean values compared to one or both the explicit and fake confluence conditions respectively: "I felt the system was taking into account my previous actions on it" (i.e. confluence *Vs*. explicit condition, $p = .04$), "I felt the system was anticipated what I was going to do next" (i.e. confluence *Vs*. explicit, $p = .01$, and confluence *Vs*. fake confluence, $p = .04$), "I felt the system was sensitive to my feelings" (i.e., confluence *Vs*. explicit, $p < .001$, and confluence *Vs*. fake confluence, $p < .001$), and "I felt the system and I understood each other" (i.e., confluence *Vs*. explicit, $p < .001$, and confluence *Vs*. fake confluence, $p < .001$). Regarding the items "I felt the system responded meaningfully" and "I felt the system helped me to refine my goals and objectives" the analysis showed differences between conditions where the confluence condition did not obtain the higher score. It seems that the users were not fully satisfied with the kind of response received from the system, although they perceived that there was a response to their internal state.

Acceptance questionnaire. We performed a MANOVA on the mean values of the acceptance questionnaire items. At multivariate level the main effect of condition did not emerge ($F > 1$). Therefore we only tested the difference with the mean value of the scale for the item scores in the whole sample, without distinguishing per condition. The results of the one sample *t*-test are shown in Table 8.

The XIM system seems to be accepted by participants consistently as a tool to support their activity. Some lower scores emerged where the focus shifts from supporting activity to supporting objective and performance at large.

Table 8. Means, Standard Deviations and results of one sample t-test for acceptance items. Negative items are in italics. Answers were on a 6-point Likert scale.

Acceptance questionnaire				
ITEMS	***M***	***SD***	***t***	***p***
1. Overall, I think information technology (computer, cell phones, …) brings about some benefits	4.92	1.13	10.17	0.00**
2. Nowadays, I think that information technology (computer, cell phones, …) is indispensable	4.89	1.12	10.16	0.00**
3. I constantly have to deal with information technology (computer, cell phones, …)	4.81	1.21	8.92	0.00**
4. When I have to use information technology (computer, cell phones, …) I fear I can break it or make some irreversible mistakes	2.44	1.08	-3.08	0.00**
5. Most issues connected to information technology (compute, cell phones, …) are difficult	2.36	0.93	-4.12	0.00**
6. The possibility of using a technology or a device that I have never used makes me feel anxious	2.11	1.30	-4.09	0.00**
7. The XIM device would be incompatible with most aspect of my activity	2.81	1.24	-0.94	0.35
8. The XIM device limits the way in which I like to perform my activity	2.69	1.41	-1.30	0.20
9. The XIM device could help reaching my objectives	3.50	1.38	2.17	0.04*
10. The XIM device could improve my performance	3.72	1.54	2.81	0.01*

11. The XIM device could improve the quality of my activity	3.61	1.40	2.62	0.01*
12. It seems easy to learn how to use XIM device	4.47	1.03	8.60	0.00**
13. It seems tiresome to use the XIM device	3.39	1.25	1.87	0.07
14. If the XIM were available to me, I would use it	3.89	1.51	3.54	0.00**
15. If the XIM device were sold at an affordable price, I would buy it	3.56	1.61	2.07	0.05
16. I think I would use the XIM device only if were forced to	2.42	1.08	-3.24	0.00**
*17. I*f people who are influent in my life recommended me to use the XIM device for a period of time, I would do so	4.25	1.48	5.07	0.00**
18. If most people in my environment used the XIM device, I would be more inclined to use it as well	3.92	1.38	3.98	0.00**
19. I think that the invasion of the privacy is not a negligible issue	2.11	1.43	-3.73	0.00**
20. I think that the XIM device threatens my privacy	2.00	1.17	-5.12	0.00**
21. Wearing the XIM components feels weird physically	2.97	1.23	-0.14	0.89
22. I think that the XIM device was pleasant	3.92	1.16	4.76	0.00**
23. I think that the XIM device was annoying	2.72	1.23	-1.35	0.19
24. I think that the XIM device was boring	2.39	0.93	-3.92	0.00**
25. I think that the XIM device was comfortable	3.61	1.10	3.33	0.00**
26. I think that the XIM device was well suited to my body	3.67	1.51	2.65	0.01*

Credibility questionnaire. We performed a MANOVA on the mean values of the credibility questionnaire items. The analysis revealed that, at multivariate level, the main effect of condition did not emerge (F < 1). Therefore, we only tested the difference with the mean value of the scale for the item scores in the whole sample, without distinguishing per condition. The results are shown in Table 9.

The values and the analysis showed that, regardless of the condition, the credibility of the system and data was high.

Table 9. Means, Standard Deviations and results of one sample t-test for credibility items. Items 6, 11, 12 are not shown because there was a high number of missing values. Answers were on a 6-point Likert scale.

Credibility questionnaire				
ITEMS	*M*	*SD*	*t*	*p*
1. The XIM device is believable	5.06	0.92	13.35	0.00**
2. …accurate	4.78	0.96	11.12	0.00**
3. … informative	4.92	1.08	10.66	0.00**
4. … interesting	4.69	1.09	9.32	0.00**
5. … relevant	4.64	0.96	10.24	0.00**
7. … objective	4.50	1.80	5.01	0.00**
8. The XIM interface is clear	4.61	0.99	9.73	0.00**
9. The graphical elements composing the interface (icons, photos) are organized in a thoughtful way on the screens	4.58	1.02	9.27	0.00**
10. The graphics are aesthetically attractive	4.33	1.10	7.30	0.00**

Presence questionnaire. We performed a MANOVA on the mean values of the presence questionnaire items. At multivariate level the main effect of condition did not emerge (F < 1). Therefore, we only tested the difference with the mean value of the scale for the item scores in the whole sample, without distinguishing per condition. The results are shown in Table 10. Regardless of the condition, the participants evaluated positively the different items of every dimensions (i.e. realism, possibility to act, quality of interface, possibility to examine, self-evaluation of performance, sounds, haptic).

Table 10. Means, Standard Deviations and results of one sample t-test for presence items. Negative items are in italics. Answers were on a 7-point Likert scale.

Presence questionnaire				
ITEMS	*M*	*SD*	*t*	*p*
1. How much were you able to control events?	4.58	1.08	6.02	0.00**
2. How responsive was the environment to actions that you initiated (or performed)?	4.67	1.10	6.39	0.00**
3. How natural did your interactions with the environment seem?	4.28	1.26	3.72	0.00**
4. How completely were all of your senses engaged?	4.17	1.16	3.45	0.00**
5. How much did the visual aspects of the environment involve you?	5.17	1.23	8.13	0.00**
6. How much did the auditory aspects of the environment involve you?	3.00	1.45	-2.06	0.05
7. How natural was the mechanism which controlled movement through the environment?	3.81	1.55	1.19	0.24
8. How aware were you of events occurring in the real world around you?	3.53	1.56	0.11	0.92
9. How aware were you of your display and control devices?	3.72	1.54	0.87	0.39
10. How compelling was your sense of objects moving through space?	4.97	1.42	6.20	0.00**
11. How inconsistent or disconnected was the information coming from your various senses?	2.69	1.14	-4.23	0.00**
12. How much did your experiences in the virtual environment seem consistent with your real-world experiences?	4.03	1.18	2.68	0.01**

13. Were you able to anticipate what would happen next in response to the actions that you performed?	5.31	1.28	8.44	0.00**
14. How completely were you able to actively survey or search the environment using vision?	4.92	1.59	5.34	0.00**
15. How well could you identify sounds?	3.61	1.87	0.36	0.72
16. How well could you localize sounds?	3.44	1.87	-0.18	0.86
17. How well could you actively survey or search the virtual environment using touch?	3.17	1.92	-1.04	0.31
18. How compelling was your sense of moving around inside the virtual environment?	4.42	1.34	4.11	0.00**
19. How closely were you able to examine objects?	5.36	1.53	7.28	0.00**
20. How well could you examine objects from multiple viewpoints?	4.75	1.25	6.00	0.00**
21. How well could you move or manipulate objects in the virtual environment?	4.75	1.30	5.79	0.00**
22. To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session?	2.86	1.40	-2.74	0.01**
23. How involved were you in the virtual environment experience?	4.78	1.17	6.53	0.00**
24. *How distracting was the control mechanism?*	2.94	1.33	-2.51	0.02**
25. *How much delay did you experience between your actions and expected outcomes?*	3.00	1.04	-2.88	0.01**
26. How quickly did you adjust to the virtual environment experience?	5.14	0.99	9.93	0.00**
27. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?	4.47	1.30	4.49	0.00**

28. *How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?*	2.53	1.18	-4.93	0.00**
29. *How much did the control devices interfere with the performance of assigned tasks or with other activities?*	2.86	1.29	-2.97	0.01*
30. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?	3.89	1.33	1.76	0.09
31. Did you learn new techniques that enabled you to improve your performance?	3.69	1.09	1.07	0.29
32. Were you involved in the experimental task to the extent that you lost track of time?	4.28	1.37	3.42	0.00**

User experience questionnaire. We performed a MANOVA on the mean values of the user experience questionnaire items. At multivariate level the main effect of condition did not emerge ($F < 1$). Therefore, we only tested the difference with the mean value of the scale for the item scores in the whole sample, without distinguishing per condition. The results are shown in Table 11. Regardless of the condition, the participants evaluated the system and the interaction positively in all the items of every dimension of UX (i.e., pleasantness, engagement, spatial presence and time perception, usability, comfort). In particular the XIM system was evaluated as pleasant, engaging, interesting, attractive, up to expectations, ease, intuitive, learnable. It received midway evaluations with respect to frustration, gratification, excitement or sustained interest.

Table 11. Means, Standard Deviations and results of one sample t-test for user experience items. Negative items are in italics. Answers were on a 6-point Likert scale.

User experience questionnaire				
ITEMS	*M*	*SD*	*t*	*p*
1. Please indicate to what extent you believe the system to be pleasant	4.14	1.13	6.07	0.00**
2. Please indicate to what extent you believe the system to be attractive	4.42	1.25	6.80	0.00**
3. Please indicate to what extent you believe the system to be engaging	4.67	1.07	9.35	0.00**
4. Please indicate to what extent you believe the system to be fun	3.92	1.16	4.76	0.00**
5. *Please indicate to what extent you believe the system to be boring*	*2.81*	*0.92*	*-1.27*	*0.21*
6. Please indicate to what extent you believe the system to be interesting	4.69	0.89	11.44	0.00**
7. *Please indicate to what extent you agree that using the system generates frustration*	*3.47*	*1.23*	*2.30*	*0.03**
8. Please indicate to what extent you agree that using the system helps keeping focused toward the objectives	4.17	1.00	7.00	0.00**
9. Please indicate to what extent you agree that using the system motivates to learn its content	4.11	0.98	6.81	0.00**
10. Please indicate to what extent you agree that using the system is a gratifying experience	3.47	1.25	2.26	0.03*
11. Please indicate to what extent you agree that using the system is an exciting activity	3.44	1.46	1.82	0.08
12. Please indicate to what extent you agree that using the system is an experience that overall meets my expectations	4.03	1.11	5.57	0.00**

13. Please indicate to what extent you agree that using the system can cause people to lose track of time	4.00	1.43	4.18	0.00**
14. Please indicate to what extent you agree that using the system completely engrosses its user	3.97	1.38	4.22	0.00**
15. Please indicate to what extent you agree that using the system leads to pay more attention to its content compared to the users' personal thoughts	4.72	1.09	9.52	0.00**
16. *Please indicate to what extent you agree that using the system causes concentration falls during the interaction*	*3.03*	*1.18*	*0.14*	*0.89*
17. *Please indicate to what extent you agree that using the system in the long run causes a decline in the interest toward the interaction*	*3.14*	*1.61*	*0.52*	*0.61*
18. Please indicate to what extent you agree that using the system is captivating	4.42	0.73	11.61	0.00**
19. Please indicate to what extent you agree that using the system arouses one's curiosity	4.72	0.70	14.73	0.00**
20. The system is easy to use	3.92	0.97	5.69	0.00**
21. The meaning of the commands is intuitively associated with their function	4.64	0.93	10.57	0.00**
22. *I had to learn a lot of things before I could get going with the system*	*2.83*	*1.18*	*-0.85*	*0.40*
23. After making a mistake, I was able to recover quickly	4.06	1.09	5.79	0.00**
24. I could easily explore the information presented on every screen	3.83	1.34	3.73	0.00**
25. I was able to manipulate the position of the brain the way I wanted	3.89	1.17	4.58	0.00**

26. The system responded to my commands the way I wanted it to	3.61	1.13	3.25	0.00**
27. I clearly understood what my position was relative to the brain at all times	4.28	1.37	5.62	0.00**
28. The system enabled me to understand the spatial relations between the different cerebral areas in clear way	3.92	1.32	4.18	0.00**
29. The system enabled me to identify the connections between different cerebral areas	4.78	1.07	9.95	0.00**
30. The execution of the commands distracted me from the task I was supposed perform	3.11	1.21	0.55	0.59
31. The cursor moved smoothly on the display	2.78	1.33	-1.00	0.32
32. The brain moved slowly on the display	3.69	1.28	3.25	0.00**
33. It was comfortable having to stand during the interaction	3.39	1.27	1.84	0.08
34. *At the end of the session my right arm was fatigued*	*3.64*	*1.62*	*2.36*	*0.02***
35. It was comfortable having to interact with large displays	4.64	1.20	8.20	0.00**

Intrinsic motivation inventory. We performed a MANOVA on the mean values of the edited version of the IMI items. At multivariate level the main effect of condition did not emerge ($F < 1$). Therefore, the level of intrinsic motivation of the participants was equivalent across conditions. We only tested the difference with the mean value of the scale for the item scores in the whole sample, without distinguishing per condition. The results are shown in Table 12. The analysis showed that, overall, participants felted motivated to use the XIM system. This questionnaire was administered to disentangle the possible influence of different levels of intrinsic motivation across conditions on the learning performance, and results allow us to rule out this possibility.

Table 12. Means, Standard Deviations and results of one sample t-test for motivation items. Negative items are in italics. Answers were on a 7-point Likert scale.

Intrinsic motivation inventory				
ITEMS	*M*	*SD*	*t*	*p*
1. I enjoyed using the XIM very much	4.89	1.43	5.83	0.00**
2. I think I’m pretty good at using the XIM	4.06	1.19	2.79	0.01**
3. I put a lot of effort into using the XIM	4.08	1.56	2.25	0.03*
4. It was important to me to do well with the XIM	4.81	1.33	5.90	0.00**
5. I felt tense while using the XIM	3.33	1.71	-0.59	0.56
6. I tried very hard while using the XIM	5.06	1.22	7.67	0.00**
7. Using the XIM was fun	4.78	1.53	5.00	0.00**
8. I would describe the XIM as very interesting	5.47	1.34	8.82	0.00**
9. I am satisfied with my performance with the XIM	3.94	1.49	1.79	0.08
10. *I felt pressured while using the XIM*	3.11	1.65	-1.41	0.17
11. *I was anxious while using the XIM*	2.78	1.61	-2.70	0.01**
12. *I didn’t try very hard at using the XIM*	2.47	1.44	-4.27	0.00**
13. While using the XIM, I was thinking about how much I enjoyed it	3.69	1.72	0.68	0.50
14. After using the XIM for a while, I felt pretty competent	4.28	1.14	4.11	0.00**
15. I was very relaxed while using the XIM	3.81	1.60	1.15	0.26
16. I am pretty skilled at using the XIM	3.92	1.18	2.12	0.04**
17. *The XIM did not hold my attention*	2.25	1.18	-6.36	0.00**
18. *I couldn’t use the XIM very well*	3.47	1.32	-0.13	0.90

NASA-TLX. We performed a univariate ANOVA on the overall mean scores of the NASA-TLX questionnaire. This questionnaire consists of a series of six items that evaluated the general workload of the participant that is composed of six dimensions (i.e. mental demand, physical demand, temporal demand, performance, effort, and frustration). We followed the procedure suggested by Hart (Hart, 2006) and we only provided the overall workload index. These data are presented in Table 13. The analysis did not revealed the effect of condition, hence participants' general workload was not different across conditions. However, the overall workload indexes were higher that 55 in all conditions and, according to the rating scale proposed in (Galičič, Fallon, Van der Putten, and Sands, 2013) this means that the workload level was generally high in all the conditions.

Table 13. Means and Standard Deviations of the Overall Workload scores per condition (NASA-TLX).

NASA-TLX	**NO CONFLUENCE** (n = 12)		**FAKE CONFLUENCE** (n = 12)		**CONFLUENCE** (n = 12)	
	M	*SD*	*M*	*SD*	*M*	*SD*
Workload overall scores	61,85	12,68	65,68	8,10	67,14	15,51

Physiological measures.

Pupil diameter. We calculated the mean pupil size in all the experimental phases in all conditions. We performed a repeated measures ANOVA with condition (three levels: no confluence, fake confluence, confluence) as between-participants factor, and time (two levels: baseline, experimental session) and experimental phase (seven levels: first session, second session/task1, second session/task2, second session/task3, third session/task1, third session/task2, third session/task3) as within participants factors. The aim of the analysis was to evaluate three aspects: (1) a potential difference in mean pupil size across conditions; (2) a potential difference between the mean pupil size during the baseline period (a period of sixty second before the beginning of every experimental phase) and the mean pupil size during the experimental phase; (3) a potential difference in mean pupil size among experimental phases. The analysis revealed the main effect of the condition, $F(2,33) = 3.41$, $p = .044$, $\eta^2_p = .17$. However, the pairwise comparisons did not highlighted differences between conditions. This result is coherent with the NASA-TLX outcome, and seems to suggest that there were no differences between conditions about the workload level. The analysis also revealed the main effect of time $F(1, 33) = 5.54$, $p = .025$, η^2_p =.14. The pairwise comparisons highlighted that the mean pupil size during the experimental sessions (M = 12.37 pixels) was larger than during the baseline periods (M = 11.44 pixels; p = .02). The analysis did not reveal any other effects.

Heart rate. We calculated the mean heart rate (beats per minute; bpm) in all the experimental phases in all conditions. We performed a MANOVA considering as dependent variables the mean heart rate in the different experimental phases. At multivariate level the main effect of condition emerged Wilks' Lambda, $F(14,54) = 2.43$, $p = .010$, $\eta^2_p = .38$. At univariate level, the main effect of condition emerged respectively for the second task $F(2,33) = 3.56$, $p = .04$, $\eta^2_p = .18$ as well as for the third task of the second task session $F(2,33) = 3.42$, $p = .04$, $\eta^2_p = .17$. Moreover, the main effect of condition emerged for the third task of the third task session $F(2,33) = 7.31$, $p < .01$, $\eta^2_p = .31$. Pairwise comparisons showed that in the second as well as in the third task of the second task session the mean heart rate in the confluence condition was lower than in the fake confluence condition ($p = .04$ for the second task; $p = .04$, for the third task). Moreover, in the third task of the third task session the heart rate in the confluence condition was lower than in both the no confluence ($p = .04$) and fake confluence ($p = .002$) conditions. Heart rate increases in response to psychological stressor (Ulrich-Lai, & Herman, 2009). Despite the fact that the results of the NASA-TLX questionnaire showed that the general workload was equivalent in the three conditions, results of heart rate analysis suggested that the kind of workload experienced in the confluence condition was not due to a higher stress level. In fact, heart rate showed that for half of the six searching tasks (i.e. all the tasks of the second and third task session) participants seemed to be less stressed in the confluence condition.

Correlation between physiological measures and learning performance. As for the pupil size, we performed a series of separated correlational analysis respectively for the no confluence, the fake confluence and the confluence conditions. We considered the mean pupil size and the learning performances in the corresponding experimental phases. In particular, we tested the correlation between: (1) the scores to the post-test1 questionnaire and the mean pupil size during the first task session; (2) the scores to the open-ended questions of the post-test2 questionnaire and the mean pupil size during the second task session; (2) the scores to the open-ended questions of the post-test3 questionnaire and the mean pupil size during the third task session. No significant correlations emerged suggesting that, during the experiment, the mean pupil size and the learning performance did not relate.

As for the heart rate, we performed another series of separated correlational analysis respectively for the no confluence, the fake confluence and the confluence conditions. We tested the correlation between the mean heart rate and the learning performances in the corresponding experimental phases. The analysis revealed three negative correlations: the lower the mean heart rate, the higher the post-test scores. In particular, in the second task session, only considering the confluence condition, a negative correlation emerged between the mean heart rate during the second task and the post-test2 scores, r = - .79, p = .002; another negative correlation emerged between the mean heart rate during the third task and the post-test2 scores, r = -.64, p = .027. Finally, in the third task session, only considering the no confluence condition, a negative correlation emerged between the mean heart rate during the second task and the post-test3 scores r = -.59, p = .043.

Discussion.

The aim of the present study was to evaluate the XIM system (Omedas et al., 2014) while participants utilized it to explore a neuroscience dataset. In particular, the participants were asked to perform some tasks that required them to freely explore the connectome and to learn as much information as possible, and to find specific cerebral areas and to learn some specific information about them. In the experiment we compared three conditions: (1) the confluence condition in which the system properly implemented some confluent features; in this condition the sentient agent utilized the physiological signals of the participant to build a representation of the psychological state of the participant himself. According to this representation, the sentient agent adapted some features of the interaction in order to support the participant's task; (2) the fake confluence condition in which the system performed some modifications of the interaction but in a random way, hence not properly to support the participant; (3) the no confluence condition in which the system did not apply any modification to the interaction.

Therefore, our aim was to evaluate the effectiveness of an adaptive system in supporting a better user experience and a greater learning performance while the participant interacted with a large dataset in a mixed-reality environment. We hypothesized that in the confluence condition the participants' learning performance and UX would be better compared to both the fake confluence and no confluence conditions in which the confluent features were not properly implemented.

As for the learning performance, the results showed that the XIM's confluent features, when properly implemented (namely, in the confluence condition), supported learning of specific information from the neuroscience dataset. In fact, in the second task session the confluence condition outperformed both the other conditions, and in the third task session, it outperformed the no confluence condition. In the confluence condition, participants learned more information about the specific areas of the brain that they had to search. Therefore, it seems that the confluent features, designed to support the participant when his/her arousal and/or cognitive load were too high, actually did it, at least during the two session of searching tasks. However there was no difference between the conditions relating to the free exploration task. We can speculate that no difference emerged due to the fact that, in this task, the participants did not need to deeply explore the connectome, but simply to acquire general information about the brain, and this information was easily accessible.

As for the user experience, the results of the questionnaires showed that the user experience did not differ across conditions, except for the sense of confluence. Regardless of the condition, participants evaluated the XIM system as able to generate a sense of presence, credible and acceptable by the users as a tool to support their activity. Overall, the system received good ratings in all dimensions of the UX irrespective of the condition. However, the results of the confluence questionnaire confirmed that in the confluence condition the participants felt the system as more confluent compared to the other conditions.

We also analyzed the physiological signals of participants while they interacted with the system in all the experimental phases. As for the pupil behavior, the results showed that there were no differences between conditions about the mean pupil size. Since the cognitive workload increases the pupil size (e.g., Bailey & Iqbal, 2008; Chen, Epps, & Chen, 2013), this result seems to suggest that there were no differences between conditions about the cognitive workload. As for the heart rate, a difference was unveiled between conditions in three out of six searching tasks composing the second and third task sessions. Namely, the mean hart rate of participants was lower in the confluence condition compared to one or both the other conditions. Since the heart rate increases in response to psychological stressors (e.g., Ulrich-Lai, & Herman, 2009), this result seems to suggest that participants in the confluence condition were less stressed compared to the other conditions. Moreover, significant correlations emerged between the mean heart rate and the learning performance. In particular, for participants in the confluence condition, for half of the searching tasks composing the second and third task sessions, a negative correlation emerged between the mean heart rate and the learning scores. Therefore, it seems that in the confluence condition, the lower was the stress level of the participants, the higher was their learning performance.

To sum up, the XIM system with confluent features seemed to support both learning performance and UX. The system made use of several sources of implicit information by both collecting various physiological signals with wearable sensors and by monitoring the information that participants explored and those which they had not yet explored. In this way the XIM system was capable of intervening in a symbiotic way. The results of the present study are encouraging, suggesting that an adaptive system can support learning of information when interacting with large datasets making use of implicit information related to the user's psychological state. In order to generalize the results, future research might test the system using other types of datasets. Moreover, additional efforts need to be devoted to test other physiological index able to represent cognitive and emotional states and processes.

Ethical concerns.

In the present study we identified some ethical concerns mainly related to the video recording of the participant during the whole experimental session, and to the use of this video recordings for research purposes. Moreover, during the experiment we also collected the participant's physiological data (eye behavior, heart rate, skin conductance) and the answers to the questionnaires items. We addressed these ethical issues by informing the participant about the experimental procedure, the data we would collected and the purposes of the study. We used an informed consent with an information note that contained all the aforementioned information (appendix 14), and a specific release note for the video-recorded material.

My contribution.

My personal contribution to the realization of this study concerns the conception of the experimental design, the data collection, the data analysis and the interpretation of the results.

4 CHAPTER FOUR

4.1 Contributions from Subliminal Perception

First of all, we need to define what is meant by subliminal stimuli. A visual stimulus can be defined as subliminal when some of its features (e.g., a very brief presentation) prevent its conscious perception. However, in order to be defined as subliminal, besides the absence of awareness about its existence, it is also necessary to prove that the stimulus is able to affect the human's mental activity and behavior.

Throughout the twentieth century, psychological research has adopted a variety of techniques to make subliminal a visual stimulus (Negri, Gamberini, & Cutini, 2014). In fact, we know a variety of ways to obtain unconscious perception of a visual stimulus.

Recently, unconscious information processing is entered in the interest of applied research in HCI. The reason for this interest lies in the fact that subliminal information processing is not worsened even if it occurs simultaneously with other cognitive processes (Debner & Jacoby, 1994). In general, by embedding subliminal stimuli in user interfaces the aim is to enrich the communication between computers and humans with a low cost for the human cognitive system. This can be particularly useful when the user's cognitive system is at risk of becoming overloaded due to a large amount of information to be processed.

The relevance of subliminal information processing for symbiotic systems lies in the fact that it could become a fundamental branch of a deeper reciprocal interaction loop between humans and machines. As we saw in the previous chapter, the computer can achieve a wider understanding of the user's state and intentions by capturing implicit signals with sensing devices. On the other hand, the computer could covertly ignite unconscious mental activity and automatic responses in the user exploiting a stimulation occurring below the "limen" of human consciousness. Therefore, subliminal stimulation could be introduced in symbiotic systems as an additional communication channel to improve the human-computer interaction.

A good illustration of this idea is presented in the work of Pizzi et al. (2012). Authors proposed a conception of a mixed-reality platform useful to support 3D visualization of information. The system is equipped with an intelligent narrative engine conceived with the aim to induce particular user experiences during the interaction with the visual information. The narrative engine takes into account both explicit behavior and psychophysiological signals of the user to adapt itself, in real time, to the user's state. Moreover, the system uses subliminal stimuli as a mechanism to covertly guide the user during the information exploration. The system might use this hidden guide to (a) assist the user when he needs help, (b) to shift the interest of the user to other information to be noticed, or (c) to maintain his interest on a particular part of information (Pizzi et al., 2012). This hidden assistance could improve the user experience because subliminal perception does not generate additional mental workload (Riener, Kempter, Saari, & Revett, 2011; DeVaul, Pentland, & Corey, 2003) and the user is not required to interrupt his task at hand.

Even though subliminal perception is a very long-standing topic in psychology, to date, only few efforts have been made to tackle issues concerning the effective use of subliminal stimuli in concrete scenarios. The most part of research has been conducted to investigate visual perception, and very abstract tasks have been used to this purpose. Conversely, we need to investigate the effectiveness of subliminal perception in more ecological scenarios to understand how subliminal stimuli can be effectively incorporated into user interfaces.

4.2 Related Work

In this section, we briefly review some recent studies representing the few attempts to investigate subliminal perception in realistic scenarios.

In a first study (Chalfoun & Frasson, 2011) subliminal cues were used in a virtual tutoring system to facilitate the users during some learning tasks. Results showed that subliminal stimulation has led to both better learning performances and also better affective states throughout the learning session. In another study (DeVaul, Pentland, & Corey, 2003) subliminal stimuli have been delivered in a head-mounted display, and results showed the effectiveness of subliminal cueing as memory retrieval aid.

Other studies (McNamara, Bailey, & Grimm, 2008; Bailey, McNamara, Sudarsanam, & Grimm, 2009) investigated the effectiveness of subliminal cueing in visual search tasks in GUIs.

A more recent study (Cetnarski, Betella, Prins, Kouider, & Verschure, 2014) investigated the use of subliminal cueing to bias the participants' behavior in a navigation task inside a mixed-reality environment. Seated inside an immersive environment representing a virtual maze, participants had to navigate within this maze. Specifically, they had to make a number of dichotomous choices between two alternative paths to advance in the virtual environment. Prior to each choice, participants were subliminally exposed to a visual stimulus which could be either a neutral stimulus or an aversive one (i.e. a spider). Some paths were negatively labeled (with the spider), and other paths were associated with the neutral stimulus. Results showed that participants were more likely to avoid paths associated with the aversive stimulus. Therefore this study demonstrated that subliminal arousing picture can bias the decision-making concerning a navigation task in a mixed-reality environment.

Findings of aforementioned few works suggests that, in concrete scenarios, subliminal stimulation is suitable for a variety of uses as those of learning support (Chalfoun & Frasson, 2011) and memory retrieval tool (DeVaul et al., 2003) and to bias decision-making in navigation tasks (Cetnarski et al., 2014).

For the best of our knowledge, to date, no studies have been conducted to investigate the effectiveness of subliminal cueing to bias selection behavior between alternative objects in concrete scenarios. This lack in research has led us to conceive the study 3.

4.3 EXPERIMENT 3: Subliminal Cueing of Selection Behavior

Introduction.

The aim of the present study was to investigate the effects of subliminal cueing in a context in which the participants were engaged in interacting with 3D objects in a Virtual Environment (VE). In particular, participants were involved in a realistic task that required them to select food items from a virtual model of a refrigerator Electrolux, developed in Unity (Figure 11).

Fig. 11. A virtual model of the refrigerator used in the study (adapted from Aranyi et al., 2014).

In previous sections we discussed the potential applicability of including subliminal cues in user interfaces to improve the interaction. However, we also stressed that there is a lack of knowledge about how to employ subliminal cueing in realistic scenarios and concrete tasks, especially for the purpose of biasing the selection behavior of people between virtual objects. Therefore, we conducted a study to tackle with the following research question: can users' selection behavior be biased by subliminal cueing in a VE? To address this question, we decided to use a series of trials in which a forced-choice task between two objects had to be performed while one of the object was subliminally cued immediately before each choice behavior. We used the visual masking to make the prime subliminal. Moreover, we tested two types of masked priming: (1) in a first condition we adopted a single exposition of the masked prime; (2) in a second condition we used a paradigm in which the masked prime was exposed multiple times. Our first hypothesis was that primed objects would be more frequently selected than expected by chance. Our second hypothesis was that the priming effect would be larger in the condition of multiple exposures of the prime than in the single presentation condition.

Method.

Participants.

Sixteen people from the academic and administrative staff of the Teesside University were recruited for this study (7 males and 9 females; mean age = 36.69; SD = 8.14). All participants had normal or corrected-to-normal vision and gave their informed consent. Participants received the equivalent of £20 pounds vouchers as incentive.

Design.

Participants were asked to perform a series of forced-choice tasks between two virtual food items in a virtual environment. In particular, one of the two food items was subliminally cued immediately before the choice behavior, and participants were asked to select the item corresponding to the cued object, to pick it up from the refrigerator and to place it on an adjacent table. The type of masked priming (single exposure *vs*. multiple exposure of the masked prime) was varied in a within-subjects design.

Setting and equipment.

The Unity 3D games engine (version 4.0.1f2) has been used for the stimuli presentation and data collection. One PC was employed in the experiment: a Dell Precision T7600 (CPU: Intel Xeon E5-2609 2.40GHz; 32GB RAM; GPU: NVidia GeForce GTX 680; OS: MS Windows 7 Enterprise 64-bit) with a 24'' Dell U2412M monitor (60Hz refresh rate, 1920x1200 resolution). In the experiment we used ten 3D food items (i.e., apple, burger, cheese, fish, lemon, pear, pepper, pie, pizza, and tomato). For each of these target items a corresponding prime has been created in greyscale (the primes had same luminosity and contrast), normalized in size, and displayed from an angle so that it appeared roughly circular. These properties of the primes allowed us to use the same masks (forward and backward) for each target object, and in this way we avoided possible confounds attributable to mask properties. The two masks were created with Adobe Photoshop CS6 by using a Perlin noise effect to deconstruct the images of the primes. Then, the deconstructed primes were equalized in contrast and overlaid to obtain the two masks (see figure 12).

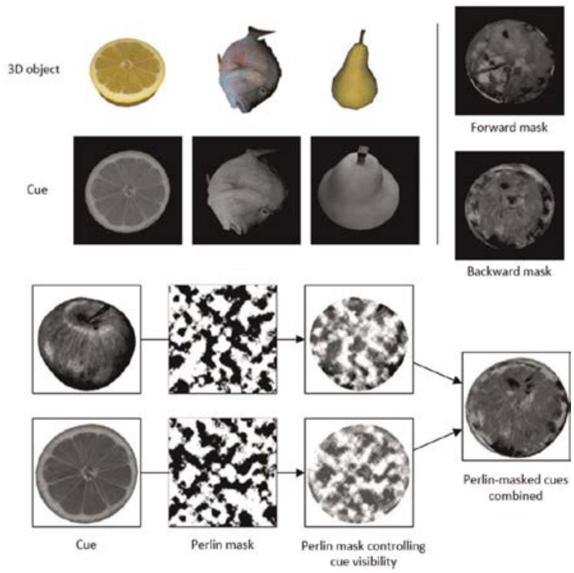


Fig. 12. Examples of masks, 3D food items and their corresponding primes. Note that the primes are in greyscale, normalized for contrast and size, and roughly circular to allow for using the same masks. The 3D objects are matched in size and rotated for presentation only. The masks were created including cues and separate Perlin masks from four objects each (adapted from Aranyi et al., 2014).

A modular event driven architecture in Unity has been developed to support the experiment. The components communicated through message passing to facilitate selection of appropriate modules for each task and convenient logging through event listening. Three animations have been implemented for single, triple and clearly-visible presentation of the stimuli and we used the alpha channels of stimuli to make the masks and prime appear correctly. Sixty frames per second animations have been used to match the refresh rate of the screen. Specifically, we used the following frame counts to approximate the presentation times: 30 animation frames for 500 ms, 12 frames for 200 ms, 2 frames for 33 ms.

As for the way to interact with the food items, a standard click and drag interface has been used. The area of the screen in which the table was displayed was defined as the drop zone. Moreover, food items that were dropped during dragging would remain hovering and could be selected again to avoid the frustration of mouse control issues.

Procedure.

The experimental procedure started with the filling in the informed consent. The experiment consisted in three phases: (1) training, (2) masked priming, and (3) prime visibility test. Before each phase, the participant was instructed with on-screen instructions. During the training phase, the participant completed 30 trials. Eighty percent of the trials in this first phase used a clearly visible (500 ms) prime and the backward mask (200 ms), while 20 percent of the trials included just a forward and a backward mask (200 ms each) without any prime. The participant was instructed to select the primed food item where he/she saw one, and to select item even in the absence of a visible prime. The purpose of including the training phase was to make the participant familiar with the VE and with the task. The screen-shots of the experimental layout are visible in Figure 13. During the masked priming phase, the participant completed the experimental trials that used the same screen layout as in the training phase. The structure of the trial is presented in Figure 14. In each trial, the experimental software firstly selected between two priming conditions: short exposure of the prime (33 ms) or clearly visible prime (500 ms). The short exposure condition constituted the main trials of the masked priming phase and had a 90 percent chance to be selected. Instead, the clearly visible condition had a 10 percent chance to

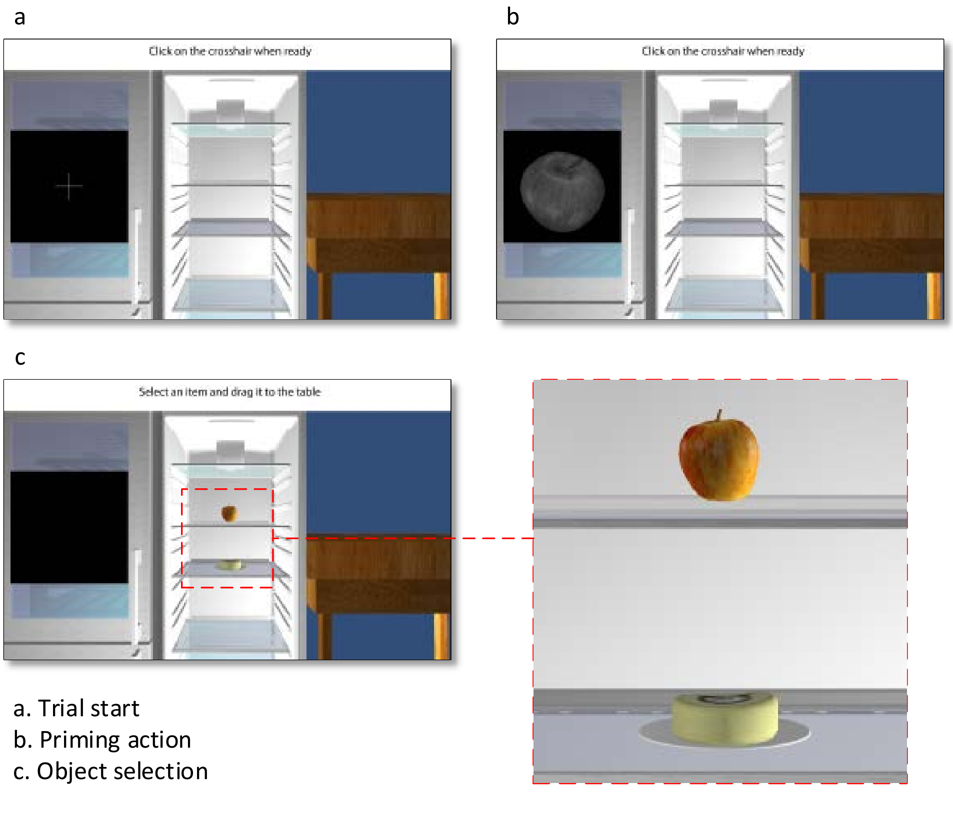


Fig. 13. Screen-shots of the experimental layout (adapted from Aranyi et al., 2014).

be selected and it was included in this phase to reinforce the selection task established in the training phase. Indeed, the participant's performance on the clearly visible condition was used simply to verify whether he/she performed the selection task according to the instructions.

When the short exposure condition was selected, the experimental software randomly selected between the single presentation of the prime (50% chance) and the three-times presentation of the prime (50% chance). Finally, the experimental software randomly selected: (1) the food item to be primed (one out of the total ten items), (2) the filler, that is the other object to be presented in the refrigerator with the target (one out of the remaining nine objects), and (3) the location of the target item in the refrigerator (top or bottom shelf).

Each trial started with empty shelves in the refrigerator located on the right side of the screen. Instead, in the priming area located on the left side of the screen a white fixation cross and the

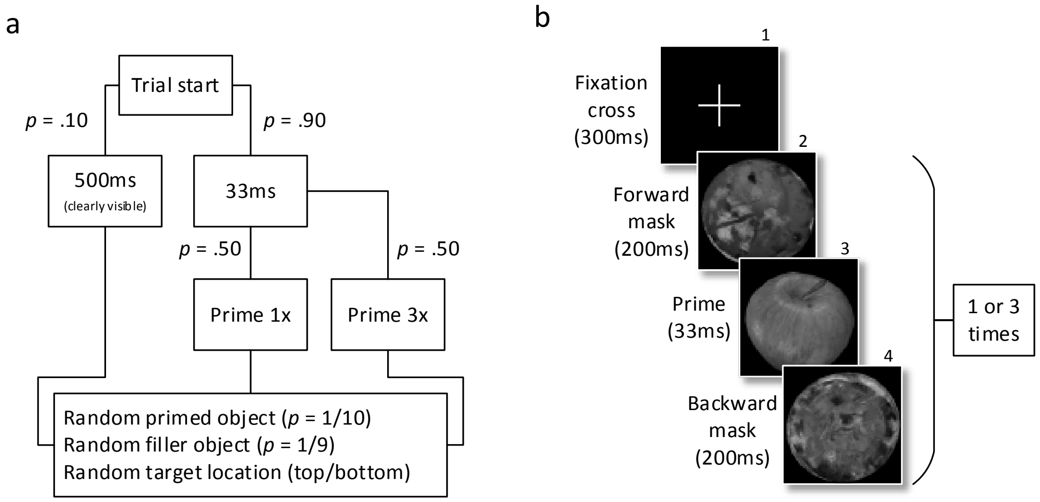


Fig. 14. Structure of experimental trials in the masked-priming phase (a), and prime presentation in the short-exposure trials (b) (adapted from Aranyi et al., 2014).

on-screen instructions "click on the crosshair when ready" were displayed (see Figure 13a).

When the participant clicked the fixation cross the experimental software was triggered to structure the trial.

The fixation cross remained visible on the screen for 300 ms and was followed by the priming sequence (see Figure 14b). If the experimental software selected the clearly visible condition, the priming sequence was the same as in the training phase. If the software selected the short exposure condition with single presentation of the prime (1x condition), the sequence was the following: 200 ms forward mask, 33 ms prime, 200 ms backward mask (see Figure 14b). If the software selected the short exposure condition with multiple exposure of the prime (3x condition), the sequence was the same as in the single exposure but repeated three times. Immediately after the priming sequence, the target object and the filler (the other food item) appeared on the shelves in the refrigerator with the on-screen instruction "select an item and drag it to the table" (see Figure 13c). The trial ended after the participant dragged an object to the table, hence the next trial started. For each trial the experimental software logged the following data: condition

ID (500ms/1x33ms/3x33ms), primed object (target) ID, filler ID, target location (top/bottom), selection outcome (congruent/incongruent), time stamp at the end of prime presentation, time stamp at the time of object selection, and time stamp of object being placed on the table.

When the experimental software had logged at least 100 completed trials for each of the short exposure conditions the masked priming phase ended.

During the prime visibility phase, the participant received each prime 12 times resulting in a total number of 120 trials. In this phase the priming sequence was the same as in the masked priming phase, and the prime was presented once or three times within each trial (60 trials for the 1x condition and 60 trials for the 3x condition). At the end of each trial, and after one second long delay (see Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003), the experimental software presented on the screen the name of a food item from the complete list of items, followed by a question mark (e.g. “Fish?”). This name was either congruent (50% of times) or incongruent (50% of times) with the identity of the primed item. The participant was asked to give an answer by clicking a “yes” or a “no” box that was located inside the refrigerator randomly on the top or the bottom shelf. The prime visibility was assessed just after the masked priming phase in order to avoid underestimating visibility due to familiarity with the presentation conditions and training effects (see Kouider & Dehaene, 2007).

Results.

Priming Effectiveness. The participant’s task was to select the item food from the refrigerator that was congruent with the primed image. As for the clearly visible trials, the success rate was 100% for 12 participants and between 94% and 97% for the remaining four participants. This result showed that, in the masked priming phase, the participants performed the task according to the instructions. As for the short exposure trials, we conducted a one-sample t-test to compare the actual success rate with the success rate expected by chance (50%). The analysis showed that the success rate (M = 55.28%, SD = 8.17) was significantly different from 50%, t(15) = 2.59, p = .02 (two-tailed), r = .56 (large[1]). This result supported our first hypothesis.

In the 1x condition the average success rate was 53.01% (*SD* = 7.60) and was not significantly different from 50%, $t_{(15)}$ = 1.59, *p* = .13, *r* = .38 (medium). However, in the 3x condition the average success rate was 57.61% (*SD* = 10.21) and was significantly different from 50%, $t_{(15)}$ = 2.98, *p* < .01, *r* = .61 (large). The analysis also revealed a statistically significant within-subjects difference between the 1x and the 3x conditions, $t_{(15)}$ = 2.55, *p* = .02, *r* = .55 (large). This result supported our second hypothesis. Moreover, while success rate in the 3x condition was normally distributed, $D_{(16)}$ = .17, *p* = .20, its distribution in the 1x condition was significantly non-normal, $D_{(16)}$ = .30, *p* < .001; specifically, the distribution had a positive skew (*z* = 2.28), which indicates a build-up of low scores. These findings demonstrated that multiple presentations of masked primes can increase the priming effect.

We needed to express the magnitude of the effect in a more tangible way and on a scale that had a meaningful zero point. To this end, we decided to express success rate in terms of the percentage of successful trials that are attainable above chance by dividing the percentage of successful trials attained above chance by the probability of trials attainable above chance[2].

In the 1x condition, participants on average had only 6% above-chance performance. Instead, in 3x condition, participants on average had 15% above-chance performance.

As for the reaction-time (RT), object selection in both 1x and 3x conditions was significantly faster in successful trials than in non-successful trials; 1x condition: mean difference between successful (*M* = 1.45 [seconds], *SD* = 0.69) and non-successful (*M* = 1.57, *SD* = 0.65) = 0.11 seconds, $t_{(1741)}$ = 3.53, *p* < .001, *r* = .08 (small); 3x condition: mean difference between successful (*M* = 1.43, *SD* = 1.11) and non-successful (*M* = 1.53, *SD* = 0.67) = 0.10, $t_{(1654)}$ = 2.12, *p* = 0.34, *r* = .05 (small). According to (Ratcliff & McKoon, 2008), this result can be interpreted

---

[1] Cohen's (1988) effect-size conventions are used: .10 – small, .30 – medium, .50 – large.

[2] $(P_{successful} - P_{chance}) / (1 - P_{chance})$

within the diffusion decision model, therefore, when the subliminal prime provides information for a choice between the two alternatives the selection behavior is faster.

Moreover, in order to explore the relationship between success rate and reaction time, we performed a median split on the basis of reaction time by subjects in both conditions (1x and 3x). Results showed that participants had significantly higher success rates in trials in which their reaction time was below median RT; 1x condition: M_{below} = 57.83% (*SD* = 8.43), M_{above} = 48.20% (*SD* = 8.52), $t_{(15)} = 5.14$, $p < .001$; 3x condition: M_{below} = 61.83% (*SD* = 13.20), M_{above} = 54.38% (*SD* = 11.11), $t_{(15)} = 2.49$, $p = .03$.

Previous research showed that the effect of masked primes is very fast fading, and the priming effect decreases substantially when the subliminal cue is not acted upon in the first second (Greenwald, Draine, & Abrams, 1996; Kouider & Dehaene, 2007). On this basis, we decided to consider only trials where participants' selection behavior occurred within one second following the end of prime presentation. The analysis revealed a substantial improvement in success rate. In the 1x condition (222 trials with RT ≤ 1 second), success rate improved by 13.05% (*M* = 66.06, *SD* = 19.70), $t_{(13)} = 3.051$, $p = .009$, which represents 32% of trials attained above chance and a large effect size ($r = .65$). In the 3x condition (278 trials with RT ≤ 1 second), success rate improved by 12.07% (*M* = 69.68, *SD* = 13.68), $t_{(14)} = 5.57$, $p < .001$, which represents 39% of trials attained above chance and a large effect size ($r = .83$). Moreover, there was no longer significant difference between success rates of the two conditions (1x and 3x) when we considered only RT ≤ 1 second trials, $t_{(13)} = 0.52$, $p = .61$.

To better explore the effect of reaction time on success rate, we grouped trials according to reaction time into three categories (within one second, between one and two seconds, and more than two seconds). We conducted a repeated-measures ANOVA with reaction time (three levels) and presentation condition (two levels) as within-participants factors (see Figure 15). The analysis revealed the main effect of time, $F_{(2, 26)} = 14.45$, $p < .001$. There was no other significant effects. When we considered only RT ≤ 1 second trials the success rate was significantly different from chance level. When we considered the trials between one and two seconds reaction time, we found that the success rate was significantly better than chance in the 3x condition ($t_{(15)} = 2.16$, $p = .05$), but not in the 1x condition ($t_{(15)} = 1.30$, $p = .21$). Finally, when we considered only trials with more than two seconds reaction time, the success rate was not significantly different from chance in both conditions (1x: $t_{(15)} = -0.93$, $p = .37$; 3x: $t_{(15)} = 1.31$, $p = .21$).

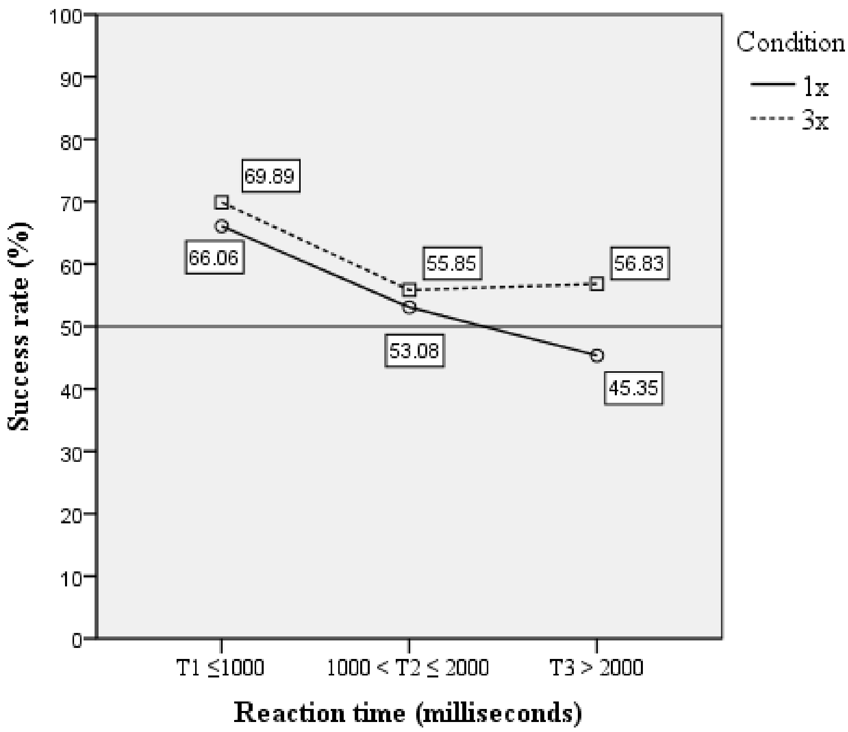


Fig. 15. The effect of reaction time on success rate across prime-presentation conditions. Note that success rate is significantly above chance level at T1 in both conditions, and at T2 in the 3x condition (adapted from Aranyi et al., 2014).

Prime Visibility. The prime visibility phase was included in the experimental procedure to assess the objective visibility of masked primes. For this purpose, we used the signal-detection theory (Macmillan & Creelman, 2004) and we calculated the *d'* sensitivity index using the hit rate and false-alarm rate (Stanislaw, & Todorov, 1999). The analysis revealed that several participants had a close to zero *d'* sensitivity index, and the average *d'* was low in magnitude. Despite this, the object visibility was significantly different from zero in both presentation conditions; 1x condition: average $d' = .45$ ($SD = .38$), $t(15) = 4.69$, $p < .001$; 3x condition: average $d' = .59$ ($SD = .53$), $t(15) = 4.46$, $p < .001$.

This result seems to suggest that participants may have seen the primes in few trials even if in the majority of trials they did not see the primes. Moreover, the analysis revealed that the object visibility was not significantly different between the two presentation conditions, $t(15) = 1.40$, $p = .19$.

This latter result suggests that the success rate improvement emerged in the 3x condition was not due to increased prime visibility. We performed a regression of objective visibility onto above-chance performance and we extrapolated the regression line to the objective threshold of null sensitivity ($d' = 0$) for the purpose of inferring implicit perception (see Greenwald, Klinger, & Schuh, 1995). According to Greenwald et al. (1995), a statistically significant intercept can be considered evidence for the presence of a priming effect in the absence of prime visibility. The analysis revealed that the intercept was equivalent to zero in both presentation conditions. According to this result we could not attribute the above-chance performance to a genuine subliminal priming effect. However, this approach may reveal to be too restrictive or even inappropriate, for instance, when the assumptions of linearity and homoscedasticity are violated (e.g., Hannula, Simons, & Cohen, 2005). We observed that, even if objective visibility was correlated to success rate in the 3x condition ($r = .70$, $p < .01$), the correlation was non-significant in the 1x condition ($r = .34$, $p = .19$). Moreover, following Field (2009), we observed heteroscedasticity; in fact, when we plotted the residuals against predicted values in the regression, the distribution funneled out. For this reason, we decided to calculate a less restrictive measure for objective visibility of primes by testing the difference of the hit rate from chance level in visibility trials. This analysis revealed that the hit rate was not significantly different from the 50% level expected by chance, 1x: $M = .45$, SD = .18 $t_{(15)} = -1.13$, $p = .28$; 3x: $M = .52$, $SD = .22$, $t_{(15)} = 0.33$, $p = .75$. According to this less restrictive measure, we assume the presence of a subliminal priming effect. Besides the objective visibility of primes, we collected a subjective judgment of visibility on a single-item seven-points Likert scale. Analysis of these data revealed that, overall, participants rated the visibility of primes as being very low, $M = 2.69$, $SD = 0.95$, Mode = 2. Moreover, subjective and objective visibility measures were uncorrelated, 1x: $r = .30$, $p = .26$; 3x: $r = .10$, $p = .71$.

Overall, these results suggested that, even if the primes had some objective visibility, this visibility was very limited and was associated with higher success rate only in the 3x condition.

Differences between Primed Objects and Subjects. In order to explore the factors of trial successfulness on a large sample of trials, we pooled the trials across participants. Overall, the 16 participants performed the selection task on 3798 trials (see Table 14).

Table 14. Descriptive statistics of pooled trials. *Note*: percentages in the final row are cumulative across conditions. (Adapted from Aranyi et al., 2014).

Successfulness	**Presentation condition**		
	1x	3x	Clearly visible
Match	924 (52.8%)	953 (57.5%)	394 (98.7%)
No match	822 (47.2%)	703 (42.5%)	5 (1.3%)
Total	1743 (45.9%)	1656 (43.6%)	399 (10.5%)

The success rate in the clearly visible condition was 98.7%. This result demonstrated that participants performed the selection task according to the instructions delivered in the masked priming phase.

Only considering trials of the short exposure condition (1x and 3x), we performed a binary logistic regression analysis to predict the success rate from the following categorical factors: presentation condition (1x or 3x), primed object (10 food items), filler object (food items) and target object location (top or bottom shelf). The analysis revealed that the model was a good fit, $\chi^2_{(20)} = 763.41$, $p < .001$; $R^2 = .20$ (Cox & Snell), .27 (Nagelkerke). The model increased the prediction accuracy from 55.1% (no model) to 70.5%, and each factor had a significant contribution to the model. The model is summarized in Table 15. Note that apple was used as the referent object to express the effect size due to its lowest objective visibility, and due to its success rate (48%) that was close to the level expected by chance. For brevity, in Table 15 we included only the significant categories within the predictors. Moreover, the effect of target location has been removed for its low effect size (odds ratio top/bottom = 1.19 [1.02; 1.39]).

Table 15. Significant predictors of trial successfulness. [a]Reference category: apple. ***p* < .01. ****p* < .001. (Adapted from Aranyi et al., 2014).

Variable	Category	B (SE)	Odds ratio	95% CI
Presentation condition		*** 2.71 (.08)	1.31	[1.13; 1.53]
Primed ID[a]	Cheese	*** 1.18 (.18)	3.26	[2.31; 4.59]
	Fish	***-0.98 (.18)	0.37	[0.26; 0.53]
	Pepper	***-0.71 (.17)	0.49	[0.35; 0.69]
	Pie	*** 1.73 (.20)	5.64	[3.83; 8.30]
	Pizza	*** 0.91 (.17)	2.47	[1.76; 3.47]
	Lemon	*** 0.69 (.17)	1.99	[1.42; 2.79]
Filler ID[a]	Fish	*** 1.27 (.19)	3.58	[2.45; 5.22]
	Pear	** 0.51 (.17)	1.66	[1.19; 2.32]
	Pepper	*** 0.86 (.18)	2.36	[1.67; 3.34]
	Pie	***-1.09 (.17)	0.34	[0.24; 0.47]
	Pizza	***-0.87 (.17)	0.42	[0.30; 0.58]

The odds of trial successfulness were 1.31 times higher in the 3x condition than those in the 1x condition. The odds of trial success was 3.26 times higher when cheese was the target object than the odds when apple was the target, 5.64 times higher if pie, 2.47 if pizza and 1.99 if lemon. Conversely, the odds of trial success was higher when apple was the target object as opposed to fish (2.70 [1/0.37]) and pepper (2.04 [1/0.49]). Due to the moderate correlation between *d'* and success rate (3x: $r = .70$, $p < .01$; 1x: $r = .34$, *ns*), we can argue that higher objective visibility of the prime alone cannot account for the differences in odds between the objects. Indeed, the significant effect of filler object on trial successfulness suggests that participants were also influenced by what was *not* primed. For instance, in presence of a filler object with a relatively highly visible prime associated with it, the participant could select the correct object by elimination, without actually seeing the prime of the target object. Moreover, it is noteworthy the fact that when pie or pizza was the filler object the odds of trial successfulness were lower than when the filler object was the apple and, conversely, when pie or pizza was the target the odds of trial successfulness were higher. This suggests that, regardless of the prime, participants had a preference for selecting these objects. We can hypothesize that the relatively strong visual resemblance between pie and pizza and the masks may have favored the choice of these objects. The selection of other objects seemed not to be affected by their visual similarity to the masks.

We also tested the effect of individual differences between participants on the priming effect. For this purpose, we regressed participant ID (categorical predictor) onto trial successfulness (binary outcome). The model was a significant fit, ($\chi^2_{(15)} = 87.22$, $p < .001$). However, this was due to the high number of trials ($N = 3399$). In fact, participant ID only improved the prediction accuracy by 0.9% ($R^2 = .03$ [Cox & Snell], .03 [Nagelkerke]). In the analysis, the reference participant had near-zero performance above chance. Only for three participants the odds of trial success were significantly higher than those of the reference participant. This indicates that the overall effect of individual differences was small.

We also tested for a possible learning effect in the masked priming phase. We regressed the serial number of each trial onto trial successfulness. The model-fit was non-significant ($\chi^2_{(1)} = 0.78$, $p = .38$, *ns*). This result rules out the possibility that the participants get more successful due to a learning effect.

Discussion.

The main contribution of the present study is the successful application of the subliminal cueing in a context in which the participants were engaged in interacting with 3D objects in a Virtual Environment. In particular, participants were involved in a realistic task in which a forced-choice between two objects had to be performed while one of the objects was subliminally cued immediately before each choice behavior. We used the visual masking to make the prime subliminal. Our first hypothesis was supported by the results. In fact, primed objects were more frequently selected than expected by chance. Our second hypothesis was also supported: the priming effect was larger in the condition of multiple exposures of the prime than in the single presentation condition.

Analysis on all trials revealed that in the 1x condition (single presentation of the prime) the participants' performance only approached statistical significance. However, this is probably due to low sample size. In the 3x condition (multiple exposure of the prime) the participants' performance was significantly above chance level with medium effect size.

The analysis conducted only on trials where participants selected an object within one second following the end of the prime presentation revealed that the performance was significantly above the chance level with a large effect size in both conditions (1x and 3x). Furthermore, the advantage of multiple exposure of the prime disappeared. These findings seem to suggest that multiple exposure of prime can prolong the priming effect.

The interface designer should take into account the quickly-fading effect of subliminal cueing, for example, by positioning subliminal cues very close to subsequent user's action, or by using multiple exposure of subliminal cues to prolong the priming effect.

As for the prime visibility, we included in the experimental procedure a large number of prime-visibility trials both for the 1x presentation condition and for the 3x. We analyzed these data using the signal-detection theory. The *d'* measure of object visibility of primes was significantly different from zero, however it was low in magnitude. This result suggested that, in a few cases, participants had seen the prime. Despite this, the prime was invisible in the majority of trials.

Moreover, from analysis emerged that the hit rate in prime-visibility trials was not significantly different from the level expected by chance. In addition, there was only a moderate correlation between *d'* measure of prime visibility and success rate that indicates that objective visibility alone cannot account for participants' performance. Finally, we also tested the subjective visibility of primes, and analysis of these data revealed that, overall, participants rated the visibility of primes as being very low. Overall, results seem to suggest that the primes were not clearly visible and, using the criterion of hit-rate probability, a subliminal priming effect emerges.

In conclusion, findings support the feasibility of including subliminal cues to influence selection behavior between 3D virtual objects and unveil the properties of the processes involved, with implications to practical application. Future research may overcome some limitations of the present study. In particular, a larger sample size would benefit data analysis. Moreover, while in the present study we used a forced-choice selection task between only two objects, future research may use more complex tasks. Finally, while in the present work we used the visual masking to make the prime subliminal, future research may take into consideration other subliminal techniques, for example visual crowding (see Negri et al., 2014).

My contribution.

This work was partially funded by the European Commission under grant agreement CEEDs (FP7-ICT-258749) and it is the result of an international collaboration which have contributed the following institutions: Teesside University, Ecole Normale Superieure Paris, University of Helsinki, Aalto University, University of Padua.

My personal contribution to the realization of this study concerns the conception of the experimental design and the interpretation of the results. These data were presented in a published paper (Aranyi et al., 2014).

5 CHAPTER FIVE

5.1 GENERAL DISCUSSION

The present work is part of that research field that has been called Human-computer confluence and that aims at investigating the emerging symbiotic relation between humans and computers. Many research efforts are nowadays devoted to investigate how to make the relationship between men and computing machines increasingly adaptive and symbiotic. That of Human-computer confluence and symbiosis between humans and computers is a very broad research field just because many disciplines are involved, from computer science to engineering, psychology, neuroscience and more. Furthermore, through the chapters of the present work, we have shown that several HCI's frameworks, in various way, provide a contribution to the human-computer symbiosis theory. In particular, we spent more to examine the contribution of embodied interaction, Physiological and Affective computing, and the role that subliminal stimulation may play in user interfaces. Precisely in these three areas of research we conducted the studies reported in the present work. As for the role of "embodiment", according to Dourish, computation should be embodied in the sense of manifested "in the world, real-time and real-space, here and now" (Dourish, 2001, p. 235). In particular we were interested to investigate the UX associated with the use of physically embodied input systems, namely systems that, exploiting gestural ways to interact with computers, are supposed to bridge the gap between digital and physical worlds. Gestural interfaces, exploiting those human skills (body movements like grasping, walking, etc.) that users are naturally predisposed to use, are expected to make interactions more natural and “transparent”, that is, intuitive and easier. In study 1 we aimed at measuring and comparing both UX and performance related to three different ways to interact with virtual objects in a mixed-reality environment. In particular, we compared the common interaction via keyboard and mouse, a fully embodied input system and, finally, an hybrid system exploiting both body movements and the use of a mouse.

Overall, the results of this study seem to suggest that, in an immersive mixed-reality environment, the fully embodied input system that does not require the use of any physical artifact is preferred to the common input system based on the use of keyboard and mouse even if participants performed better with this latter. In this regard, it is important to notice that in this study we did not put in place any training. However, future research might consider the opportunity to implement it in order to make the participants more familiar with the new input system and to avoid that the traditional system results in better performances only because participants have a greater expertise level in using it. Despite the absence of training, participants did not evaluate better the keyboard/mouse compared with the fully embodied input system. In addition, despite the participants’ performance (task execution time) was lower when they used the embodied system, they nonetheless evaluated this input system as the more pleasant during the whole experiment. Overall, findings of study 1 seemed to confirm that the embodied interaction can create a “confluence” between the digital world of computer system and the world of human natural skills, resulting in a space of interaction that improves the UX.

Our investigation on Human-computer confluence and symbiosis has since moved to consider the contribution of physiological and affective computing. We were interested in evaluating the contribution that implicit components of the user’s psychological state could give to improve the symbiotic interaction with a system. In particular, in study 2 our aim was to evaluate the effectiveness of an adaptive system in supporting a better user experience and a greater learning performance while the participant interacted with a large dataset in a mixed-reality environment. The same mixed-reality environment used in study 1, this time was equipped with a new intelligent component that, using some physiological measures (electrodermal activity, heart rate, pupil dilation), represented in real time the participant’s state in terms of arousal and cognitive load. According to this representation, the system applied some modifications to the information displayed on the user interface in order to support the participant during the interaction. Therefore, the intelligent part of the system was expected to create a user-computer confluence collecting information that connected to a user's implicit level of expression. Overall, the results showed that the system with implicit confluent features seemed to support both learning performance and UX. Specifically, as for the learning performance, the results showed that the implicit confluent features supported learning of specific information from the neuroscience dataset. As for the user experience, the results of the questionnaires showed that, regardless of the condition (three conditions were used, and only in one the confluent features were properly implemented), participants evaluated the system as able to generate a sense of presence, credible and acceptable as a tool to support their activity. Overall, the system received good ratings in all dimensions of the UX irrespective of the experimental condition. However, the results of the confluence questionnaire confirmed that in the confluence condition the participants felt the system as more confluent compared to the other conditions. Interestingly, the mean hart rate of participants was lower in the condition in which the confluent features were properly implemented compared to other conditions. Since the heart rate increases in response to psychological stressors (e.g., Ulrich-Lai, & Herman, 2009), this result seems to suggest that participants in the confluence condition were less stressed compared to the other conditions. In other worlds, when the system used the implicit signals in order to facilitate the user, it actually did it successfully and this assistance made possible a reduction in the level of stress of the user.

The results of study 2 are encouraging, suggesting that an adaptive system can actually support learning of information when interacting with large datasets making use of implicit information related to the user's psychological state. Surely, the results need to be generalized to other types of dataset and other setting of interaction.

In study 2, the system's configuration allowed an expansion of the bandwidth of communication with the user. By using physiological signals as inputs to the system, the human-computer communication was enriched by a flow of implicit information transmitted by the user and received by the computer. The aim of study 3, was to investigate the feasibility of introducing a flow of implicit information in the opposite direction, from the computer to the user. In particular, we investigated the possibility of introducing subliminal stimuli in user interfaces to make the system capable of guiding and supporting the user with cues not entering the “cone of light” of consciousness. We wondered if subliminal information processing could represent the missing branch of the implicit interaction loop between humans and machines.

As we saw in study 2, the computer can achieve a wider understanding of the user’s state and intentions by capturing implicit signals with sensing devices. On the other hand, the computer could covertly ignite unconscious mental activity and automatic responses in the user by exploiting subliminal stimuli. In study 3, participants were involved in a realistic task in which a forced-choice between two 3D virtual objects had to be performed while one of the objects was subliminally cued immediately before each choice behavior. The visual masking technique was used to make the cue subliminal. The results showed that cued objects were more frequently selected than expected by chance demonstrating a subliminal priming effect. Moreover, another important result concerns the introduction of a condition in which the subliminal cue was delivered multiple times in sequence. Results showed that the priming effect was larger in the condition of multiple exposures of the prime than in the single presentation condition. Therefore, the main contribution of study 3 is the successful application of the subliminal cueing in the context of a realistic VE with participants engaged in a concrete task. Findings support the feasibility of including subliminal cues to influence selection behavior between 3D virtual objects. Moreover, some properties of the subliminal cueing were unveiled with important implications to practical application. In particular, we refer to the quickly-fading effect of subliminal cueing, and to the capacity of multiple exposure of the cue to prolong the priming effect. The interface designer should take into account the quickly-fading effect of subliminal cueing, for example, by positioning subliminal cues very close to subsequent user’s action, or by using multiple exposure of subliminal cues.

Overall, findings of study 2 and 3 leave us free to forecast systems capable of supporting a reciprocal information exchange with the user to an implicit level of interaction in which the computer can achieve a deeper understanding of the user’s needs, and covertly “promote” automatic responses in the user in order to support him.

Naturally, both the acquisition of implicit data by the user, and subliminal stimulation of the user raise ethical concerns.

Ethical concerns.

The Human-Computer confluence shares some ethical issues with other types of technology. Specifically, symbiotic systems relate to technologies that collect and elaborate information both from the single user and from large masses of users. This information might be collected also without users being aware of it, and systems might use it to build a model of users' profile and behaviors. The principal risks inherent in this situation relate to potential threat to privacy and to potential misusage of information. These risks are even greater when the collected information is sensitive in addition to being personal, for instance when the system collects medical data. Jacucci et al. (2014) summarized these risks in several categories, mainly: users identification based on collected data; permanence of personal information beyond the time needed; public disclosure of confidential information about a user.

However, symbiotic systems involve additional specific risks connected to the users loss of agency. We mean that symbiotic systems collect implicit data and, on the basis of this data, they select the information which must be shown to the user. In this way, the system has an intrinsic persuasive power. This hidden persuasive power might be magnify if the system makes use of subliminal stimuli to guide the user. Even though the final goal of using implicit information, both to deeply understand the user and to direct his behavior, is the improvement of the interaction, the question whether the user should be aware that the system utilizes implicit information arises.

That of symbiotic systems is an emerging field of research and, consequently, the reflection about the ethical issues must still be addressed in part. In the first instance, having to deal with an intrinsic persuasive power, that is with the power to produce changes in the user's behavior, we think that the ethical discussion about persuasive technologies is particularly relevant even for symbiotic systems. About this, Smidt (2012) argued that the voluntariness of behavioral changes is the essential ethical requirement for persuasive technologies. On this basis, we believe that, even in the case of symbiotic systems, the users should be aware that the system is using implicit information and giving an ad hoc feedback resulting in a covert persuasion. When the user knowingly agrees to interact with a system that acts in such a way to assist him during the interaction, the supportive, hidden influence that eventually could be exerted is not in contrast with the user's voluntariness previously expressed.

Appendices

Appendix 1.

INFORMED CONSENT (DLgs 196/03)
The present research is part of the EU funded CEEDs project (The Collective Experience of Emphatic Data System). The experiment takes place at the HTLab A01, Dipartimento di Psicologia Generale, Università degli Studi di Padova, and consists in the execution of a few tasks, during which you will have to interact with some virtual objects within a highly immersive Mixed-reality environment. The interaction will require you to perform some movements and gestures, mainly with your right arm and your right hand or, alternatively, the use of a wireless keyboard and mouse. After the task you will be asked to fill in a set of questionnaires. The duration of the experiment is approximately 90 minutes.
Once the experiment is over you will be debriefed in detail about its goals, and we will welcome your questions.
During the task, we will acquire the following data:

- Video recordings of the whole session;
- Your answers to the questionnaires;
- Some behavioral and performance data.

Please keep in mind that you can withdraw from the experiment at any time, and you will be asked no questions at all. If you retire from the experiment, all of your data will be kept confidential, and you will not be awarded the compensation.
All data will be stored at HTLab and it won't be divulged to other parties. The data will only be used for research purposes and in an aggregate way.
HTLab follows the disposition about data confidentiality (Dlgs. N. 196/2003); only the people conducting the research will have access to it within the scope of their research and they are allowed to publish it only in by maintaining the anonymity of the participants.
Image takens from the video recordings will be utilized in scientific publication or presentation only if you specify your consent by signing here.
DECLARATION
I, the undersigned Last Name ______________________________ First Name ______________________________
Age: _______ Gender: F M Nationality: ____________________

DECLARE

- That I have been allowed to ask questions;
- That I have read and that I understood the previous section and all of its contents;

I THEREBY GIVE MY CONSENT

- To take part in the research within the modalities defined in the previous note;
- To the use of my personal data and the use of the video recordings for research purposes;

Signature________________________________

- To the use of part of the video recorded material for being published within scientific journals and conferences for the purpose of explaining the results of the research (not mandatory to participate)

Signature________________________________

I will also withhold from divulging anything relating to the experiment goals and hypothesis until the end of the data collection phase, approximately three months from now

Date ____________, place_________________________
(ID: ________) Signature________________________________

Appendix 2.

PRE-TEST QUESTIONNAIRE

Please answer the following questions by ticking the corresponding box or writing in the appropriate space

1) Gender
☐ Female ☐ Male
2) Age
3) Nationality
4) Do you have color-perception problems (e.g. red/green blindness)?
☐ YES ☐ NO
5) What is your dominant hand?
☐ Right ☐ Left
6) What is your English proficiency level?
☐ None ☐ Basic ☐ Intermediate ☐ Advanced ☐ Native speaker

7) How often do you play videogames?
☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ Always
8) How often do you use large displays (50-inch or more)?
☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ Always

9) How often do you use…			
Keboard/Mouse	Kinect	Wii	Joystick
☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ Always	☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ Always	☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ Always	☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ Always

10) Have you ever taken courses that covered neuroanatomy? If so, what was the name of the course/courses?

11) How would you define your knowledge of neuroanatomy?
☐ None ☐ Basic ☐ Intermediate ☐ Expert
12) How many lobes does the human brain comprise?
☐ I don’t know ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8
13) Could you list the lobes that make up the human brain?
14) Could you describe the function of the lobes that compose the human brain?
15) Are you familiar with the term “connectome”?
☐ YES ☐ NO
16) If so, what does it refer to?

17) How would you define your knowledge of the connectome?
☐ None ☐ Basic ☐ Intermediate ☐ Expert

Appendix 3.

POST-TEST QUESTIONNAIRE 1

Please answer the following questions by ticking the corresponding box or writing in the appropriate space

1) How many lobes does the human brain comprise?
☐ I don't know ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8
2) Could you list the lobes that make up the human brain?
3) Could you describe the function of the lobes that compose the human brain?

4) What information do you remember about the Temporal lobe?
5) Which lobe possesses the highest number of nodes?
6) Did you utilize all the graphic and textual information present in the virtual environment? Describe what kind of information was presented on each of the three panels.
7) What was the most difficult command to execute?
8) What was the easiest command to execute?
9) In general, what would you change about the command system?

10) In general, what would you change about the interface?

Appendix 4.

POST-TEST QUESTIONNAIRE 2

Write down all the information you can remember about the **“Pars triangularis”** area:

....

Write down all the information you can remember about the **“Cuneus”** area:

....

Write down all the information you can remember about the **“Parahippocampal”** area:

....

To which cerebral lobe does the **“Cuneus”** area belong to?

- Frontal
- Parietal
- Temporal
- Occipital

To which cerebral lobe does the **“Parahippocampal”** area belong to?

- Frontal
- Parietal
- Temporal
- Occipital

To which cerebral lobe does the **“Pars Triangularis”** area belong to?

- Frontal
- Parietal
- Temporal
- Occipital

Appendix 5.

POST-TEST QUESTIONNAIRE 3

Write down all the information you can remember about the **“Pars opercularis”** area:

....

Write down all the information you can remember about the **“Postcentral”** area:

....

Write down all the information you can remember about the **“Superior parietal”** area:

....

What is the function of the **“Postcentral”** area?

- o Within this area resides the primary somatosensory area, the main receptive area for the sense of touch;
- o This area is in charge of controlling the movements of the eye; furthermore it controls some motoric processes and it is involved in the elaboration of nociceptive stimuli;
- o It is the area of the cerebral cortex where are elaborated ,an at unconscious level, the dangers and problems which an individual is subject to in the normal course of their own experiences;
- o This area plays an important role in long term memory and spatial navigation;
- o None of the above

What is the function of the **“Pars opercularis”** area?

- o This area plays a role in several functions usually linked to the emotion or the bodily regulation (homeostasis) . This area, together with the pars triangularis area, makes up the Broca’s area, an important neuroanatomical region for linguistic production;
- o This area is involved mainly in the coordination motor-perceptive (e.g. direct the movements of the eyes);
- o This area controls motor movements;
- o None of the above

To which cerebral lobe does the **“Superior Parietal”** area belong to?

- o Frontal
- o Parietal
- o Temporal
- o Occipital

Appendix 6.

CONFLUENCE QUESTIONNAIRE

Please, express your level of agreement with the following statements, with reference to your interaction with the XIM system

Overall I am satisfied with the system

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

I felt the system

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

…was taking into account my previous actions on it

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

…responded like it knew what I wanted

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

…was responding to more than my explicit requests

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

…responded meaningfully

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

…anticipated what I was going to do next

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

…was an extension of my body

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

…was an extension of my brain

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

…was sensitive to my feelings

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

…helped me to refine my goals and objectives

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

…and I understood each other

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

…was useful

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

…made my task easier

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

…enabled me to discover something relevant

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

Appendix 7.

USER EXPERIENCE QUESTIONNAIRE

1) Please indicate to what extent you believe the system to be …

… pleasant

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

… attractive

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

… engaging

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

… fun

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

… boring

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

… interesting

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

2) Please indicate to what extent you agree that using the system

… generates frustration

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

… helps keeping focused toward the objectives

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

… motivates to learn its content

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

… is a gratifying experience

Completely disagree					Completely agree		Don’t know
1	2	3	4	5	6		

… is an exciting activity

Completely disagree					Completely agree		Don’t know
1	2	3	4	5	6		

… is an experience that overall meets my expectations

Completely disagree					Completely agree		Don’t know
1	2	3	4	5	6		

… can cause people to lose track of time

Completely disagree					Completely agree		Don’t know
1	2	3	4	5	6		

… completely engrosses its user

Completely disagree					Completely agree		Don’t know
1	2	3	4	5	6		

… leads to pay more attention to its content compared to the users' personal thoughts

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

... causes concentration falls during the interaction

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

... in the long run causes a decline in the interest toward the interaction

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

...is captivating

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

... arouses one's curiosity

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

Please indicate to what extent you agree with each of these statements:

3) The system is easy to use

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

4) The meaning of the commands is intuitively associated with their function

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

5) I had to learn a lot of things before I could get going with the system

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

6) After making a mistake, I was able to recover quickly

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

7) I could easily explore the information presented on every screen

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

8) I was able to manipulate the position of the brain the way I wanted

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

9) The system responded to my commands the way I wanted it to

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

10) I clearly understood what my position was relative to the brain at all times

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

11) The system enabled me to understand the spatial relations between the different cerebral areas in a clear way

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

12) The system enabled me to identify the connections between different cerebral areas

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

13) The execution of the commands distracted me from the task I was supposed to perform

Completely disagree					Completely agree	Don’t know
1	2	3	4	5	6	

14) The cursor moved smoothly on the display

Completely disagree					Completely agree	Don’t know
1	2	3	4	5	6	

15) The brain moved slowly on the display

Completely disagree					Completely agree	Don’t know
1	2	3	4	5	6	

16) It was comfortable having to stand during the interaction

Completely disagree					Completely agree	Don’t know
1	2	3	4	5	6	

17) At the end of the session my right arm was fatigued

Completely disagree					Completely agree	Don’t know
1	2	3	4	5	6	

18) It was comfortable having to interact with large displays

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

Appendix 8.

ACCEPTANCE QUESTIONNAIRE

Please express your level of agreement with the statements below:

1) Overall, I think that information technology (computer, cell phones, …) brings about some benefits

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

2) Nowadays, I think that information technology (computer, cell phones, …) is indispensable

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

3) I constantly have to deal with information technology (computer, cell phones, …)

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

4) When I have to use information technology (computer, cell phones, …) I fear I can break it or make some irreversible mistakes

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

5) Most issues connected to information technology (computer, cell phones, …) are difficult to me

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

6) The possibility of using a technology or a device that I have never used makes me feel anxious

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

7) The XIM device would be incompatible with most aspects of my activity

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

8) The XIM device limits the way in which I like to perform my activity

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

9) The XIM device could help reaching my objectives

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

10) The XIM device would improve my performance

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

11) The XIM device could improve the quality of my activity

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

12) It seems easy to learn how to use XIM device

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

13) It seems tiresome to use the XIM device

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

14) If the XIM device were available to me, I would use it

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

15) If the XIM device were sold at an affordable price, I would buy it

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

16) I think I would use the XIM device only if I were forced to

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

17) If people who are influent in my life recommended me to use the XIM device for a period of time, I would do so

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

18) If most people in my environment used the XIM device, I would be more inclined to use it as well

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

19) I think that privacy breaches are a serious issue nowadays

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

20) I think that the XIM device threatens my privacy

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

21) Wearing the XIM components feels weird physically

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

I think that the XIM device was…

22) …pleasant

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

23) …annoying

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

24) …boring

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

25) …comfortable

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

26) …well suited to my body

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

Appendix 9.

CREDIBILITY

Please, express your level of agreement with the statements below:

1) Overall, the contents are believable

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

The data provided by the XIM device is…

2) …accurate

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

3) …informative

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

4) …interesting

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

5) …relevant

Completely disagree					Completely agree	Don't know
1	2	3	4	5	6	

6) …updated

Completely disagree					Completely agree	Don't know
1	2	3	4	5	6	

7) …objective

Completely disagree					Completely agree	Don't know
1	2	3	4	5	6	

8) The XIM interface is clear

Completely disagree					Completely agree	Don't know
1	2	3	4	5	6	

9) The graphical elements composing the interface (icons, photos) are organized in a thoughtful way on the screens

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

10) The graphics are esthetically attractive

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

11) The developers who realized the system are authoritative

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

12) The developers who realized the system are expert

Completely disagree					Completely agree		Don't know
1	2	3	4	5	6		

Appendix 10.

PRESENCE QUESTIONNAIRE

1. How much were you able to control events?

Completely disagree						Completely agree
1	2	3	4	5	6	7

2. How responsive was the environment to actions that you initiated (or performed)?

Completely disagree						Completely agree
1	2	3	4	5	6	7

3. How natural did your interactions with the environment seem?

Completely disagree						Completely agree
1	2	3	4	5	6	7

4. How completely were all of your senses engaged?

Completely disagree						Completely agree
1	2	3	4	5	6	7

5. How much did the visual aspects of the environment involve you?

Completely disagree						Completely agree
1	2	3	4	5	6	7

6. How much did the auditory aspects of the environment involve you?

Completely disagree						Completely agree
1	2	3	4	5	6	7

7. How natural was the mechanism which controlled movement through the environment?

Completely disagree						Completely agree
1	2	3	4	5	6	7

8. How aware were you of events occurring in the real world around you?

Completely disagree						Completely agree
1	2	3	4	5	6	7

9. How aware were you of your display and control devices?

Completely disagree						Completely agree
1	2	3	4	5	6	7

10. How compelling was your sense of objects moving through space?

Completely disagree						Completely agree
1	2	3	4	5	6	7

11. How inconsistent or disconnected was the information coming from your various senses?

Completely disagree						Completely agree
1	2	3	4	5	6	7

12. How much did your experiences in the virtual environment seem consistent with your real-world experiences?

Completely disagree						Completely agree
1	2	3	4	5	6	7

13. Were you able to anticipate what would happen next in response to the actions that you performed?

Completely disagree						Completely agree
1	2	3	4	5	6	7

14. How completely were you able to actively survey or search the environment using vision?

Completely disagree						Completely agree
1	2	3	4	5	6	7

15. How well could you identify sounds?

Completely disagree						Completely agree
1	2	3	4	5	6	7

16. How well could you localize sounds?

Completely disagree						Completely agree
1	2	3	4	5	6	7

17. How well could you actively survey or search the virtual environment using touch?

Completely disagree						Completely agree
1	2	3	4	5	6	7

18. How compelling was your sense of moving around inside the virtual environment?

Completely disagree						Completely agree
1	2	3	4	5	6	7

19. How closely were you able to examine objects?

Completely disagree						Completely agree
1	2	3	4	5	6	7

20. How well could you examine objects from multiple viewpoints?

Completely disagree						Completely agree
1	2	3	4	5	6	7

21. How well could you move or manipulate objects in the virtual environment?

Completely disagree						Completely agree
1	2	3	4	5	6	7

22. To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session?

Completely disagree						Completely agree
1	2	3	4	5	6	7

23. How involved were you in the virtual environment experience?

Completely disagree						Completely agree
1	2	3	4	5	6	7

24. How distracting was the control mechanism?

Completely disagree						Completely agree
1	2	3	4	5	6	7

25. How much delay did you experience between your actions and expected outcomes?

Completely disagree						Completely agree
1	2	3	4	5	6	7

26. How quickly did you adjust to the virtual environment experience?

Completely disagree						Completely agree
1	2	3	4	5	6	7

27. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?

Completely disagree						Completely agree
1	2	3	4	5	6	7

28. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

Completely disagree						Completely agree
1	2	3	4	5	6	7

29. How much did the control devices interfere with the performance of assigned tasks or with other activities?

Completely disagree						Completely agree
1	2	3	4	5	6	7

30. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?

Completely disagree						Completely agree
1	2	3	4	5	6	7

31. Did you learn new techniques that enabled you to improve your performance?

Completely disagree						Completely agree
1	2	3	4	5	6	7

32. Were you involved in the experimental task to the extent that you lost track of time?

Completely disagree						Completely agree
1	2	3	4	5	6	7

Appendix 11.

IMI (Intrinsic Motivation Inventory)

Please, express your agreement with each of the following statements:

1) I enjoyed using the XIM very much

Completely disagree						Completely agree
1	2	3	4	5	6	7

2) I think I'm pretty good at using the XIM

Completely disagree						Completely agree
1	2	3	4	5	6	7

3) I put a lot of effort into using the XIM

Completely disagree						Completely agree
1	2	3	4	5	6	7

4) It was important to me to do well with the XIM

Completely disagree						Completely agree
1	2	3	4	5	6	7

5) I felt tense while using the XIM

Completely disagree						Completely agree
1	2	3	4	5	6	7

6) I tried very hard while using the XIM

Completely disagree						Completely agree
1	2	3	4	5	6	7

7) Using the XIM was fun

Completely disagree						Completely agree
1	2	3	4	5	6	7

8) I would describe the XIM as very interesting

Completely disagree						Completely agree
1	2	3	4	5	6	7

9) I am satisfied with my performance with the XIM

Completely disagree						Completely agree
1	2	3	4	5	6	7

10) I felt pressured while using the XIM

Completely disagree						Completely agree
1	2	3	4	5	6	7

11) I was anxious while using the XIM

Completely disagree						Completely agree
1	2	3	4	5	6	7

12) I didn’t try very hard at using the XIM

Completely disagree						Completely agree
1	2	3	4	5	6	7

13) While using the XIM, I was thinking about how much I enjoyed it

Completely disagree						Completely agree
1	2	3	4	5	6	7

14) After using the XIM for a while, I felt pretty competent

Completely disagree						Completely agree
1	2	3	4	5	6	7

15) I was very relaxed while using the XIM

Completely disagree						Completely agree
1	2	3	4	5	6	7

16) I am pretty skilled at using the XIM

Completely disagree						Completely agree
1	2	3	4	5	6	7

17) The XIM did not hold my attention

Completely disagree						Completely agree
1	2	3	4	5	6	7

18) I couldn't use the XIM very well

Completely disagree						Completely agree
1	2	3	4	5	6	7

Appendix 12.

NASA Task Load Index

Please evaluate your session by putting an "X" on each of the six scales at the point that matches your experience. Each line has two endpoint descriptors that describe the scale. Note that "performance" goes from "good" on the left to "bad" on the right.

Mental Demand

Low High

Physical Demand

Low High

Temporal Demand

Low High

<u>Performance</u>

Good Poor

Effort

Low High

Frustration

Low High

Appendix 13.

WEARABILITY QUESTIONNAIRE

The head-mounted eye-tracker is easy to wear

Strongly disa-gree	Disagree	Neither agree neither disa-gree	Agree	Completley agree

Wearing the head-mounted eye-tracker is bothersome

Strongly disa-gree	Disagree	Neither agree neither disa-gree	Agree	Completley agree

Once I wore it, the head-mounted eye-tracker was stable

Strongly disa-gree	Disagree	Neither agree neither disa-gree	Agree	Completley agree

As time went on I stopped noticing that I was wearing the head-mounted eye-tracker

Strongly disa-gree	Disagree	Neither agree neither disa-gree	Agree	Completley agree

Wearing the head-mounted eye-tracker interfered with the task

Strongly disa-gree	Disagree	Neither agree neither disa-gree	Agree	Completley agree

The t-shirt is easy to wear

Strongly disa-gree	Disagree	Neither agree neither disa-gree	Agree	Completley agree

Wearing the t-shirt is bothersome

Strongly disa-gree	Disagree	Neither agree neither disa-gree	Agree	Completley agree

As time went on I stopped noticing that I was wearing the t-shirt

Strongly disa-gree	Disagree	Neither agree neither disa-gree	Agree	Completley agree

Having to wear the t-shirt interfered with the task

Strongly disa-gree	Disagree	Neither agree neither disa-gree	Agree	Completley agree

The glove is easy to wear

Strongly disa-gree	Disagree	Neither agree neither disa-gree	Agree	Completley agree

Having to wear the glove was bothersome

Strongly disa-gree	Disagree	Neither agree neither disa-gree	Agree	Completley agree

As time went on I stopped noticing that I was wearing the glove

Strongly disa-gree	Disagree	Neither agree neither disa-gree	Agree	Completley agree

Having to wear the glove interfered with the task

Strongly disa-gree	Disagree	Neither agree neither disa-gree	Agree	Completley agree

It bothered me that I had to stand during the interaction

Strongly disa-gree	Disagree	Neither agree neither disa-gree	Agree	Completley agree

At the end of the session my right arm was fatigued

Strongly disa-gree	Disagree	Neither agree neither disa-gree	Agree	Completley agree

I found comfortable having to interact with large displays

Strongly disa-gree	Disagree	Neither agree neither disa-gree	Agree	Completley agree

Appendix 14.

INFORMED CONSENT (DLgs 196/03)

The present research is part of the EU funded CEEDs project (The Collective Experience of Emphatic Data System). The experiment takes place at the HTLab A01, Dipartimento di Psicologia Generale, Università degli Studi di Padova, and consists in the execution of a few tasks, during which you will have to interact with some virtual objects within a highly immersive Mixed-reality environment. The interaction will require you to perform some movements and gestures, mainly with your right arm and your right hand. After the task you will be asked to fill in a set of questionnaires. The duration of the experiment is approximately 2 hours and 30 minutes. For your participation, you will be awarded 15 euro.
Once the experiment is over you will be debriefed in detail about its goals, and we will welcome your questions.
During the task, we will acquire the following data:

- Video recordings of the whole session;
- Your answers to the questionnaires;
- Some behavioral and psychophysiological measures (HR, skin conductance, respiratory rate, eye-movements), which will be acquired by means of sensors that you will be required to wear.

Please keep in mind that you can withdraw from the experiment at any time, and you will be asked no questions at all. If you retire from the experiment, all of your data will be kept confidential, and you will not be awarded the compensation.
All data will be stored at HTLab and it won't be divulged to other parties. The data will only be used for research purposes and in an aggregate way.
HTLab follows the disposition about data confidentiality (Dlgs. N. 196/2003); only the people conducting the research will have access to it within the scope of their research and they are allowed to publish it only in by maintaining the anonymity of the participants.
Image takens from the video recordings will be utilized in scientific publication or presentation only if you specify your consent by signing here.

DECLARATION
I, the undersigned Last Name ______________________________ First Name ______________________________

Age: _______ Gender: F M Nationality: ____________________

DECLARE

- That I have been allowed to ask questions;
- That I have read and that I understood the previous section and all of its contents;

I THEREBY GIVE MY CONSENT

- To take part in the research within the modalities defined in the previous note;
- To the use of my personal data and the use of the video recordings for research purposes;
  Signature_________________________________
- To the use of part of the video recorded material for being published within scientific journals and conferences for the purpose of explaining the results of the research (not mandatory to participate)
  Signature_________________________________

I will also withhold from divulging anything relating to the experiment goals and hypothesis until the end of the data collection phase, approximately three months from now

Date ____________, place_________________________
(ID: ________) Signature_________________________________

References

Åman, P., Liikkanen, L. A., Jacucci, G., & Hinkka, A. (2014). OUTMedia–Symbiotic Ser-vice for Music Discovery in Urban Augmented Reality. In Symbiotic Interaction (pp. 61-71). Springer International Publishing.

Andolina, S., & Forlizzi, J. (2014). A multi-touch interface for multi-robot path planning and control. In Symbiotic Interaction (pp. 127-132). Springer International Publishing.

Aranyi, G., Kouider, S., Lindsay, A., Prins, H., Ahmed, I., Jacucci, G., ... & Cavazza, M. (2014). Subliminal cueing of selection behavior in a virtual environment. Presence: Teleoperators and Virtual Environments, 23(1), 33-50.

Arsiwalla, X. D., Zucca, R., Betella, A., Martinez, E., Dalmazzo, D., Omedas, P., ... & Verschure, P. F. (2015). Network dynamics with $BrainX^3$: a large-scale simulation of the human brain network with real-time interaction. Frontiers in neuroinformatics, 9.

Athukorala, K., Lagerspetz, E., von Kügelgen, M., Jylhä, A., Oliner, A. J., Tarkoma, S., & Jacucci, G. (2014, April). How carat affects user behavior: implications for mobile battery awareness applications. In Proceedings of the 32nd annual ACM conference on Human factors in computing systems (pp. 1029-1038). ACM.

Babiloni, F., Rossi, D., Cherubino, P., Trettel, A., Picconi, D., Maglione, A. G., ... & Babiloni, F. (2015). A Neuroaesthetic Study of the Cerebral Perception and Appreciation of Paintings by

Titian Using EEG and Eyetracker Measurements. In Symbiotic Interaction (pp. 21-32). Springer International Publishing.

Bailey, B. P., & Iqbal, S. T. (2008). Understanding changes in mental workload during execution of goal-directed tasks and its application for interruption management. ACM Transactions on Computer-Human Interaction (TOCHI), 14(4), 21.

Bailey, R., McNamara, A., Sudarsanam, N., Grimm, C.: Subtle gaze direction. ACM Transactions on Graphics (TOG) 28(4), 100 (2009)

Ball, G., Breese, J. (2000). Emotion and personality in a conversational agent. Embodied conversational agents, 189-219.

Bandyopadhyay, P., Ruotsalo, T., Ukkonen, A., & Jacucci, G. (2014). Navigating complex information spaces: a portfolio theory approach. In Symbiotic Interaction (pp. 138-144). Springer International Publishing.

Barefoot, J. C., Dahlstrom, W. G., & Williams, R. B. (1983). Hostility, CHD incidence, and total mortality: a 25-year follow-up study of 255 physicians. Psychosomatic Medicine, 45(1), 59-63.

Beatty, J., & Kahneman, D. (1966). Pupillary changes in two memory tasks. Psychonomic Science, 5(10), 371-372.

Benyon, D. (1993). Adaptive systems: a solution to usability problems. User modeling and User-adapted Interaction, 3(1), 65-87.

Bernardet, U., i Badia, S. B., Duff, A., Inderbitzin, M., Le Groux, S., Manzolli, J., ... & Verschure, P. F. (2010). The eXperience induction machine: a new paradigm for mixed-reality interaction design and psychological experimentation. In The Engineering of Mixed Reality Systems (pp. 357-379). Springer London.

Betella, A., Bueno, E. M., Kongsantad, W., Zucca, R., Arsiwalla, X. D., Omedas, P., & Verschure, P. F. (2014, April). Understanding large network datasets through embodied interaction in virtual reality. In Proceedings of the 2014 Virtual Reality International Con-ference (p. 23). ACM.

Betella, A., Cetnarski, R., Zucca, R., Arsiwalla, X. D., Martínez, E., Omedas, P., ... & Verschure, P. F. (2014, April). BrainX 3: embodied exploration of neural data. In Proceedings of the 2014 Virtual Reality International Conference (p. 37). ACM.

Biocca, F., Harms, C., & Burgoon, J. K. (2003). Toward a more robust theory and measure of social presence: Review and suggested criteria. Presence, 12(5), 456-480.

Brookings, J. B., Wilson, G. F., & Swain, C. R. (1996). Psychophysiological responses to changes in workload during simulated air traffic control. Biological psychology, 42(3), 361-377.

Cetnarski, R., Betella, A., Prins, H., Kouider, S., Verschure, P.F.: Subliminal Response Priming in Mixed Reality: The Ecological Validity of a Classic Paradigm of Perception. Presence: Teleoperators and Virtual Environments 23(1), 1-17 (2014)

Chalfoun, P., Frasson, C.: Subliminal cues while teaching: HCI technique for enhanced learning. Advances in Human-Computer Interaction 2011, 2 (2011)

Chen, S., Epps, J., & Chen, F. (2013, March). Automatic and continuous user task analysis via eye activity. In Proceedings of the 2013 international conference on Intelligent user interfaces (pp. 57-66). ACM.

Chittaro, L. (2012). Passengers' safety in aircraft evacuations: Employing serious games to educate and persuade. In Persuasive technology. Design for health and safety (pp. 215-226). Springer Berlin Heidelberg.

Cohen, J. (2013). Statistical power analysis for the behavioral sciences. Academic press.

Cohen, S., Tyrrell, D. A., & Smith, A. P. (1991). Psychological stress and susceptibility to the common cold. New England journal of medicine, 325(9), 606-612.

Consolvo, S., Klasnja, P., McDonald, D. W., & Landay, J. A. (2009, April). Goal-setting considerations for persuasive technologies that encourage physical activity. In Proceedings of the 4th international Conference on Persuasive Technology (p. 8). ACM.

Damasio, A. (2005). Descartes' error: Emotion, reason, and the human brain. Penguin. com.

Debner, J.A., Jacoby, L.L.: Unconscious perception: attention, awareness, and control. Journal of Experimental Psychology: Learning, Memory, and Cognition 20(2), 304 (1994)

DeVaul, R.W., Pentland, A., Corey, V.R. (2003). The memory glasses: subliminal vs. overt memory support with imperfect information. In: Proceedings of the Seventh IEEE International Symposium on Wearable Computers (ISWC 2003), pp. 146-153 (2003)

Di Flumeri, G., Borghini, G., Aricò, P., Colosimo, A., Pozzi, S., Bonelli, S., ... & Babiloni, F. (2015). On the use of cognitive neurometric indexes in aeronautic and air traffic management environments. In Symbiotic Interaction (pp. 45-56). Springer International Publishing.

Dourish P.: Seeking a Foundation for context-aware computing. Human-Computer Interaction, 2001, 16 (2-4): 229-241, (2001)

Eng, K., Babler, A., Bernardet, U., Blanchard, M., Briska, A., Conradt, J., ... & Klein, D. (2002). Ada: Constructing a synthetic organism. In Intelligent Robots and Systems, 2002. IEEE/RSJ International Conference on (Vol. 2, pp. 1808-1813). IEEE.

Engelbart, D. C. (2001). Augmenting human intellect: a conceptual framework (1962).

Fairclough, S. (2015). A Closed-Loop Perspective on Symbiotic Human-Computer Interaction. In Symbiotic Interaction (pp. 57-67). Springer International Publishing.

Fairclough, S. H. (2009). Fundamentals of physiological computing. Interacting with computers, 21(1), 133-145.

Field, A. (2009). Discovering statistics using SPSS. Sage publications.

Fogg, B. J. (2002). Persuasive technology: using computers to change what we think and do. Ubiquity, 2002(December), 5.

Galičič, M., Fallon, E., van der Putten, W., & Sands, G. (2013). Applying NASA-TLX to Prostate Seeds Brachytherapy. Patient & Healthcare Provider Safety, London, November 2013.

Gamberini L., Spagnolli A., Prontu L., Furlan S., Martino F., Rey Solaz B., Alcañiz M., Lozano J. A. (2013) How Natural is a Natural Interface? An Evaluation Procedure Based on Action Breakdowns Personal and Ubiquitous Computing, 17: 69-79.

Gamberini, L., Spagnolli, A., Blankertz, B., Kaski, S., Freeman, J., Acqualagna, L., ... & Jacucci, G. (2015). Developing a Symbiotic System for Scientific Information Seeking: The MindSee Project. In Symbiotic Interaction (pp. 68-80). Springer International Publishing.

Gamberini, L., Spagnolli, A., Corradi, N., Jacucci, G., Tusa, G., Mikkola, T., ... & Hoggan, E. (2012). Tailoring feedback to users' actions in a persuasive game for household electricity conservation. In Persuasive Technology. Design for Health and Safety (pp. 100-111). Springer Berlin Heidelberg.

Golenia, J. E., Wenzel, M., & Blankertz, B. (2015). Live Demonstrator of EEG and Eye-Tracking Input for Disambiguation of Image Search Results. In Symbiotic Interaction (pp. 81-86). Springer International Publishing.

Greenwald, A. G., Draine, S. C., & Abrams, R. L. (1996). Three cognitive markers of unconscious semantic activation. Science, 273(5282), 1699-1702.

Greenwald, A. G., Klinger, M. R., & Schuh, E. S. (1995). Activation by marginally perceptible (" subliminal") stimuli: dissociation of unconscious from conscious cognition. Journal of experimental psychology: General, 124(1), 22.

Hannula, D. E., Simons, D. J., & Cohen, N. J. (2005). Imaging implicit perception: promise and pitfalls. Nature Reviews Neuroscience, 6(3), 247-255.

Hart, S. G. (2006, October). NASA-task load index (NASA-TLX); 20 years later. In Proceedings of the human factors and ergonomics society annual meeting (Vol. 50, No. 9, pp. 904-908). Sage Publications.

Hess, E. H., Polt, J. M. (1960). Pupil size as related to interest value of visual stimuli. Science, 132(3423), 349-350.

Hore, S., Tyrvainen, L., Pyykko, J., & Glowacka, D. (2014). A reinforcement learning approach to query-less image retrieval. In Symbiotic Interaction (pp. 121-126). Springer International Publishing.

Horvitz, E. (1999, May). Principles of mixed-initiative user interfaces. In Proceedings of the SIGCHI conference on Human Factors in Computing Systems (pp. 159-166). ACM.

Hsieh, Y. T., Jylhä, A., & Jacucci, G. (2014). Pointing and Selecting with Tactile Glove in 3D Environment. In Symbiotic Interaction (pp. 133-137). Springer International Pu-blishing.

Isen, A. M., Daubman, K. A., & Nowicki, G. P. (1987). Positive affect facilitates creative problem solving. Journal of personality and social psychology, 52(6), 1122.

Isen, A.M., 2000. Positive Affect and Decision Making. In: Lewis, M., Haviland, J. (Eds.), Handbook of Emotions. Guilford, New York.

Ishii, H. and Ullmer, B. 1997. Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms. Proc. ACM Conf. Human Factors in Computing Systems CHI’97 (Atlanta, GA). New York: ACM.

Jacucci, G., Spagnolli, A., Freeman, J., & Gamberini, L. (2014). Symbiotic interaction: a critical definition and comparison to other human-computer paradigms. In Symbiotic In-teraction (pp. 3-20). Springer International Publishing.

Japuntich, S. J., Zehner, M. E., Smith, S. S., Jorenby, D. E., Valdez, J. A., Fiore, M. C., ... & Gustafson, D. H. (2006). Smoking cessation via the internet: a randomized clinical trial of an internet intervention as adjuvant treatment in a smoking cessation intervention. Nicotine & Tobacco Research, 8(Suppl 1), S59-S67.

Kahneman, D. (1973). Attention and effort (p. 246). Englewood Cliffs, NJ: Prentice-Hall.

Kapoor, A., Burleson, W., & Picard, R. W. (2007). Automatic prediction of frustration. International journal of human-computer studies, 65(8), 724-736.

Kouider, S., & Dehaene, S. (2007). Levels of processing during non-conscious perception: a critical review of visual masking. Philosophical Transactions of the Royal Society of London B: Biological Sciences, 362(1481), 857-875.

Lang, P. J. (1995). The emotion probe: studies of motivation and attention. American psychologist, 50(5), 372.

Licklider, J. C. R. (1960). Man-computer symbiosis. Human Factors in Electronics, IRE Transactions on, (1), 4-11.

Lombard, M., & Ditton, T. (1997). At the heart of it all: The concept of presence. Journal of Computer-Mediated Communication, 3(2), 0-0.

Macmillan, N. A., & Creelman, C. D. (2004). Detection theory: A user's guide. Psychology press.

McNamara, A., Bailey, R., Grimm, C.: Improving search task performance using subtle gaze direction. In: Proceedings of the 5th symposium on Applied perception in graphics and visualization, pp. 51-56 (2008)

Moreno, J. C., Asin, G., Pons, J. L., Cuypers, H., Vanderborght, B., Lefeber, D., ... & Roa, J. (2014). Symbiotic wearable robotic exoskeletons: the concept of the BioMot project. In Symbiotic Interaction (pp. 72-83). Springer International Publishing.

Negri, P., Gamberini, L., & Cutini, S. (2014). A Review of the Research on Subliminal Techniques for Implicit Interaction in Symbiotic Systems. In Symbiotic Interaction (pp. 47-58). Springer International Publishing.

Negri, P., Omedas, P., Chech, L., Pluchino, P., Minelle, F., Verschure, P. F., ... & Gamberini, L. (2015). Comparing Input Sensors in an Immersive Mixed-Reality Environment for Human-Computer Symbiosis. In Symbiotic Interaction (pp. 111-125). Springer International Publishing.

Nicolae, I. E., Acqualagna, L., & Blankertz, B. (2015). Tapping Neural Correlates of the Depth of Cognitive Processing for Improving Human Computer Interaction. In Symbiotic Interaction (pp. 126-131). Springer International Publishing.

North, J. D. (1954). The rational behavior of mechanically extended man. Boulton Paul Aircraft Ltd., Wolverhampton, Eng.

Omedas, P., Betella, A., Zucca, R., Arsiwalla, X. D., Pacheco, D., Wagner, J., ... & Verschure, P. F. (2014, April). XIM-Engine: a software framework to support the development of interactive applications that uses conscious and unconscious reactions in immersive mixed reality. In Proceedings of the 2014 Virtual Reality International Conference (p. 26). ACM.

Picard, R. W. (2000). Affective computing. MIT press.

Pizzi, D., Kosunen, I., Viganó, C., Polli, A.M., Ahmed, I., Zanella, D., Cavazza, M., Kouider, S., Freeman, J., Gamberini, L., Jacucci, G.: Incorporating subliminal perception in synthetic environments. In: Proceedings of the 2012 ACM Conference on Ubiquitous Computing (UbiComp 2012), pp. 1139-1144. ACM (2012)

Pluchino, P., Gamberini, L., Barral, O., & Minelle, F. (2014). How semantic processing of words evokes changes in pupil. In Symbiotic Interaction (pp. 99-112). Springer International Publishing.

Ratcliff, R., & McKoon, G. (2008). The diffusion decision model: theory and data for two-choice decision tasks. Neural computation, 20(4), 873-922.

Riecke, B. E., & von der Heyde, M. (2002). Qualitative Modeling of Spatial Orientation Processes using Logical Propositions. TR 100, MPI for Biological Cybernetics. Avaliable: ww. kyb. mpg. de/publication. html.

Riener, A., Kempter, G., Saari, T., Revett, K.: Subliminal Communication in Human-Computer Interaction. Advances in Human-Computer Interaction (2011)

Rosis, F. D., Pelachaud, C., Poggi, I., Carofiglio, V., Carolis, B. D. (2003). From Greta's mind to her face: modelling the dynamics of affective states in a conversational embodied agent. International Journal of Human-Computer Studies, 59(1), 81-118.

Ruotsalo, T., Peltonen, J., Eugster, Manuel J.A. Gowacka, D, Konyushkova, K., Athukorala, K., Kosunen, I., Reijonen, A, Myllymki, P., Jacucci, G., Kaski, S.: Directing Exploratory Search with Interactive Intent Modeling. In: ACM International Conference on Information and Knowledge Management (2013)

Rutkowski, T. M., Shimizu, K., Kodama, T., Jurica, P., & Cichocki, A. (2015). Brain–Robot Interfaces Using Spatial Tactile BCI Paradigms. In Symbiotic Interaction (pp. 132-137). Springer International Publishing.

Schalk, G. (2008). Brain–computer symbiosis. Journal of neural engineering, 5(1), P1.

Serim, B. (2014). Querying and display of information: symbiosis in exploratory search interaction scenarios. In Symbiotic Interaction (pp. 115-120). Springer International Pu-blishing.

Smids, J. (2012). The voluntariness of persuasive technology. In Persuasive technology. Design for health and safety (pp. 123-132). Springer Berlin Heidelberg.

Spagnolli, A., & Gamberini, L. (2005). A Place for Presence. Understanding the Human Involvement in Mediated Interactive Environments. PsychNology Journal, 3(1), 6-15.

Spagnolli, A., Bracken, C. C., & Orso, V. (2014). The role played by the concept of presence in validating the efficacy of a cybertherapy treatment: a literature review. Virtual Reality, 18(1), 13-36.

Spagnolli, A., Corradi, N., Gamberini, L., Hoggan, E., Jacucci, G., Katzeff, C., ... & Jönsson, L. (2011). Eco-feedback on the go: Motivating energy awareness. Computer, 44(5), 38-45.

Special Initiative: Symbiotic human-machine interaction. (n.d.). In *European Commission website.* Retrieved from http://cordis.europa.eu/fp7/ict/fet-proactive/symbiosis_en.html

Stanislaw, H., & Todorov, N. (1999). Calculation of signal detection theory measures. Behavior research methods, instruments, & computers, 31(1), 137-149.

Ulrich-Lai, Y. M., & Herman, J. P. (2009). Neural regulation of endocrine and autonomic stress responses. Nature Reviews Neuroscience, 10(6), 397-409.

van Erp, J. B., Veltman, H. J., & Grootjen, M. (2010). Brain-based indices for user system symbiosis. In Brain-Computer Interfaces (pp. 201-219). Springer London.

Veltman, J. A., & Gaillard, A. W. K. (1996). Physiological indices of workload in a simulated flight task. Biological psychology, 42(3), 323-342.

Vorberg, D., Mattler, U., Heinecke, A., Schmidt, T., & Schwarzbach, J. (2003). Different time courses for visual perception and action priming. Proceedings of the National Academy of Sciences, 100(10), 6275-6280.

Weiser, M. 1991. The Computer for the Twenty-First Century. Scientific American. 265(3), 94-104.

Wenzel, M. A., Moreira, C., Lungu, I. A., Bogojeski, M., & Blankertz, B. (2015). Neural Responses to Abstract and Linguistic Stimuli with Variable Recognition Latency. In Symbiotic Interaction (pp. 172-178). Springer International Publishing.

Wilson, G. F., & Russell, C. A. (2003). Operator functional state classification using multiple psychophysiological features in an air traffic control task. Human Factors: The Journal of the Human Factors and Ergonomics Society, 45(3), 381-389.

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. Presence: Teleoperators and virtual environments, 7(3), 225-240.

RINGRAZIAMENTI

Ringrazio il Professor Gamberini e la Professoressa Spagnolli per avermi guidato con sensibilità ed amicizia fino al traguardo unico del dottorato. Porterò sempre con me i loro insegnamenti, il ricordo delle esperienze vissute insieme, e di come essi hanno continuato a credere in me anche nei momenti difficili.

Ringrazio il Professor Jacucci per avermi accolto nel suo meraviglioso gruppo di ricerca per il mio periodo all'estero. Kiitos Giulio!

Ringrazio Milena, per avermi sostenuto sempre, anche quando le è costato molto.

Ringrazio Giulia, bambina meravigliosa! Lei sa aggiungere colori vivaci alla mia vita quotidiana.

Ringrazio mia mamma e mio papà che hanno saputo incoraggiare il cambiamento di un figlio un po' nubivago, un po' volandolo. Senza il loro sostegno e amore niente sarebbe stato possibile.

Ringrazio mia zia Adriana che mi appoggia sempre, anche se ambissi a fare il Sindaco progressista.

Ringrazio Federico! Fratello mio… la tua umanità e il tuo amore discreto sono una delle mie certezze. Vorrei stringerti in un abbraccio lungo mille anni!!

Ringrazio Valeria, mia sorella accademica, verso la quale nutro un profondo affetto e senso di protezione, anche se poi, spesso… è spettato a lei incoraggiarmi. Tanto bene Valeee!!!!!

Ringrazio il mio amico e collega Stefano, alias il Cardullo. Che dire? Ho scritto amico… intendo AMICO! Ogni altro attributo mi sembra riduttivo.

Ringrazio Andrea e Alessandra per essere amici sensibili.

Ringrazio i Proff. Luigi e Luciana per aver continuato a cercarmi.

Ringrazio Patrik e Alessandro per esserci sempre stati quando ero nel panico!

Ringrazio Piero per aver edulcorato le mie tisane con il suo miele, ma soprattutto… per le chiacchiere fatte insieme durante le quali, ne sono sicuro, le parole gli uscivano dal cuore.

Ringrazio Jeeg Robot d'Acciaio che difende la Terra.

Ringrazio Stefano e Graziano, i miei amici sempiterni.