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CICLO XXIV°

PERIPERSONAL AND EXTRAPERSONAL SPACE: LINE BISECTION EXPERIMENTS IN REAL AND VIRTUAL ENVIRONMENTS

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RIASSUNTO

L’interesse da parte dell’uomo di comprendere come lo spazio che lo circonda sia percepito ed elaborato stimola la ricerca scientifica e sperimentale ormai da diversi decenni. Inoltre, fin dalle prime interazioni umane con ambienti virtuali generati al computer, l'interesse per questo argomento ha ottenuto sempre maggiore attenzione, anche allo scopo di verificare se il comportamento osservato negli ambienti virtuali è simile a quello osservato negli ambienti reali. Le tecnologie di realtà virtuale sono attualmente impiegate in diversi settori, dall’implementazione in campo medico alla riabilitazione di disturbi psicologici e neuropsicologici, dall’utilizzo in campo militare allo sfruttamento in ambito industriale. I risultati positivi ottenuti attraverso l’utilizzo della realtà virtuale continuano a supportare questa nuova tecnologia e la sua evoluzione. La ricerca sulle reazioni del cervello umano durante le interazioni con tali ambienti sintetici svolge un ruolo importante da un punto di vista neuropsicologico, nonché in termini di affidabilità e credibilità dello strumento.

Di particolare importanza nell’ambito dello studio della percezione spaziale è la questione riguardante la sua diversa rappresentazione che distingue l’ambiente circostante in spazio peripersonale, o spazio vicino, definito lo spazio di raggiungimento dei nostri arti, e spazio extrapersonale, o spazio lontano, definito lo spazio oltre il raggiungimento dei nostri arti. Evidenze neuropsicologiche confermano l'esistenza di differenti meccanismi neurali coinvolti nella rappresentazione dello spazio peripersonale ed extrapersonale. Inoltre, è noto che l’utilizzo di normali strumenti provochi una rielaborazione percettiva dello spazio, espandendo la rappresentazione dello spazio peripersonale ad includere la parte di spazio extrapersonale occupata dalle estremità degli strumenti manipolati.

Lo scopo del presente elaborato è di analizzare e comprendere alcuni degli aspetti ancora inesplorati in questo ambito di ricerca, nonché di aggiungere informazioni alla teoria di base. A tal fine, sono stati condotti diversi esperimenti al fine di indagare i seguanti aspetti:

- il limite di espansione dello spazio peripersonale attraverso l’utilizzo di uno strumento;

- le aree cerebrali coinvolte nella percezione dello spazio peripersonale ed extrapersonale;
- l’influenza della posizione del corpo e delle braccia nella percezione dello spazio peripersonale ed extrapersonale;
- infine, il meccanismo coinvolto nella modulazione della percezione dello spazio extrapersonale.

Nel primo capitolo è esposta una rassegna teorica sullo spazio peripersonale ed extrapersonale, sulle aree cerebrali coinvolte nella loro rappresentazione, attraverso l’analisi di ricerche ed esperimenti condotti con soggetti animali; in seguito, sono esaminati ulteriori studi realizzati con partecipanti umani, in diverse situazioni e modalità, al fine di delineare il funzionamento di questo particolare fenomeno percettivo.

Nel secondo capitolo è presentata la letteratura riguardante le applicazioni in ambito virtuale inerenti allo studio della percezione spaziale all’interno di ambienti artificiali. Nella prima parte del capitolo sono introdotti i concetti di base sul funzionamento di questa particolare tecnologia; in seguito sono esposte evidenze empiriche a sostegno dell’utilità e delle potenzialità che questa nuova tecnologia fornisce. Infine viene analizzata una serie di ricerche inerenti al fenomeno di percezione dello spazio peripersonale all’interno di ambienti virtuali.

Nel terzo capitolo è presentata la ricerca, ed in particolare sono illustrati gli scopi, la metodologia, le procedure sperimentali e gli strumenti utilizzati per gli esperimenti condotti. Il paradigma sperimentale utilizzato all’interno del presente lavoro è stato il compito di bisezione di linea. Si tratta di un paradigma sperimentale ampiamente utilizzato poiché relativamente semplice per i partecipanti da svolgere, tuttavia valido in termini di risultati riguardo attenzione visuospaziale e percezione.

Il primo studio ha avuto come obiettivo principale quello di capire fino a che distanza l’utilizzo di uno strumento possa espandere lo spazio peripersonale. I risultati hanno mostrato un ampliamento dello spazio percepito peripersonale, durante la manipolazione dello strumento fino alla distanza di 240 cm.

L'obiettivo del secondo studio è stato di identificare le aree cerebrali coinvolte durante un compito di attenzione visuospaziale in ambiente virtuale, tramite l’utilizzo della tecnica di neuroimmagine Spettroscopia Funzionale del Vicino Infrarosso (i.e., functional Near Infrared Spectroscopy; fNIRS). L’esperimento rappresenta uno dei primi tentativi di indagare i correlati neurali tramite l’utilizzo della fNIRS durante un’esperienza di realtà virtuale immersiva.

La posizione del corpo può modificare il modo di percepire lo spazio circostante e lo spazio oltre la distanza di raggiungimento delle braccia. Sulla base di risultati ottenuti in studi precedenti, il terzo esperimento è volto a verificare se la sensazione di avere il corpo bloccato o libero di muoversi durante un compito di attenzione visuospaziale, abbia implicazioni sulla modulazione percettiva nello spostamento attentivo dallo spazio peripersonale a quello extrapersonale. I risultati hanno mostrato che sia nel primo sia nel secondo caso, si assiste ad uno spostamento attentivo netto, è non graduale, durante la transizione dallo spazio peripersonale a quello extrapersonale.

La posizione del braccio può influenzare il modo di percepire lo spazio circostante e lo spazio oltre la distanza di raggiungimento del braccio. Sulla base di risultati ottenuti in studi precedenti, il quarto esperimento è volto a verificare se la distensione del braccio davanti al corpo o il suo posizionamento lungo un fianco durante un compito di attenzione visuospaziale, abbia implicazioni sulla modulazione percettiva dello spazio peripersonale ed extrapersonale. I risultati hanno confermato che la posizione del braccio influenza l’attenzione visuospaziale.

Infine, l’ultimo esperimento ha indagato nello specifico le cause alla base dell’espansione dello spazio peripersonale durante l’utilizzo di uno strumento. Si ritiene che sia la capacità di manipolare attivamente lo spazio l'elemento essenziale per indurre l'espansione dello spazio peripersonale. Tuttavia, come osservato in studi precedenti, è possibile che anche la continuità visiva dalla mano verso la regione di spazio manipolato sia una caratteristica fondamentale per modulare l'espansione dello spazio peripersonale. I risultati confermano l’ipotesi che la caratteristica essenziale per indurre l'espansione dello spazio peripersonale è rappresentata dalla manipolazione attiva della regione di spazio osservata.

Gli studi riportati nel presente elaborato hanno esplorato diverse questioni riguardanti la comprensione della percezione dello spazio circostante e le sue implicazioni sui processi di attenzione ad essa collegati. Nel quarto capitolo sono discussi e valutati i risultati alla luce della letteratura di riferimento.

SUMMARY

The human interest on understanding how the surrounding space is perceived and processed has stimulated the scientific and experimental research in this field for several decades. Moreover, from the earliest human interaction with computer-generated virtual environments, interest in this subject has received increasing attention, in order to verify whether the observed behavior in virtual environments is similar to that seen in real environments. Virtual reality technologies are currently used in different fields, from the implementation in medicine to the rehabilitation of neuropsychological and psychological disorders, from the use in the military to the exploitation in industry. The positive results obtained through the use of virtual reality continue to support this new technology and its evolution. Research on the human brain mechanisms involved during interactions with these synthetic environments plays an important role from a neuropsychological point of view, and in terms of reliability and credibility of the instrument.

Of particular importance in the study of spatial perception is the question of its representation that distinguishes the surrounding environment in peripersonal space, or near space, the space within arm reach, and extrapersonal space, or far space, defined the space beyond the arm reach. Neuropsychological evidences confirm the existence of different neural mechanisms involved in peripersonal and extrapersonal space representation. Moreover, it is known that the use of standard tools results in a modulation of the perceptual space, expanding the representation of peripersonal space to include the part of extrapersonal space occupied by the end of the tools manipulated.

The aim of the present study is to analyze and understand some unclear aspects of this area of research, and to add information to the basic theory. To this end, several experiments were conducted to investigate the following aspects:

- peripersonal and extrapersonal space limits during tool-use;
- neural circuits involved in representation of peripersonal and extrapersonal space;

- body and arm position influence in the perception of peripersonal and extrapersonal space;
- the mechanism involved in extrapersonal space perception.

The first chapter is an overview of peripersonal and extrapersonal space theories, and of the brain areas involved in their representation, through the analysis of researches and experiments with animal subjects; next, further studies are examined with human participants, in different situations and methods, in order to define the characteristics of this perceptual phenomenon.

The second chapter presents the literature concerning the applications in the virtual reality field in the study of artificial environments spatial perception. The first part of the chapter introduces the basic concepts of the technology. Then, empirical evidences that support the utility and potential of this new technology are exposed Finally, an analysis of the researches concerning the phenomenon of peripersonal space perception in virtual environments is provided.

The third chapter presents the research, and particularly explains the, methodology, experimental procedures and materials used for the experiments. The experimental paradigm used in the present work was the line bisection task. It is a widely used experimental paradigm since relatively easy for participants to perform, but provides valid results in terms of perception and visuospatial attention.

The first study aimed to understand how far up tool-use can expand peripersonal space. The results showed an expansion of perceived peripersonal space when handling a tool up to a distance of 240 cm.

The second study explored which brain areas are involved in a visuospatial attention task performed in a virtual environment, by using the neuroimaging technique functional Near Infrared Spectroscopy (i.e., fNIRS). The experiment represents one of the first attempts to investigate the neural correlates by using the fNIRS during an immersive virtual reality experience.

Body position can influence the perception of the surrounding space and the space beyond arm reaching distance. Based on previous results, the third experiment investigated if the feeling of having the body blocked or free to move during a visuospatial attention task has implications in the attentional shift that modulates peripersonal and extrapersonal space perception. The results showed that both for the first and the second case, an abrupt attentional shift, not gradual, during the transition from peripersonal to extrapersonal space was observed.

Arm position can influence the perception of the surrounding space and the space beyond arm reaching distance. Based on previous results, the fourth experiment investigated whether having the arm stretched or bent during a visuospatial attention task, has implications in the modulation of peripersonal and extrapersonal space perception. The results confirmed that the position of the arm affects visuospatial attention.

The last experiment has specifically investigated the underlying causes of peripersonal space expansion when using a tool. It is believed that is the ability to actively manipulate the space the essential feature to induce the peripersonal space expansion. But, as noted in previous studies, it is possible that the visual continuity from the hand toward the manipulated region of space represents the key feature in modulating peripersonal space expansion. The results confirm the hypothesis that the essential feature in order to induce peripersonal space expansion is represented by the active manipulation of the observed region of space.

The studies reported in the present study explored several issues relating to the understanding of the perception of the surrounding space and its implications on the attentional processes related. In the fourth chapter the results are discussed and evaluated.

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CHAPTER 1

1.1. PERIPERSONAL AND EXTRAPERSONAL SPACE

Body movement throughout the natural environment involves that the brain constantly monitors body positions and movements in relation to nearby objects. The brain has to compute a neural representation of the body, called the ‘body schema’, and of the space surrounding the body, which is called the ‘peripersonal space’. By definition, there are the postural scheme, represented by body position and movement, processed by the brain through kinesthetic and proprioceptive afferent impulses, and the sensorial scheme, represented by body afferent impulses from visual, auditory and tactile stimuli (Holmes & Spence, 2004). Peripersonal space is defined as the space immediately surrounding our body; on the other hand, extrapersonal space is defined as the space beyond the arm reaching distance (Previc, 1998; Vallar & Maravita, 2009; see Figure 1.1.). The brain elaborates peripersonal space stimuli differently from that in extrapersonal space. This distinction is justified by the fact that, following brain damage of the right hemisphere, some patients show behavioral deficits in object-perception within peripersonal space. For example, in finding the true centre drawn on a sheet of paper, patients show less difficulty when they are asked to perform the task with a laser pointer when the lines are presented in the extrapersonal space. Moreover, the multisensory representation plasticity of peripersonal space represents an important topic; when humans and animals see themselves in a mirror or a monitor, or when they see artificial body parts, their peripersonal space representation is altered creating a new perceptual visual configuration of the body in regards to the surrounding environment. This situation produces conflicts between different senses. Through looking at ourselves in a mirror, on a monitor, or at artificial body parts, we can see how our body appears in a specific position, while contemporary we feel that the body is in another position (Graziano, 1999; Graziano, Cooke, & Taylor, 2000; Maravita, Spence, Clarke, Husain, & Driver, 2000; Maravita, Spence, Sergent, & Driver, 2002; Botvinick & Cohen, 1998; Pavani, Spence, & Driver, 2000). Also the use of inanimate objects (i.e., normal tools) to extend our body limits has important implications in peripersonal space comprehension and in how they could be incorporated into the ‘body schema’ (Maravita & Iriki, 2004; Berti & Frassinetti, 2000; Johnson-Frey, 2004).

1.2. PERIPERSONAL SPACE IN THE BRAIN

Peripersonal space neural representation is constructed within a network of cerebral regions that interact with one another. To create a space representation around the body and individual body parts that can be reached by the hands, the brain has to elaborate arm position in this space. This representation can be produced through various reference systems, for example centered on the body or centered on the eye. The term ‘reference system’ is used to define the centre of a coordinate system that represents objects and their relations (Grefkes & Fink, 2005). For example, if we imagine that we are sitting in a kitchen while watching a coffee cup over the table, its position can be described with a different reference system. In relation to our eyes, the cup is straight in front of us; in relation to our left arm, the cup is on the right. Thus, the cup position could be described also with a reference system that depends on the

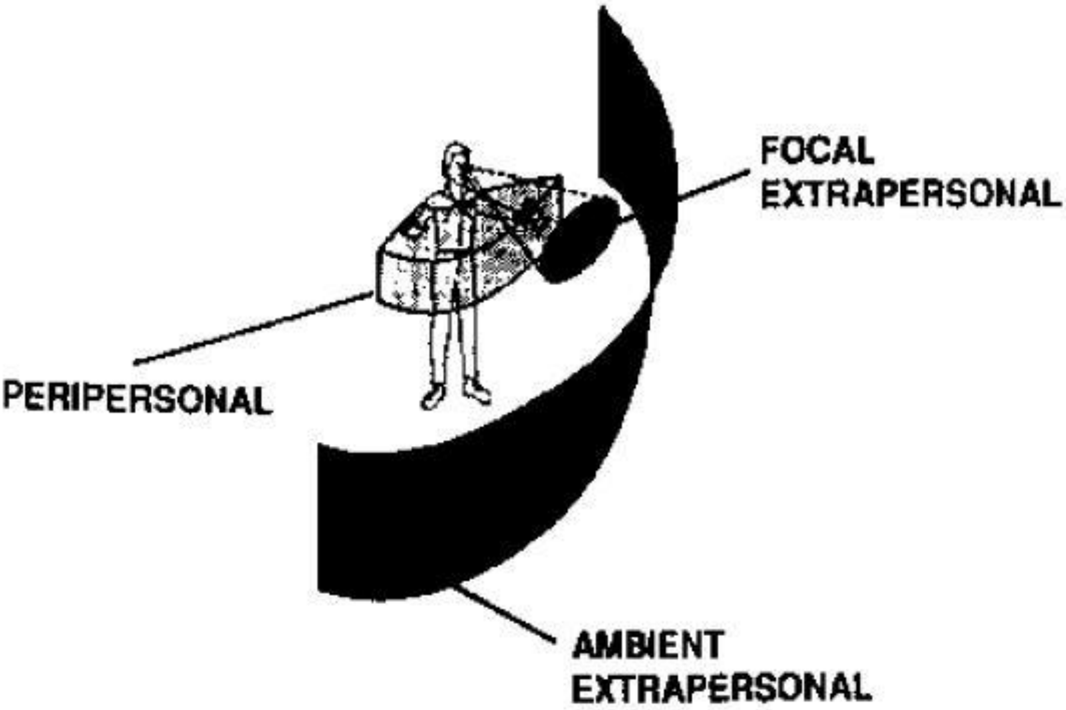


Figure 1.1. Peripersonal and extrapersonal space (from Previc, 1998).

external world, such as using a reference system depending on the position relative to the table. Then, a retinotopic reference system will take every retinoic fovea as centre and will represent visual objects relative to this origin point. In a reference system centered on the head, objects are represented independently from the eye movements, and in a reference system centered on the body, objects are represented independently from the head and eye movements. Both reference systems centered on the body or body parts are important in the representation of peripersonal space. A reference system centered on the body exists that represents topographically the body surface, in the primary somatosensory cortex and in other different brain areas (i.e., secondary somatosensory cortex, putamen, premotor cortex, primary motor cortex). Visual signs received relative to body part positions can be addressed to the areas interested in this somatotopic representation to transmit the visual space around the individual body parts. It is possible that the brain uses the most appropriate system to elaborate information: for visual signs, it uses a retinotopic system; for eye movement, it uses an eye-centered system. Finally, for auditory signs and head movements, a system centered on the head is used by the brain (Grefkes & Fink, 2005). For the visuotactile peripersonal space and for the control and representation of body positions and movements, the most appropriate reference system seems to be the one centered on individual body parts. Several brain areas were discovered that elaborate multisensory spatial maps with a reference system centered on individual body parts, such as putamen, Area 7b, and the intraparietal ventral cortex (VIP) (Graziano & Gross, 1993; 1995).

1.2.1. Peripersonal Space in the Motor System

The human motor system consists of several parallel pathways with hierarchical organization. The first control level consists of the brainstem nuclei. The second control level is represented by the primary motor cortex. The third and final control level is represented by other cortical motor areas such as the cerebellum and basal ganglia (Rizzolatti, Luppino, & Matelli, 1998). Within the human motor system, the premotor cortex plays an important role in the representation of peripersonal space. The premotor cortex, equivalent to Brodmann's area 6, is generally divided into two major regions named area F4 and area F5. Area F4 is the most important, located behind Area F5 and belonging to the premotor ventral cortex (PMv). This area and the primary motor cortex contain somatotopic maps of the arms, the hands and the face. Several neurons in PMv respond both to somatosensory and visual stimulation. Therefore, the spatial region in which visual stimulation is effective in the activation of these neurons is modulated by the position of the arms in the space (Fogassi et al., 1996; Graziano, Yap, & Gross, 1994). For example, PMv cells with tactile receptive fields on the right arm react to visual stimuli in the right portion of space when the arm is kept behind a monkey's back. When the arm is moved to the centre of the visual field, same cells now react to visual stimuli in the centre of the visual field. Neuron analysis with this receptive field on the face shows that visual receptive fields move when the head rotates, but not when they change their fixation point (Graziano, Hu, & Gross, 1997a; Graziano, Hu, & Gross, 1997b). These results seem to demonstrate the presence of a reference system centered on body parts, because neuron reactions were analyzed either when the monkeys were looking at a specific position and when the fixation point was not controlled. Independently from eye position, visual stimuli presented near specific body parts activate neurons with somatosensory receptive fields in those specific body parts. PMv neurons that fire with visual stimuli presented in peripersonal space keep responding even though the object is not seen any more. If the object is removed silently and without been seen while in the dark, the neurons will continue responding. Firing rate decreases only when light is turned on and the subject understands that the object was moved (Graziano, Hu, & Gross, 1997a). These neurons compute the presence of the object in peripersonal space independently from the sensorial modality initially perceived. In fact, some premotor cortex areas are specialized in such a way that approaching visual objects can be detected, which makes it easier for the body to plan and execute defensive movements to avoid these objects (Graziano, Taylor, & Moore, 2002; Farnè, Demattè, & Ladavas, 2003). These are also neurons that have somatosensory, visual, and auditory receptive fields centered on the lateral and posterior side of the head. Responses of most of these cells to the auditory stimuli were dependent on the stimulus distance from the head and the stimulus size (Graziano, Reiss, & Gross, 1999).

Finally, neurons that respond to visual stimuli approaching the monkey’s arm became dependent also on a fake arm located realistically near the animal (Graziano, 1999). When the real arm was moved, visual receptive fields moved too, with optimal responses when stimuli approached the arm. When the real arm was hidden under a cover, and only the proprioceptive information was available relative to the arm position, the visual receptive fields’ movement was decreased when the arm was moved. Moreover when a fake arm was positioned over the cover, rather than positioned over the real arm hidden from the animal’s view, the movement of the artificial arm provoked the displacement of the receptive fields even when the real arm remained steady.

These results provide evidence that the premotor ventral cortex is involved in the multisensory representation of peripersonal space. The representation is centered on single body parts; it reproduces the space surrounding the arms, the hands and the face, and integrates the visual, auditory and somatosensory information relative to the perceived stimuli position.

1.2.2. Peripersonal Space in the Attentional System

Several models of human attentional system have been proposed and discussed over the years (Posner, 1980; Kahneman, 1973). Generally, brain areas found to be involved in the functioning of the attentional system are: the right parietal cortex, the superior culliculus, the pulvinar and the cingulate gyrus (Posner & Raichle, 1994; Mesulam, 2002). As for the premotor cortex, it seems that the most relevant areas involved in the representation of peripersonal space are the Area 5 of the posterior parietal cortex (PPC), the VIP and Area 7b (Graziano & Gross, 1995). Somatosensory impulses project from the thalamus to the primary somatosensory cortex in the central sulcus and in the post-central gyrus. Area 5 of the posterior parietal cortex is located behind the post-central somatosensory cortex and receives inputs from the primary somatosensory cortex. It is suggested that Area 5 elaborates posture and body movements, and responds to the somatosensory inputs relative to arm position (Graziano et al., 2000). When an artificial monkey arm was placed realistically along the animal’s side, neurons sensitive to the perceptual position of the real arm covered responded more when the artificial arm was perceived in a similar position. The discharge amount of those neurons was influenced mostly by the perceived position of the arm but also by the visual information. Neurons’ sensitivity to the appearance of the artificial arm was remarkable, because the discharge amount was not influenced by an artificial arm positioned in an unrealistic way or a left arm attached to the right shoulder.

Although Area 5 neurons integrate visual and proprioceptive signs when encoding the position of body parts, it seems that these neurons don’t represent multisensory peripersonal space through a reference system centered on single body parts as observed before. When they were analyzed to obtain visual responses using stimuli kept in the experimenter's hand, these same neurons did not show visual response properties associated to the monkey's arm position (Graziano et al., 2000). On the other hand, Iriki et al. (1996a) analyzed somatosensory monkey neurons in the anterior intraparietal sulcus (aIPS, suggested to be the same Area 5 in humans; Rizzolatti et al., 1998) and found that they respond to moving stimuli held in the experimenter's hand. Therefore, it could be possible that those cells represent peripersonal space around the arm with a reference system centered on the body. Cells in the aIPS commonly have somatosensory properties, along with visual responses, especially at the aIPS base. It should be noted that the evoking responses stimuli were represented by food. Graziano et al. (2000) used food too, but to distract the monkeys' attention from the visual test stimulus and noted that they tend to fixate on food pieces. Typically, neurons that represent peripersonal space in the premotor cortex show visual responses only to three-dimensional stimuli that move within peripersonal space, which is mostly sensitive to tactile receptive fields on the bodies of animals. Moreover, these neurons do not respond to visual stimuli projected onto a screen, even when the screen is located near the animal. These neurons were recorded while the animal was anesthetized as well as while the animal was awake. Responses were also recorded when the stimulus was not linked with any reward and the monkey had learned to ignore it. Additionally, stimuli in Iriki studies were always presented in a centripetal trajectory that approached or moved away from the animal's hand (Iriki, Tanaka, & Iwamura, 1996a; Obayashi, Tanaka, & Iriki, 2000). In Fogassi et al. (1996) and Graziano et al. (1997b) studies, receptive field tests were performed with stimuli presented along a parallel trajectory, that were independent to hand, eye or head position. As the stimuli were presented mostly near the animal's hand, it is possible that the registered neural responses were not related to the neural responses for the stimuli presented within peripersonal space centered on single body parts (Iriki et al., 1996a).

Neurons analyzed by Iriki et al. (1996a) were also studied in other fields. Iriki et al. (1996b), discovered that neurons of the entire post-central gyrus and in the intraparietal sulcus anterior/medial side were influenced by motivational and attentional factors. For example, during a reward task, IPS anterior side cells begin to fire when the stimulus appears, maintaining the activation during the task and diminishing only when the reward was received. MacKay and Crammond (1987), encountered a group of posterior parietal cortex neurons that showed an anticipatory activity for somatosensory stimulation. This condition was expressed as a changing in the firing rate every time the experimenter approached a monkey's hand or shoulder. Those neurons responded to the skin and proprioceptive stimulation of the interested area. Finally, a group of Area 5 neurons responded only when the monkey extended the arm to take or manipulate an object of interest but not when the animal performed simple movements with the same joints and muscles, or extended the arm to other objects it was not as interested in. These neurons were active before the effective hand movement and had a low firing rate; when the target stimulus was identified, the firing rate remained constant (Mountcastle, Lynch, Georgopoulos, Sakata, & Acuna, 1975).

1.3. PERIPERSONAL SPACE IN HUMANS

Human peripersonal space was studied and analyzed through conducting experiments both with brain damaged patients and with normal people. The goal was to discover if the same principles documented for animals, can also be applied to humans. Ladavas (2002) conducted experiments with neuropsychological patients in several situations to determine if brain damage influences the nature of the peripersonal space visuotactile representation. Most of these patients were affected by left tactile extinction; people with this syndrome can distinguish tactile stimulation on the right or left hand, but if the tactile stimulation is delivered simultaneously on both hands, only the right hand tactile stimulation is detected correctly (di Pellegrino, Ladavas, & Farnè, 1997; Mattingley, Driver, Beschin, & Robertson, 1997). This deficiency could be explained in terms of competition between hand neural representation in the right and left cerebral hemispheres. A right hand tactile stimulus activates a somatosensory representation of the touched body part in the left hemisphere. On the contrary, a tactile stimulation on the left body side activates a somatosensory representation of the right hemisphere. In the case of patients who have damaged right hemispheres, the left hemisphere representation is stronger than in the right hemisphere; therefore, in the simultaneous tactile stimulus condition, the stronger representation of the tactile stimulus in the left hemisphere competes with the limited resource of the elaboration of the contralateral representation thus bringing a more frequent failure in the recognition of the left tactile stimulus in respect to the single unilateral stimulation condition.

Therefore, if peripersonal space is encoded in terms of visuotactile bimodal representation, and if right hemisphere damage impairs this representation, then visual stimuli in the right peripersonal space should interfere in the identification of left side space tactile stimuli. In fact, di Pellegrino et al. (1997) found that in visual stimulation, the experimenter’s finger movements over the patient’s right hand led to a complete extinction of all the left tactile simultaneous stimulations. When the right visual stimulus was presented far from the hand, or when the patient kept his hand behind his back, the left tactile stimulation identification increased significantly. Moreover, when the arms were crossed (in the way that the left hand was placed in the right hemi-space and vice versa), visual stimulation near the right hand once again led to extinction for the left hand tactile stimulus. These findings demonstrate that visuotactile spatial interactions centered on the hand change relative to the position of the hand in the space and confirm that visuotactile peripersonal space is represented according to a coordinate system centered on body parts, as shown through the studies on single neurons in the monkey’s premotor and posterior parietal cortex (Graziano & Gross, 1995; Graziano et al., 1997b).

Besides the crossmodal extinction, crossmodal facilitation in the altered tactile identification was also studied (Ladavas, Zeloni, & Farnè, 1998; Ladavas, Farnè, Zeloni, & di Pellegrino, 2000). According to the assumption that the deficit is provoked by an unbalanced competition between the visuotactile representation in the right and left hemispheres, the simultaneous visual and tactile stimulation of the left hand and the tactile stimulation of the right hand should enhance the number of identifications for the left tactile stimulation. The results of both the simultaneous visual and tactile stimulation differ from the results produced by the simultaneous tactile stimulation alone. Halligan et al. (1996), have reported a patient who did not normally identify the tactile stimulation on his left arm; the vision of his arm that was being touched by the experimenter, instead, induced a tactile feeling. Moreover, di Pellegrino and Frassinetti (2000) studied a patient with a right parietal-temporal lesion, in which the perception of a left visual stimulus was facilitated when the patient's hand was placed near the screen in which the stimulus was projected.

Peripersonal space deficits were studied not only with an arm centered reference system but also with face centered ones. Ladavas et al. (1998) reported a study in which visual stimuli near the face was effective in provoking extinction of simultaneous tactile stimuli. Tactile stimuli on the right cheek were effective in provoking extinction of simultaneous tactile stimuli on the left cheek. The extinction effect was modulated by the distance of stimuli presentation. Furthermore, although the majority of crossmodal extinction studies consider mostly tactile and visual stimulation, there is the possibility of a tactile-auditory extinction, which would lead to an auditory peripersonal space representation (Ladavas, Pavani, & Farnè, 2001; Farnè & Ladavas, 2002). The right auditory stimulation interferes with a simultaneous left tactile stimulation more when the stimulus (pure sound or white noise) is presented near the head than when it is farther from the head.

In the same way, single neurons registered in the premotor ventral cortex that have tactile receptive fields behind the monkey's head respond also to auditory stimulation (Graziano et al., 1999). But, instead of representing the auditory space confined around the only tactile receptive field, it seems that they represent the space around the head like a whole. These multisensory neurons, as well as the damaged right hemisphere patients that derive representations in auditory crossmodal extinction, appear to code the auditory space as immediately surrounding the head. This kind of auditory peripersonal representation can operate as part of an alerting system in humans and animals in cases of auditory events near the head, for which a rapid orientating response is required.

Deficits discovered in neuropsychological patients seem to reflect the same multisensory integration principles found on monkey premotor cortex single neurons. Peripersonal space representation is centered on the body or body parts, confined within the space immediately surrounding the body thus involving the information integration from somatosensory, proprioceptive, visual and auditory sensorial modalities.

1.3.1. Peripersonal Space Plasticity

The plasticity of the body representation and peripersonal space are variable that make it possible for us to successfully utilize mirror reflections in the environment. This feature allows us to identify ourselves, and lets us perform actions in front of a mirror. We recognize ourselves in the mirror and can perform movements in the surrounding environment using mirror reflections as our visual guides.

This issue was analyzed by Maravita et al. (2000) during their study with a neuropsychological patient affected by crossmodal extinction. The patient could see his hands covered, reflected in a mirror located in peripersonal space. The patient’s tasks consisted of recognizing tactile stimuli applied to his left hand, simultaneously presented with visual stimuli (flashes). When the visual stimuli were presented near the real hand in the mirror, it was effective in cancelling the identification of the 33% tactile stimuli. When the patient was further analyzed with a triple stimulation (both left and right tactile stimulation with right visual stimulation), the percentage of unidentified tactile stimuli increased to 72%.

Testing the increase of visuotactile extinction when hands are observed in a mirror was further researched with a crossmodal congruency task with normal adult participants (Maravita, Spence, Sergent, & Driver, 2002). Participants were requested to quickly discern the height position of vibrotactile stimuli delivered to the thumb (low position) or to the forefinger (high position) of the left or right hand. Additionally, a distracting visual stimulus was delivered in one of the four possible positions (on the right or left hand thumb or forefinger). Participants were also requested to ignore visual stimuli. When visual stimuli appeared at the same height (congruent position) of the vibrotactile stimulus, reaction times were faster and less discrimination errors were committed, than when visual and vibrotactile stimuli were delivered at different heights (incongruent condition). In the mirror version of the task, the crossmodal congruency effect was higher when the patients were looking at their hands in the mirror instead of watching only visual stimuli. The crossmodal congruency effect was also higher when a pair of artificial hands was used. These results suggest that there is a quick codification of peripersonal space around the hands when they are watched in the mirror. The identification of visual stimuli applied to a body part, seen in peripersonal space, seems to be perceived in extrapersonal space, but subsequently recoded as peripersonal stimulation through mirror reflection (Spence, Pavani, Maravita, & Holmes, 2004).

Artificial hands were also used to study visuotactile effects through direct vision, instead of through mirror reflections. When normal adults watch a touched artificial hand while they feel a tactile stimulation in the same position on their hidden hand, the touch seen on the artificial hand is perceived as a tactile sensation of their own hand (Botvinick & Cohen, 1998). The vision of an artificial hand being touched also enhances the identification of a simultaneous tactile stimulation toward a real hidden hand (Rorden, Heutink, Greenfield, & Robertson, 1999). Similarly, in the case of crossmodal extinction of left tactile stimulations, where an artificial right hand is positioned in front of patients, visual stimuli delivered to the artificial hand cancel simultaneous tactile stimuli on the left hand (Farnè, Pavani, Menghello, & Ladavas, 2000). Position as well as orientation of the artificial hand must be similar to that of the real hand to produce this effect. These effects are similar to those obtained in Graziano et al. (2000) study, where Area 5 neurons that code arm position become more active when an artificial arm is seen in the same position as the real one because visual and somatosensory information are not in conflict.

Pavani et al. (2000) used the crossmodal congruency task to analyze the effect of artificial arm orientation on visuotactile interference in normal adults. When artificial hands were positioned incongruently in regards to the hidden real arm, a small effect was detected due to the presence of the artificial hands in modulating the magnitude of the crossmodal congruency effect. On the contrary, when the artificial hands were aligned with the real arms, the crossmodal congruency effect was larger than when artificial arms were absent. The enhancement of this interference on the vibrotactile performance identification suggests that artificial body parts, positioned in a realistic way in regards to real body parts, can modulate the brain representation of visuotactile peripersonal space. Visual stimuli near artificial hands have a greater interference on tactile discrimination when the hand is in a realistic position.

1.3.2. Expanding Peripersonal Space

Tool-use could modulate the representation of peripersonal space. The issue has been explored in different ways: through neuropsychological patients with neglect syndrome in peripersonal and extrapersonal space, and through crossmodal extinction with normal adults using the crossmodal congruency task. Researches with neuropsychological patients focus on the dissociation between neglect in peripersonal and extrapersonal space which leads to the existence of two different neural systems in the integration of the two spaces (Halligan & Marshall, 1991). Unilateral spatial neglect (NSU), also known as neglect or spatial attention disorder, is a syndrome that implies a disability to pay attention and discern consciousness in the space opposite to the cerebral lesion (generally the left one). This syndrome can be haptic, (Aglioti, Smania, & Peru, 1999), auditory (Bellman, Meuli, & Clarke, 2001), and visual (Vallar, 1998). NSU is usually associated with a lesion in the right lateral prefrontal premotor area or in the inferior and superior lateral parietal areas (Vallar, 1998). It is known specifically that the posterior parietal cortex (PPC) is important in the unilateral visuospatial neglect (Leibovitch, et al., 1998; Vallar, 1998), even if a lesion of the inferior parietal cortex could interfere with visuospatial actions to the contralateral side (Husain, Mattingley, Rorden, Kennard, & Driver, 2000). Patients with these lesions cannot perceive their contralateral visual field side. They fail to draw the contralateral side of objects, and do not eat food in the contralateral visual side of the plate. Thus they strongly do not orientate toward the neglected hemifield (Bisiach, 1993; Rafal, 1994). This does not mean that stimuli in the neglected hemifield are not coded, but instead that the stimuli codification does not have influence on the neural processes that underlie verbal and non-verbal behavior (Rafal, 1994). A classic task to test visuospatial neglect is the line bisection task (Marshall & Halligan, 1989; Pizzamiglio, Committeri, Galati, & Patria, 2000). The subjects are requested to indicate the centre of horizontal lines. A lesion of the parietal cortex induces dysfunctional performances; the subjects affected by right parietal lesions indicate the centre on the right half of the lines. When normal adults perform the line bisection task, there is a significant tendency to overestimate the width of the left side of the line related to its right side. This pseudoneglect (Bowers & Heilman, 1980; Jewell & McCourt, 2000), which is the opposite of the patients' normal parietal neglect, is modulated by the stimuli distance of presentation; it is higher in peripersonal space than for extrapersonal space (McCourt & Garlinghouse, 2000). This issue was recently investigated by Longo and Lourenco (2006). They asked participants to bisect lines at four different distances (i.e., two in the near spaces and the other two in the far space) using a laser pointer or a set of wooden sticks of different length. When the laser pointer was used, a clear shift from the left to the right of the true lines midpoint was present in the transition from peripersonal to extrapersonal space. When wooden sticks were used, researchers observed a constant error in the left in all distances, similar to that observed with the laser pointer in the peripersonal space. Therefore, these results seem to indicate that the use of a tool increases the area of peripersonal space. With regard to the neglect syndrome Halligan and Marshall (1991) asked their patients to indicate the center of some lines in spaces that were close as well as far away from them. In near space, patients indicated the perceived center of the lines with their fingers. However, in far space they were allowed to use a laser pointer. In the space located at a closer distance, a constant error to the right from the center of the line was found. There was no error present in the space located at a farther distance.

Berti and Frassinetti (2000) have extended this line of research by asking a patient with severe left visuospatial neglect, to bisect lines at a close distance (50 cm) and at a distance that was farther away (100 cm). The patient was allowed to bisect lines with his hand, a laser pointer and, only at the farther distance, with a wooden stick. It was necessary to keep the right hand, which the patient used to point with, near the midline of the body. When the laser pointer was used in near space, the patient committed more of the errors to the right. At a farther distance, using the laser pointer, the error rate decreased. In near space, when the patient used his finger to point, the percentage of errors to the right was similar to errors made in the condition with the laser pointer. But when the patient used the stick at the farther distance, the percentage of errors increased. Tool-use in the interaction with the lines in the extrapersonal space led to a clear left neglect in the patient, which was the same as that obtained in the peripersonal space. Without tools, the deficit was severe only in the patient's peripersonal space.

Two other studies of crossmodal extinction with patients suffering from brain injury support the theory that the use of a tool could influence the peripersonal space. In the first experimental study, Farnè and Ladavas (2000) had tested patients with tactile extinction to recover objects in extrapersonal space using a rake with the right hand. After a training period with the tool, the crossmodal extinction was examined presenting visual stimuli at the far end of the tool, in extrapersonal space. Tactile stimuli on the left hand simultaneously presented with visual stimuli on the right were recognized only in half of tests performed immediately after the use of the tool. In the three control conditions (before the use of the instrument, after a short interval following the use of the instrument, and after a control pointing task) tactile stimuli on the left hand were detected in 75% of trials. Therefore, after a short period of active tool-use to manipulate objects in extrapersonal space, visual space around the end of the tool was incorporated into peripersonal space. Thus, the stimuli presented on the end of the tool interfered significantly with the simultaneous recognition of tactile stimulation. It seems that extrapersonal space is then incorporated into peripersonal space.

In the second experiment, Maravita et al. (2001) introduced additional control conditions to analyze the factors that contribute to this putative modulation of peripersonal space. Their patient, which suffered from extinction, has been studied in three different conditions: with visual stimulation close to the hand while two long sticks were contested, with sticks placed in front of the patient without being manipulated in order for them to use visual inspection, and, finally, with visual stimulation presented in extrapersonal space without the sticks. Visual stimuli on the right peripersonal space hand eliminated almost all of simultaneous tactile stimuli on the left hand, while visual stimuli in extrapersonal space eliminated only 34% of simultaneous tactile stimuli. Only when the tool was kept active in the hand, which connected the body to visual stimuli that were farther away, did the crossmodal extinction to tactile stimuli on the left hand increase significantly.

Finally, the crossmodal congruency task has been successfully used to analyze the modulation of visuotactile peripersonal space, through the manipulation of tools by normal participants (Maravita, Spence, Kennett, & Driver, 2002). In the crossmodal congruency task, distracting visual stimuli are presented near the hands, where two vibrotactile stimulators are placed. However, Maravita et al. (2002) have positioned visual stimuli at the top and bottom-ends of two golf clubs that were given to participants to grasp in each hand. They were asked to discern the position of vibrotactile stimuli while trying to ignore the visual ones. During the four trials of the experiment, the golf clubs were also crossed at one point, so that visual stimulation on the tip of the left golf club was detected in the right visual field for half trials and in the left visual field for the other half. Usually, visual stimuli presented in the same portion of space have greater interference in tactile discrimination, than when they are present in the portion of space opposite to the midline. However, with crossed tools, the left visual field was associated with the right hand, and the right visual field with the left hand. Congruency effects for visual stimuli opposite to tactile ones were greater for the same portion of space where the tools were crossed. This visuotactile space modulation depended largely on the active manipulation of tools, since it had not been observed while participants manipulated the tools passively.

CHAPTER 2

2.1. VIRTUAL REALITY

The concept of peripersonal space in Virtual Reality (VR) field of research can be placed within a more general concept, that of the sense of presence within a virtual environment, which includes not only purely neuropsychological aspects of the medium but also social and communicative ones. As yet few studies have been conducted in the specific field of research into the perception of virtual peripersonal space, different VR resources will be analyzed by integrating the information that these resources provide, grouped to give an overview of the latest discoveries and developments that may bring us to the understanding of this specific phenomenon. Additionally, a brief introduction to VR technologies will be presented.

By definition, a VR system is considered as a ‘set of computing devices that can enable a new type of human-computer interaction’ (Steuer, 1992; Ellis, 1994). The first part of this definition, 'set of computing devices', refers precisely to the technical features of a VR system, a set of tools to obtain information (input devices) through which the user is able to provide the computer with various input data, that will be integrated and modified by the computer software to form dynamic 3D images. These dynamic 3D images will be returned to the user through information tools (output devices). Therefore, a VR experience can be defined as a computer-generated three-dimensional environment in which the user or users interact with each other and with the Virtual Environment (VE) as if they were actually inside (Stanney, 2002). The second part of the definition, 'new type of human-computer interaction', is connected to the psychological aspects of this new technology and hence the diverse opportunities offered for the investigation of different psychological areas, and also refers to the experiences that VR technologies are capable of provoking.

There are three main VR categories: the immersive, the non-immersive and semi-immersive. The immersive VR is a state in which the user is partially sensorially isolated within the VE. This condition is made possible by:

- an apparatus display and sound system, usually a helmet (i.e., Head Mounted Display; HMD,), able to isolate the user from the external environment and to present three-dimensional computer-generated environments;
- a sensor position (i.e., tracker) that captures the user's movements and communicates them to the computer so that it can change the display image according to the user's perspective.

The non-immersive VR, instead of the HMD, implement a typical monitor, and eventually active or passive 3D-glasses. In this case, the user's impression is to visualize the three dimensional world created by the computer through a sort of window. Finally, semi-immersive systems, CAVE, are based on projection screens with different forms and degrees of convexity able to isolate the subject from the outside world, and allow playback of adequate indices of depth. The immersive VR has the advantage of conveying an high involvement sense, but in some cases may induce headache or nausea caused by asynchronous sensory stimulation, especially in the case of multi-sensory, vision and movements, one. Non-immersive VR, on the other hand, often fails to convincingly persuade the user to participate in the VR experience.

One of the most successful VR technologies is represented by three-dimensional environments. The effectiveness of this technology is due to the fact that humans use vision as the dominant sense. This success has ensured that the base of most of the VR systems is the generation of 3D computer visual illusion, a virtual environment (Wilson, 1997).

The development of VR has also increased the amount of information that can be entered into the system. Unlike the traditional input derived from the use of mouse and keyboard used, with the introduction of VR systems, the interest shifted to encompass all the possible actions that a user can potentially perform; movements and actions become possible sources of information for the system. There are three main types of devices that can record the user's bodily changes:

- devices to register body movements in the space;
- devices to register the rotational movements of body parts (like the head);
- devices to register the information of the peripheral limbs (such as handling and tactile information).

For example, to navigate a VE the system creates a correspondence between the upper limb movement and the walking direction, through the implementation of a joystick or similar devices. Usually, after a training period on the potential and actual movements offered by the device, users are able to navigate the VE in a sufficient and automatic way. The VR system is able to recognize not only where the user is located with respect to the generating VR environment, but also the user's head orientation and what is being viewed. Orientation sensors combined with translational movement sensors allow the VR system to calculate user position or the relative position of the limbs with, for example, an object or a specific point in the space (Stanney, 2002). Moreover, the user can manipulate virtual objects and modify their shape or position. To do this, the user wears a virtual glove (Data Glove) that allows the direct manipulation of objects. A Data Glove consists of a set of accurate motion sensors that can register finger movements and calibrate them with the virtual image of the manipulated object. Therefore, the VR allow a new type of human-computer interaction, where the computer is not as an expert system or a calculation device, but a tool to generate perceptual/motor processes where the user is a source of data. In some cases, this condition can be compared to a natural learning method able to change the cognitive processing and the ways in which knowledge is generated. These aspects are essential to investigate in order to fully develop the potential that this technology has introduced in the human-computer interaction psychology field (Riva, 2008).

2.1.1. The Concept of Presence

Recently researchers have begun to integrate the concept of presence (Biocca, 1997; Lombard & Ditton, 1997; Lombard, Reich, Grabe, Bracken, & Ditton, 2000) within existing mediated experiences, from book reading (Gerrig, 1993), to the interaction with immersive VR environment. The desire to go beyond the limits of human sensory channels through the use of technological devices represents a major stimulus to the development of media technologies and simulation of reality (Biocca, Kim, & Levy, 1995; Lombard & Ditton, 1997; Rheingold, 1991). The concept of presence is of high practical relevance in the design and evaluation of products intended for media and computer interfaces, especially in the field of entertainment (movies, television and video games), telecommunications (videoconferencing, computer-supported collaborative work), education (online education, virtual campuses, training simulation) and medicine (telemedicine, telesurgery).

Since the technologies to simulate people and create interactions have become increasingly sophisticated, computer scientists, psychologists and communication experts have placed greater emphasis on the study of this phenomenon. Consequently, the concept of presence has become highly relevant, not only in advanced human-computer interfaces theories for VR systems (Biocca, 1997; Held & Durlach, 1992; Lombard & Ditton, 1997; Loomis, 1992; Sheridan, 1995; Steuer, 1992; Witmer & Singer, 1998), but also for traditional media like television, movies and books (Kim & Biocca, 1997; Lombard et al., 2000). The concept of presence is often referred to as telepresence, virtual presence, or mediated presence. The term telepresence was coined by Marvin Minsky (1980) to emphasize the possibility that human operators could have the feeling of being physically transported to a remotely operated workspace through teleoperative systems. With higher quality simulations and sensory feedback technologies, the author believed that telepresence could afford to perform safer and less expensive interventions in hazardous locations (i.e., mines, nuclear power plants, the ocean depth, space operations), to create new medical and surgery, to reduce transportation cost, allowing the freedom to work from home without leaving the workplace. Sheridan (1992) has defined telepresence as 'the sensation of actually being in the remote location of the operations' (p.120). Scholerb (1995) concluded that telepresence occurs when a user perceives himself to be physically present in a remote environment; finally, McLellan (1996) has defined it as the feeling of being in a different place from where you really are. 'Virtual presence' is a term that Sheridan (1992) coined to refer to the feeling of presence during the interaction with VR technologies, thus distinguishing virtual presence, the feeling of presence in a VE, from telepresence, originally associated with teleoperative systems. To confine the concept of presence in the specific context of mediated perception, communication experts often use the term 'mediated presence', concluding that the perception of an unmediated natural environment should not be included in ‘presence’ studies as it expands too much the research area.

Lee (2004) proposed to use the term presence, as opposed to telepresence and virtual presence, in a generic way without specifying any technological field, as it could potentially be applied to the analysis of future technologies which have not yet been categorized. The attempt to discern mediated perception from natural perception may not be useful because the natural perception can include the mediated one. The conceptual distinction between sensation and perception clarifies this point: sensation is the simple detection of sensory stimuli materialized by a specific kind of physical energy; the perception, on the other hand, is the subjective interpretation of sensory stimuli influenced both by sensation and subjective factors such as previous experiences, expectations, emotions and cognitive processes (Baron, 2001). This perspective could explain that the real world natural perception is mediated in the same way as is that of a computer-generated virtual world (Loomis, 1992). For this reason, scholars define natural mediated perception to be the first order of mediated experience, and technology mediated perception to be the second order of mediated experience.

However, there have been various attempts to explain the concept of presence. Steuer (1992) has defined as 'the degree to which a person has the feeling of being present in a mediated, rather than in the physical environment' (p. 76). Witmer and Singer (1998) refer to the presence as 'the subjective experience of being in a place or an environment, even when a person is physically located in another' (p. 225). Biocca (1997) has traced the origins of the term and concluded that the presence can be generalized as the illusion of 'being in a specific place'. Real or simulated, the sense of presence is perceived between the physical state (real environment), the virtual state (mediated environment), and the imaginative state (daydreaming) (Kim & Biocca, 1997). After an extensive review of previous conceptualizations, Lombard et al. (2000) defined presence as 'the perceptual illusion of non-mediation' (Lombard & Ditton, 1997). The term 'perception' indicates that the sense of presence involves continuous (real time) processing of the human cognitive, affective and sensory system toward the environmental stimuli (Lombard et al., 2000). 'Non mediation' indicates a phenomenon in which the user fails to perceive the existence of a communicative medium in the environment and responds as if the medium is not present.

However, ‘presence’ is a common psychological behavior induced by specific cognitive mechanisms such as automatic and modular information processes (Cosmides & Tooby, 1992; 1994; Sherry & Schacter, 1987). In this sense, human perception is, at different levels, a modulated version of human sensations. This definition, therefore, does not confine the concept of presence to mediated perception, because it excludes the possibility of the sense of presence during non-mediated experiences. For example, while interacting with a robot, people may feel strongly that they are interacting with a real person. In this case, social presence, a psychological state in which you do not notice the non-humanity of artificial objects, occurs when the experience is not filtered by any technology. Finally, according to Riva and Waterworth (2003; Riva, Waterworth & Waterworth, 2004; Riva, 2008), presence can be described as a selective and adaptive mechanism, which allows the user to improve the ability to coordinate actions through the separation between 'internal' and 'external' sensory flux. The more the body is able to feel a high level of presence during an activity, the greater the participation in the activity, increasing the likelihood that the latter is carried out correctly.

One of the most relevant aspects of VR that has most interested the scientific community is definitely the means to determine a close relationship between the technology and the body; interfaces are increasingly adapting to the 'embodiment' that human possess and, in the same time, humans are gradually integrating with the interactions mediated by technological artifacts (Mantovani, 2002). Every communication media involves, in different ways, people who, through the interaction with it, are able to obtain relevant information. However, the human mind is not disembodied but strictly tied to the body to which it is connected and from which it continuously acquires new information from the outside world (Damasio, 1995). This condition can be defined by the term ‘embodied’: the body is, on the one hand, the frame of reference in which experiences take place, on the other, the body becomes, through senses, the main link between the mind and the world (Lakoff & Johnson, 1980). One of the consequence of this embodiment, is the human propensity to create and use artifacts that extend the possibilities of action in the environment. Through the use of artifacts, a person transparently extends his boundaries. Technological progress has enabled the development of advanced systems capable of almost completely immersing the user in an alternate sensory isolated reality. Sheridan (1992) defines the physical presence of a VR system as the amount of sensory stimulation that the system provides: the greater the amount of stimulation, the greater the sense of presence experienced by the user during the virtual experience. The addition of tactile sensory stimulation generally considered of lesser importance, such as smell and touch, resulted in a greater fidelity during the virtual experience. Along with increased sensory stimulation, particular attention has been given to the involvement of motor interactions with the VE. The introduction of the mouse has ‘embodied’ the common method for interacting with computers, as it detects body movements, which constitute relevant information for the system (Bardini, 1997). According to this view, and pursuing an embodiment ideal of the interaction with VE, position trackers sensitive to motion changes, translation devices to register speed and force during body movements, and more precise haptic feedback hardware were developed.

2.2. PERIPERSONAL SPACE IN VIRTUAL REALITY

When a user interacts with a VE, and finds an internal representation of himself, because this becomes a subjective representation of itself, it is important that a mental model of this specific situation is established. The model is created searching analogies not within physical similarities but in the essential characteristics of the body schema. Once the mental-self model in the virtual world is made possible, it can be used to interact (Stanney, 2002). The concept of body schema has been discussed in the first part of Chapter 1, and it is in fact at this point that a parallel can be drawn between the perception of peripersonal space in a real environment and the corresponding perception in a virtual one. Research on body image, unfortunately, shows us how, even in the simulated world, these perceptions turn out to be unstable (Fisher & Cleveland, 1968). Some studies also show how the use of VR, especially immersive kinds, can radically alter the user's body schema. When a user tries to grasp an object in a virtual environment, for example, there may be a discrepancy between the body schema, which allows the coordination of the movement in the physical world, and the representation of motion in simulated space (Biocca & Rolland, 1998). This can produce a mismatch between user actions and virtual simulation, which reduces the embodiment in VR and the resulting sense of presence. Teleoperated systems, as mentioned previously, allow the user to manipulate objects in the real world through a remote real environment (an example is the vehicle used by NASA for Mars exploration). In telerobotics, telepresence is associated with the concept of distal attribution (Loomis, 1992), that is, self externalization to include remote tools that phenomenologically becomes extensions of the body, even if they are not physically part of it. Where teleoperated systems allow remote manipulation of real-world environments and objects within them, VE allows users to interact with computer-generated or synthetic environments.

Perception satisfies the individual need to control moment-to-moment behaviors and actions within a constantly changing environment. The development of visual perception regarding the objects’ shape and environmental patterns is highly dependent on correlations between vision and the relevant incoming information from other sense organs (especially the tactile and kinesthetic) through an active environment exploration behavior, which outlines a stable and yet flexible representation of multisensory space (Ijsselsteijn, 2005). Remote manipulation studies (Smets, Overbeeke, & Stratmann, 1987) have shown a significant perceptual advantage between active observers, who with head movements could control the movements of a remote camera (generating motion parallax), compared with passive observers receiving the same visual input, but without the ability to change the point of view. These results are consistent with those found for VE by Welch et al. (1996) who found that participants who could actively control a simulated environment showed a greater sense of presence than those passively exposed to the same environment. Whether or not the technology becomes a transparent extension of our body depends greatly on the natural plasticity of the brain, which is constantly able to adapt to altered sensorimotor contingencies, as telesystems studies have shown. Further evidence about the highly plastic nature of body image comes from a study of adaptation processes that affect the body image of people with amputated limbs. Ramachandran et al. (1995) analyzed patients with an amputee limb while watching their intact arm in a mirror reflection, so that the image was perceived as a substitute for arm amputee. Several subjects reported feeling that their 'ghost' arm was being touched when they saw the image of their intact arm being touched in the mirror. Since the space that surrounds us can be segmented according to different levels, the most important of which are peripersonal space (the space immediately surrounding the individual) and extrapersonal space (the space which requires body movements to be explored), telepresence technologies can be interpreted as attempts to overcome these limitations of spatial segmentation. Berti and Frassinetti (2000) studied a right hemisphere damaged patient, with a near to far space dissociation showing a strong visual spatial neglect. Using a line bisection task, neglect appeared in near space and not in far space when a laser pointer was used. However, neglect appeared in far space when a wooden stick was used to indicate the line’s midpoint, which was also done to indicate for the neglect in near space. An artificial extension of the body (i.e., the wooden stick) causes a re-processing of the perception of far space in near space, essentially as with telepresence. The degree to which non-organic artifacts, such as artificial hands, can be perceived as extensions of the body has strong relevance in the context of telepresence (Ijsselsteijn, 2005). Understanding the conditions that underlie this integration could have implications in the design of VE, teleoperated systems and representation modalities of the body in such mediated environments. Additionally, it could improve the understanding of telepresence experiences and of the psychological and brain mechanisms involved in the distinction between real self and virtual self, and between reality and mediation. This knowledge could also help to develop tactile virtual reality technologies (Held & Durlach, 1993), prosthesis for amputees (Ramachandran & Rogers-Ramachandran, 1996; Ramachandran, Rogers-Ramachandran, & Cobb, 1995; Sathian, Greenspan, & Wolf, 2000) and navigational supports for those who suffer from visual deficits (Hoover, 1950).

Empirical VR evidences pertinent to the understanding of the distinction between peripersonal space and extrapersonal space has been obtained from research with patients suffering from neglect. Castiello et al. (2004) wanted to determine whether space perceptual processing could be due to a perceptual improvement of the affected neglect space relative to the non-affected one, rather than simply analyzing whether there was an improvement of neglect in near space and neglect in far space; they also wanted to understand whether tool-use is a necessary condition for the elaboration of the perceptual space. Using VR, the authors asked six patients suffering from neglect to reach out and grab a real object while simultaneously observing a virtual hand grasping a virtual object within a VE. The virtual hand was controlled in real time by the real hand. After a training period, patients coded the visual stimuli within the neglected area in the same way as those presented in the normal one. It was possible to create links between the neglected area and the normal one, without the need to manipulate a tool, that is, creating a connection between the movement of the hand and the real image of the virtual hand, thus allowing the patient to use the virtual image to guide the real hand in neglected space. This result, presumably, may occur following the formation of a specific single neural circuit that controls the visuo-proprioceptive integration. During the manipulation in the VE, the same neural structure, the cortex, and the related bimodal neurons encountered in studies of Iriki et al. (2001) could be involved. Receptive fields may have been broadened to include the virtual hand, causing strong response to stimuli near the virtual hand, even when it was placed in the damaged contralateral visual field. In another study, Kim et al. (2004) have designed a VR system to evaluate and train patients with unilateral neglect; the VE consisted of a road divided into three sectors with a ball placed at the center. After a calibration task in which the midline was measured from the point of view of the subject, the participant was asked to identify the ball as it moved to the right or the left visual field, using his gaze, which itself was moving a small cross attached to the head of the subject. During the task visual and auditory cues were also present to help in identifying the ball; the system measured various parameters such as angle of deviation, the scan time, the signal's number and the measure of error detection. The objective of this study was, however, to verify the suitability and feasibility of a VR system for patients suffering from unilateral spatial neglect. In fact, only a correlation between the VR system used and the line bisection and cancellation letters tasks could be observed. The possibility that this program can be used as a tool for rehabilitation for patients suffering from unilateral neglect was partially confirmed, but further modifications and future research must still be carried out.

Finally, with regard to neglect patient studies, it must be mentioned that a research protocol (Baheux, Yoshizawa, Seki, & Yasunobu, 2006) in which a VR system that provides a credible environment through multi-sensory stimulation (vision, touch and hearing) is in development. This system aims to provide a more detailed characterization of the neglected space, allowing the monitoring of the patient's progress. It consists of a CRT monitor, stereoscopic vision glasses, an infra-red camera to detect gaze movements, an haptic interface (Phantom Premium, http://www.sensable.com/haptic-phantom-premium.htm) and a three-dimensional sound system. The haptic interface was used to provide tactile feedback for virtual objects, while the stereoscopic glasses were used to determine the degree of neglect in near and far space. The tasks to be completed were the classic paper and pencil tests specifically simulated in a VE: the line bisection task, the drawing task and the task of deleting an object. The presentation was similar for all tasks: a sheet of paper was placed on a table and the haptic device was used to control the pen. The overall system combines a stereoscopic VE supported by auditory and tactile feedback to enable a high degree of immersion and provides relevant information on how the patient performs the test and, most importantly, through the eyes’ movement detection, the patterns of eye scanning can be recorded.

CHAPTER 3

3.1. EXPERIMENT 1: The limit of peripersonal and extrapersonal space

3.1.1. Introduction

Conscious perceptual experience of the surrounding space is unitary and integrated. However, neuropsychological, neurophysiological, and behavioral studies have shown that distinct brain and cognitive mechanisms are implicated in coding peripersonal (within reach) and extrapersonal (beyond reach) space. For instance, spatial neglect (SN; i.e., a neuropsychological disorder of contralesional awareness, usually affecting the left hemispace following right hemisphere damage; for review, see Halligan, Fink, Marshall, & Vallar, 2003), can selectively impair the conscious processing of the contralesional peripersonal space but not the conscious processing of the contralesional extrapersonal space (Halligan & Marshall, 1991). The inverse dissociation has also been reported (Cowey, Small, & Ellis, 1994). That is, some SN patients process the contralesional peripersonal space more efficiently than the contralesional extrapersonal one.

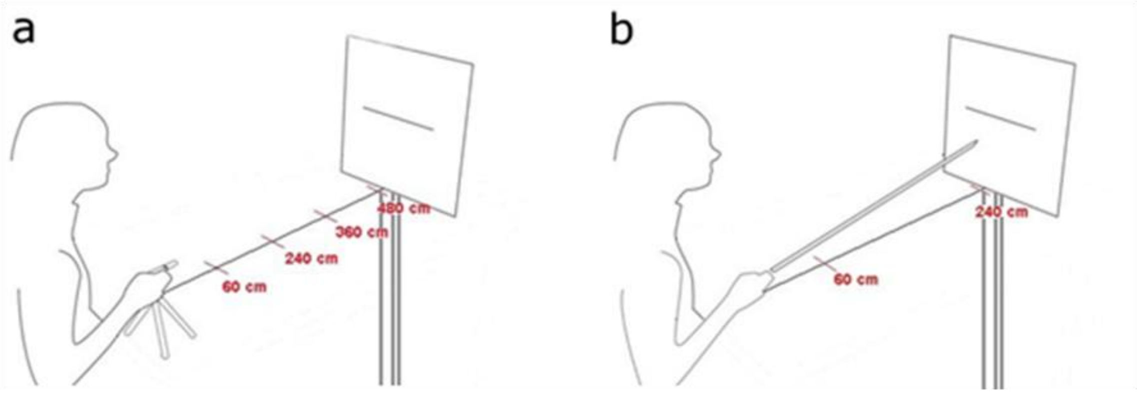
Rizzolatti et al. (1983), using intracellular neurophysiological recordings in monkeys, proposed that lesions to Brodmann’s area 6 can result in SN limited to the peripersonal space, whereas lesions to Brodmann’s area 8 can result in selective SN for the extrapersonal space. In addition, distinct mirror neurons encode peripersonal and extrapersonal space properties in monkeys (Caggiano, Fogassi, Rizzolatti, Thier, & Casile, 2009).

The peripersonal/extrapersonal distinction has also been reported in studies on healthy participants, using the line bisection task. When healthy participants are required to bisect a line, they systematically misbisect to the left of the veridical midpoint (pseudoneglect; for review, see Jewel & McCourt, 2000). However, this is true only when line bisection is performed in the peripersonal space. Indeed, healthy participants misbisect to the right of the veridical midpoint, when line bisection is performed in the extrapersonal space (Bjoermont, Cowey, & Walsh, 2002; Gamberini, Seraglia, & Priftis, 2008; Longo & Lourenco, 2006; McCourt & Garlinghouse, 2000; Varnava, McCarthy, & Beaumont, 2002). Weiss et al. (2000) showed, in a positron emission study on healthy participants, that the dorsal visuomotor stream (dorsal occipital cortex and parietal cortex in the intraparietal sulcus) was activated when line bisection was performed in peripersonal space, while the ventral visuoperceptual stream (ventral occipital cortex and medial temporal cortex) was activated when line bisection was performed in extrapersonal space. Thus, line bisection in healthy participants can be affected by specific properties of the peripersonal and extrapersonal space.

All of the aforementioned studies reported evidence in favor of a clear distinction between peripersonal and extrapersonal space. Nonetheless, the peripersonal/extrapersonal distinction may be modulated by tool use that can expand the dimension of the peripersonal space to what is considered to be extrapersonal space. For instance, introducing a tool to bisect lines in far space was found to extend the neglected area in SN patients (Ackroyd et al., 2002; Berti & Frassinetti, 2000; Neppi-Mòdona et al., 2007; Pegna et al., 2001). Tool-use also modified space representation in macaque monkeys (Iriki et al., 1996), extinction patients (Maravita et al., 2001), and healthy participants (Maravita et al., 2002). Finally, a leftward shift was also observed in line bisection when the latter was performed using a tool (i.e., stick) expanding the peripersonal space into the extrapersonal one (Gamberini et al., 2008; Longo & Lourenco, 2006). In contrast, an overall rightward shift was reported when participants performed line bisection using a tool that did not expand the peripersonal space into the extrapersonal space (i.e., a laser pointer). In summary, the distinction between peripersonal and extrapersonal space is not a rigid one, but can, instead, be modulated by tool use. However, some researches provide different points of view about this expansion of peripersonal space, suggesting that only the active side of the tool manipulated in the extrapersonal space is responsible for the same performance obtained in the peripersonal one (Holmes, Sanabria, Calvert & Spence, 2007; Holmes, Calvert, & Spence, 2007; Collins, Schicke, & Röder, 2008; Yue, Bischof, Zhou, Spence, & Röder, 2009).

Both Gamberini et al. (2008) and Longo and Lourenco (2006) reported the expansion of the peripersonal space into the extrapersonal space through tool-use, up-to a distance of 120 cm. However, few studies have investigated whether the peripersonal space could be expanded by tool use beyond 120 cm (Serino, Bassolino, Farnè, & Làdavas, 2007; Neppi-Mòdona et al., 2007). In addition, we aimed to investigate whether line bisection is modulated by expanding viewing distances within the extrapersonal space (i.e., 240, 360, 480 cm). To test these hypotheses, we asked healthy participants to perform line bisection presented at four distances: 60, 240, 360, 480 cm. Participants bisected lines using either a wooden stick only at the distances of 60 and 240 cm, or with a laser pointer for all the distances. We expected that participants would misbisect to the left of the veridical midpoint using the laser pointer, for lines presented in the peripersonal space but to the right of the midpoint for lines presented in the extrapersonal space. In contrast, we expected that participants would constantly bisect to the left of the veridical midpoint using the sticks, both for lines presented in the peripersonal and for lines presented in the extrapersonal space, indexing the expansion of the peripersonal space by tool use.

Figure 3.1.1. Representation of the experimental setting: a) the four distances (60-, 240-, 360-,480-cm) used in the laser pointer condition, b) the two (60-, 240- cm) distances used in the wood stick condition.



3.1.2. Method

Participants

Thirty participants with normal or corrected-to-normal vision took part in the experiment (15 males; M = 24.53 years, S.D. = ±3.63 years, range = 20–34 years). All participants gave their informed consent to participate in the study. Results from the Edinburgh Handedness Inventory (Oldfield, 1971), showed a majority of right-handed participants (M = 53.67 , S.D. = ±48.81).

Materials

There was one viewing distance for peripersonal space (60 cm) and three viewing distances for extrapersonal space (240, 360, and 480 cm). Lines measured 8, 16, 32, 64, and 128 cm (height: 2 mm). Lines measuring 8, 16, 32, and 64 cm were presented in the centre of a white sheet of paper (width: 66 cm; height: 50 cm). Each sheet of paper was positioned in the centre of a 93 x 71 cm wooden panel attached to a mobile apparatus composed of a 93 x 43 cm horizontal wooden base and a 200 cm vertical bar. Lines measuring 128 cm were, instead, printed in the centre of a plastic panel (width: 130 cm; height: 50 cm). The distance between the floor and the lines was 116.5 cm. Two wooden sticks (lengths: 78.6 and 250 cm) were used to perform line bisection at the viewing distances of 60 and 240 cm, respectively (see Figure 3.1.1.). Sticks ended with a point at the end opposite to the grasped one, in order to facilitate line bisection. The laser pointer was positioned in front of the chinrest and it was mounted on the head of a tripod (height: 10 cm) in order to avoid the effects of natural handshaking. The laser pointer projected a red point (diameter: 2 mm) to indicate the midpoint of the line (see also Gamberini et al., 2008).

Procedure

After the completion of the informed consent module (see Appendix 1A), the Edinburgh Handedness Inventory (Oldfield, 1971; see Appendix 2) and after have read the instructions (see Appendix 3), participants were invited to seat sit in front of a table (length: 62 cm; width: 100 cm) and to position their head in a chin rest, in order to guarantee that the distance between the participant's eyes and the displayed line was maintained constant. Participants were required to bisect each line, displayed at one of the four viewing distances (i.e., 60, 240, 360, or 480 cm). Lines of 128 cm were presented only in the extrapersonal space (distances: 240, 360, and 480), because participants were unable to perceive the entire line at the distance of 60 cm. Participants first performed a practice block (i.e., 5 trials using the stick and 5 trials using the laser pointer), followed by two experimental blocks (stick block and laser pointer block). Each experimental block comprised 38 (total: 76 trials). Order of stimuli and order of viewing distances were randomized. Order of blocks (stick vs. laser pointer) was counterbalanced among participants. On half the trials participants performed bisection starting from the right endpoint of the line, while on the other half participants performed bisection starting from the left endpoint of the line. Participants handled and moved the stick or the laser pointer with their dominant hand. The experimenter marked the centre of each line when the participant was sure about his/her decision and then the next trial started. No feedback regarding accuracy was provided. Participants had no time limit to complete the task.

3.1.3. Results

Statistical analysis was performed using the Statistical Software Package SPSS 17.0. There were two independent variables (i.e., device [two levels: stick, laser pointer] and viewing distance [four levels: 60, 240, 360, 480 cm]). The dependent variable was the mean difference (as error percentage) between the observed midpoint (i.e., the midpoint indicated by the participant) and the true midpoint of the line. Positive values of the dependent variable indicate shifts to the right of the true midpoint, whereas negative values indicate shifts to the left of the true midpoint. Data for repeated measures analysis, including devices and distances, were available only for the distances of 60 and 240 cm. For the other two distances (i.e., 360 and 480 cm), it was possible to analyze only the laser pointer performance. First a two-way analysis of variance (ANOVA) for repeated measures was conducted with Device (laser vs. sticks) and Distance (i.e., 60 cm vs. 240 cm) as factors. There was a significant main effect of Device F(1, 28) = 9.08, p = 0.005, indicating a mean bias to the left of the midpoint when the stick was used (M = −0.087 % error) and a mean bias to the right of the midpoint when the laser pointer was used (M = 0.169 mm). The main effect of Distance was also significant, F(1, 28) = 11.88, p = 0.002, showing a left to right shift when the laser pointer was used, during the transition from near to far space (60 cm = -0.21 vs. 240 cm = 0.55).

The interaction Device by Distance was significant, F(1, 28) = 11.01, p = 0.003. Paired comparisons revealed a significant difference between 60 and 240 cm, for the laser pointer, t(29) = -4.73, p = .000, whereas this difference was not significant for the sticks. In the next analysis, we considered only the laser pointer device and all distances (i.e., 60, 240, 360, 480 cm). A one-way ANOVA for repeated measures revealed a significant effect of Distance F(3, 84) = 10.33, p = 0.000. A repeated contrast showed that this effect was significant only between the distances of 60 and 240 cm, F(1, 29) = 22.373, p = 0.000. No significant effects were observed between the other distances (240 cm vs. 360 cm and 360 cm vs. 480 cm; see Figure 3.1.2.).

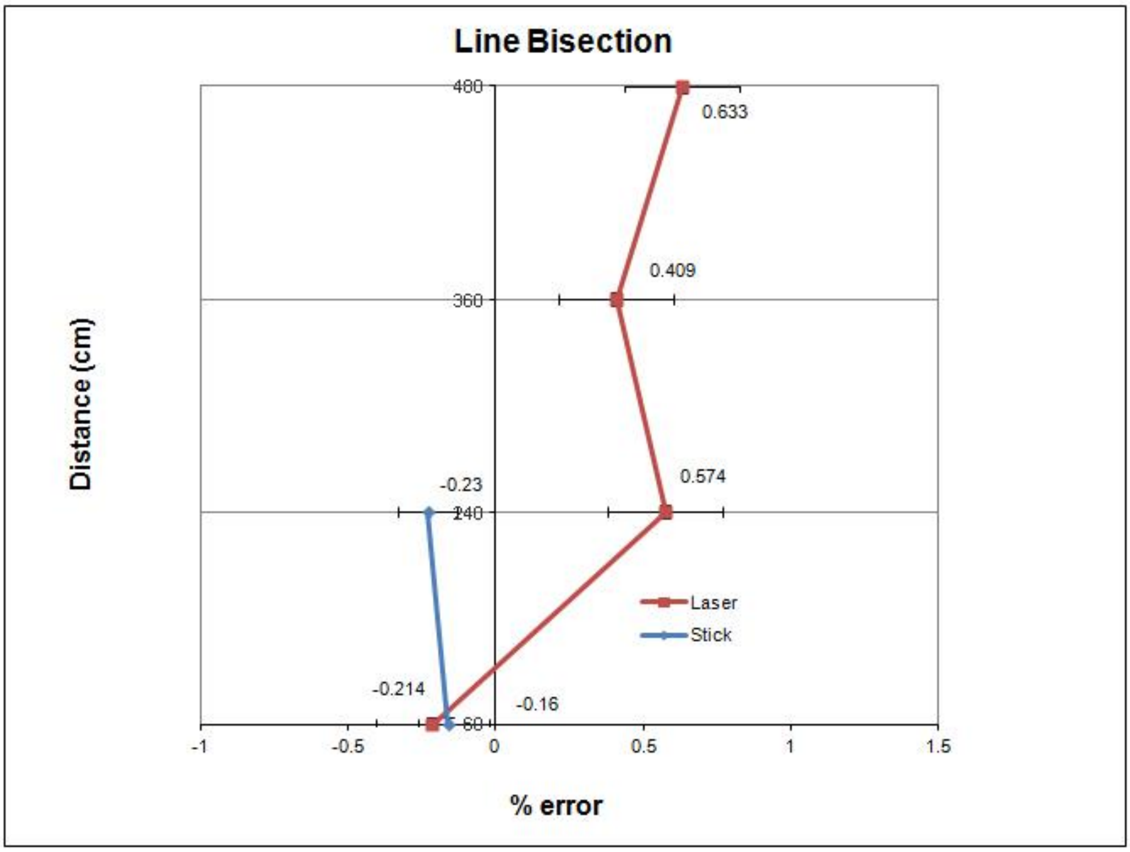


Figure 3.1.2. Graph of the behavioral results. The graph shows the mean percentage error (X axis) along the distances of line presentation, 60-, 240-, 360- and 480 cm (Y axis) for the device used (i.e., laser vs. sticks). Negative values indicate an error on the left of the lines midpoint; positive values indicate an error on the right of the lines midpoint. Error bars represent the standard error ±SE.

3.1.4. Discussion

Using a pointer laser (i.e., a device that does not expand the peripersonal space), a clear shift to the right of the midpoint of the line was present in extrapersonal space and remained stable for the three distances used (240, 360, 480 cm). In contrast, line bisection performance was characterized by a reliable leftward shift when performed in peripersonal space (i.e. 60 cm). Therefore, these findings further corroborate the assumption that space representation can be divided into two main areas: the peripersonal and the extrapersonal. However, a tool can modify this distinction, extending peripersonal space representation to the limit of the tool handled. Indeed, a constant shift to the left of the midpoint was present in peripersonal space (60 cm) and was also observed in the expanded peripersonal space (240 cm), when participants performed bisection using a stick (i.e., a device that does expand the peripersonal space). Thus, we report that peripersonal space can be expanded to extrapersonal space through tool use up to a distance of 240 cm. To the best of our knowledge only another study reported the implementation of a larger distance with a control group of healthy participants and observing the same tendency (300 cm; Neppi-Mòdona et al., 2007); they used carbon material to build the stick, that is lighter than wood. In the present study, one of the problem for not build a longer wooden stick (longer than 240 cm), was the excessive weight and, consequently, the incorrect and uncomfortable handling by the participants. Further research is required to determine the maximum distance up to which the peripersonal space can be expanded.

3.2. EXPERIMENT 2: Neural correlates of peripersonal and extrapersonal space

3.2.1. Introduction

Virtual reality in Cognitive Neuroscience

Nowadays, Virtual Reality (VR) is a useful tool in several fields and has reached a considerable value in medical, psychological, and neuropsychological treatments (Wiederhold & Wiederhold, 2000; Gold, Kim, Kant, Joseph, & Rizzo, 2006; Merians, Poizner, Boian, Burdea, & Adamovich, 2006; Optale et al., 2010; Tanaka, Ifukube, Sugihara, & Izumi, 2010; Tomikawa, et al., 2010). Because virtual reality interactions take place within artificial worlds, it is difficult to compare, analyze, and interpret results with those obtained during real life experiences. Quantitative data that was gathered during the interaction of participants with the synthetic environment and qualitative data obtained through questionnaires and self-report measures both represent valuable methods but, at the same time, are not sufficient findings to completely support this advanced and useful tool (i.e., VR).

Studies employing recent brain imaging techniques have shown that immersive VR interactions activate the same brain areas as those activated in the corresponding situation in reality (Campbell et al., 2009; Clemente et al., 2010). Nonetheless, there is also evidence that different brain regions are activated when participants observe real objects than when they observe virtual ones (Decety et al., 1994; Perani et al., 2001).

Nowadays, the most commonly used brain imaging techniques are Functional Magnetic Resonance Imaging (fMRI; de Charms, 2008), Electroencephalography (EEG; Niedermeyer & Lopes da Silva, 2004), and Positron Emission Tomography (PET; Ter-Pogossian, Phelps, Hoffman, & Mullani, 1975). FMRI monitors brain activity by using blood oxygen level dependent (BOLD) responses. EEG records electrical activity along the scalp that is produced by the firing of neurons within the brain. PET detects gamma rays emitted by a tracer, which is injected into the body by means of a biologically active molecule. A major problem in utilizing these brain imaging techniques is the study of how the neural system correlates virtual reality experiences, especially with reference to fMRI and PET, in which there is ‘immersion’ within the artificial environment. Huge machinery dimensions, disturbing noise, and electro-magnetic interferences with other instrumentations, along with the horizontal and unnatural position of the participant during scans’ acquisition, constitute the most limiting factors in the use of the aforementioned techniques with VR paradigms. Above all, researchers have to find alternative research techniques in order to avoid electro-magnetic interferences between brain imaging machinery and virtual reality instrumentation, often to the detriment of immersion in the virtual scenario. The studies that are reported here are divided into non-immersive and immersive ones, according to the specific brain imaging technique used. Non-immersive techniques are those in which the virtual environment is visualized through normal desktop monitors. Immersive techniques are those in which Head Mounted Displays (HMD), 3D glasses, or similar equipments are used to visualize the virtual environment.

VR applications and studies with fMRI vary in different disciplines (for a review, see Wiederhold & Wiederhold, 2008). Astur et al. (2005), administered a virtual version of the 8-arm radial maze task to normal adults, and found a bilateral activation of the hippocampus, which is responsible for three-dimensional spatial memory (Parslow et al., 2005; Iaria, Petrides, Dagher, Pike, & Bohbot, 2003; Maguire et al., 1998; O’Keefe & Nadel, 1978). Calhoun et al. (2004) observed the activation of several separate brain networks when participants were asked to drive a simulated car under the effect of alcohol. With respect to the participants who were affected by alcohol, participants who were not affected by alcohol showed specific activations in the orbitofrontal (OF) and motor regions, whereas visual and medial frontal regions were not activated. Overall, fMRI scans showed that alcohol intoxication may affect OF/anterior cingulate areas as well as motor and cerebellar regions (Calhoun, Carvalho, Astur, & Pearlson, 2005; Calhoun et al., 2002; Jeong et al., 2006; Meda et al., 2009). Slobunov et al. (2006) were the first to identify which brain areas were activated in response to a VR visual field motion, when participants experienced egomotion (i.e., the actual motion of the body as a response to the presence of optic flow) and vection (i.e., the illusory self-motion following a moving background). Largest activations were found bilaterally within the area V5 and the superior temporal sulcus, which is known to be specifically involved in the perception of biological motion.

In the studies mentioned above, participants visualized virtual scenarios through the mirror reflection of an LCD screen placed outside the fMRI machine. Thus, participants did not have full immersion into the virtual environment. Hoffman et al. (2004) developed a system which uses prototype VR goggles inside the fMRI machine. This study explores the neural correlation of virtual reality during pain situations. Hoffman et al. found that pain-related brain activity was significantly reduced in the VR condition with respect to the non-VR one, in all regions of interest: the anterior cingulate cortex, the primary (S1) and secondary (S2) somatosensory cortices, the insula, and the thalamus. In addition, Lee et al. (2005) investigated which brain areas of smokers are activated when smoking-related cues are compared with neutral ones. fMRI scans showed an increased activation in the smoking-related cues condition, principally in the prefrontal cortex (PFC) and in the left anterior cingulate cortex (ACC). These results are found to be consistent with the findings of previous studies (Due, Huettel, Hall, & Rubin, 2002; Brody et al., 2004). Note that stereoscopic MR-compatible goggles were also used in this study.

A field of interest that should be brought to attention is the realization of specific devices and tools to avoid electromagnetic interferences during fMRI registration caused by surrounding or supplementary equipment. Important factors that influence MRI registration are: the distance between the imaging region and other electronic components (e.g., cables, sensors, or transducers), the shielding system, the filtering system, etc. (Gassert, Chapuis, Bleuler, & Burdet, 2008). The development, validation, and testing of a prototype of a force feedback device for VR-fMRI was the topic of the study by di Diodato et al. (2007). In the experiment, participants had to touch a virtual object in two different conditions: one with force feedback and the other one with no-force feedback. In the force feedback condition, higher brain activation was recorded in the left primary somatosensory cortex (S1), in the bilateral supplementary somatosensory cortex (S2), and in the posterior insula, which is consistent with previous fMRI studies analyzing brain activity in response to somatosensory stimuli (Polonara, Fabri, Manzoni, & Salvolini, 1999). Moreover, an adaptation of the Phantom Premium 1.5 haptic device has been created to perform grasping operations in virtual environments during fMRI recordings (Hribar, Koritnik, & Munih, 2009). A data-glove with tactile feedback for virtual reality fMRI experiments has been also developed (Ku et al., 2003). Moreover, Resonance Technology Inc. (http://www.mrivideo.com/) with its recent and growing use in Brain Computer Interface (BCI; Zhao, Zhang, & Cichocki, 2009; Friedman et al., 2007; Leeb et al., 2007), has recently developed VR glasses compatible with the fMRI machinery.

EEG remains a useful tool for studying the neurophysiological correlations of VR experiences (Pugnetti, Mendozzi, Barbieri, Rose, & Attree, 1996). For instance, EEG has been used to study the neurophysiological correlations during a non-interactive VR experience where a group of adolescents were requested to watch roller coaster rides. The aim of this study was to measure spatial presence during visual processing. The results showed an activation of the parietal areas responsible for spatial navigation (Baumgartner, Valko, Esslen, & Jäncke, 2006). The aim of another recent study was to explore whether specific brain activation patterns were associated with driving at excessive speeds (Jancke, Brunner, & Esslen, 2008). In this study a virtual driving simulator was used to simulate realistic driving conditions. Compared with normal driving in which traffic rules were strictly followed, excessively fast driving resulted in the activation of the right lateral prefrontal cortex and α-band activity was increased. Bischof et al. (2003) measured EEG activity while healthy, normal participants navigated through virtual mazes using desktop screens. They found a positive relation between the frequency of theta episodes (Kahana, Sekuler, Caplan, Kirschen, & Madsen, 1999) and the difficulty of maze navigation. After immersive VR therapy (VRT) was conducted, a group of 20 alcohol-dependent participants reduced the craving for alcohol, by increasing alpha wave activity in the frontal areas (Lee et al., 2009).

In one of the first studies that used PET to investigate neural correlation during a virtual navigation task, the researchers found that navigation in humans is supported by a network of brain areas: the right hippocampus, the right caudate nucleus, the right inferior parietal lobule, and the medial parietal regions (Maguire et al., 1998; Jeong et al., 2006). Horikawa et al. (2004) used PET to identify brain areas involved in a simulated driving task. They found activation in the thalamus, the midbrain, the cerebellum, and the posterior cingulate gyrus, suggesting an involvement of these areas in the maintenance of driving performance.

Finally, some preliminary studies (Alcaniz, Rey, Tembl, & Parkhutik, 2009; Rey, Alcañiz, Tembl, & Parkhutik, 2010) used the Transcranial Doppler sonography brain imaging technique (TCD), which employs ultrasounds to measure blood flow speeds of the major brain arteries (Aaslid, Markwalder, & Nornes, 1982; Ringelstein, Kahlscheuer, Niggemeyer, & Otis, 1990), to investigate the neural correlations of presence during VR interactions. Rey et al. (2010) asked two groups of participants to interact with the virtual environment either stereoscopically, in a CAVE-like environment (i.e., a surround-screen, surround-sound, projection-based VR system), or monoscopically, on a large-screen. Results show that Blood Flow Velocity (BFV) increased in the Middle Cerebral Artery (MCA) when participants were in the CAVE condition, where a higher involvement and sense of presence was predicted (Bouchard et al., 2010).

The next paragraph presents a new and growing methodology to study real-time brain area activation called functional Near-infrared Spectroscopy (fNIRS) while it was used during a virtual reality experiment. Low-cost, portability, and reasonable spatial resolution, are the positive characteristic of fNIRS together with the use of an adapted HMD to grant a full immersion into the virtual environment.

fNIRS and Cognitive Neuroscience

Functional Near-Infrared Spectroscopy is a promising brain imaging technique that allows researchers to localize and measure cerebral blood-flow and oxygenation. It is a real-time diagnostic and non-invasive technique that is capable of measuring tissue oxygenation through the use of low-cost and portable instrumentation. The fNIRS uses optical radiation (i.e., photons which wavelength is near the infrared range [NIR]: 700-950 nm). The fNIRS probes have light sources, which penetrate tissues, and detectors (optical fibers), which detect light radiations leaked from biological tissue after completing a deep and bent variable path (characterized by multiple scattering events, see below) on the same side of the light source. The typical inter-optode distance ranges between 2.5 and 4 cm; this permits near-infrared light to penetrate biological tissue of about 1.5-2.5 cm in depth. Near-infrared light in the biological tissue undergoes two main processes known as ‘scattering’ and ‘absorption’ which are both wavelength dependent. Scattering, a process where the light is forced to deviate from a rectilinear trajectory because of the resistance of the tissue, is measured by the scattering coefficient (µs). On the other hand, biological tissue absorption, a process that is caused by the presence of hemoglobin and light that is retained by the tissue, is measured by the absorption coefficient (µa). Oxygenate hemoglobin (HbO) and deoxygenate hemoglobin (HbR) have different NIR absorption rates. This difference produces separate measurements of the two Hb types and, thus, creates oxygen saturation (StO2; i.e., the quantification of the ratio of HbO with respect to the total amount of hemoglobin in the microcirculation). After the neural activation of a cluster of neurons in a given region, the HbO concentration in this region increases to supply the additional oxygen demand of active neurons, and the HbR concentration decreases almost simultaneously (the phenomenon that relates neural activity with hemodynamic activity is called neurovascular coupling, see Villringer & Dirnagl, 1995; note that fMRI inference is also based on neurovascular coupling). The typical HbO response function is characterized by a sluggish temporal profile when compared to that of neural activity. Usually, hemodynamic activity begins to increase after about 1 s following changes in neural activity, and reaches its peak in around 5-7 s after neural activity, and slowly returns to baseline activity after 12-15 s. Most fNIRS instruments can measure the emission of the intensity of constant and continuous light and is capable of obtaining relative measures of tissue oxygenation (StO2). The fNIRS technologies are in continuous evolution. The improvement of spatial resolution, for example, remains one of the most studied problems and several solutions have been suggested (Owen-Reece et al., 1999). Furthermore, the statistical interpretation of fNIRS data, together with the constant improvement of methods for eliminating artifacts automatically (Hoshi, 2005), has been developed and refined over the years (Villringer & Chance, 1997; Strangman, Boas, & Sutton, 2002).

The fNIRS applications in neurosciences and recent studies have explored the neural correlation of several human behaviors. Miyai et al., 2001 found neural activation of medial primary sensorimotor cortices and supplementary motor areas during walking activities. In a simple reaching task, Shimada et al. (2004) reported a decrease in oxy- and total-Hb in the dorsal prefrontal area that appears to be responsible for the visuomotor recalibration process. Visual perception was investigated in a recent study that reported the activation of the primary and the secondary visual cortices (presumably V1–V3) in a checkerboard paradigm (i.e., the presentation of a flashing visual checkerboard stimulus). Also studied was the activation of the motion perception area (V5) in a paradigm consisting of moving colored stimuli (Schroeter et al., 2004). Additionally, the checkerboard pattern was implemented in a study where an activation of the occipital cortex was seen in infants aged 2–4 months, which is similarly observed in the adult brain (Taga, Asakawa, Maki, Konishi, & Koizumi, 2003). The fNIRS has also been used in the study of executive functions. Hoshi et al. (2003) confirmed that the central executive of working memory is implemented in the prefrontal cortex (PFC). Using an event-related Stroop task with incongruent, congruent, and neutral trials, Schroeter et al. (2002) found a stronger brain activation (hemodynamic response) in the lateral prefrontal cortex bilaterally during the incongruent condition.

There are several advantages of fNIRS, when compared to other imaging techniques (e.g., fMRI, PET). First, fNIRS is easily portable and has a lower cost. Second, fNIRS allows the participants to be almost totally free in their movements. The third reason is that it uses only light sources, thus, fNIRS is completely non-invasive. The fourth advantage of fNIRS is that it possesses a temporal resolution of 100 Hz or higher, which is significantly greater than those of fMRI and PET. Finally, by being interference-free, fNIRS permits multiple simultaneous registrations with fMRI, PET, and EEG. In fact, fNIRS represents one of the most useful brain imaging techniques for replicating and validating data and registrations acquired with fMRI (Hoshi, 2005;

Huppert, Hoge, Diamond, Franceschini, & Boas, 2006; Irani, Platek, Bunce, Ruocco, & Chute, 2007).

The fNIRS, however, has some limitations. First, only cortical activity can be examined with fNIRS, resulting in limited depth penetration of near-infrared light into the skull. Second, the anatomical information cannot be directly inferred by fNIRS, thus it must be obtained with the help of other techniques. Second, hair can interfere with the transmission of light to the source, the scalp, or the detector. Finally, given that the participants are almost totally free to move, the holder must be fixed on the head in order to ensure a correct registration and to avoid motion artifacts (Hoshi, 2005; Huppert et al., 2006; Irani et al., 2007).

There have been no attempts so far to study the neural correlations of immersive virtual reality experiences with fNIRS. Previous studies have implemented VR but only in a non-immersive desktop setting. Combe et al. (2010), for example, have studied the neural correlations of depth perception in a 3D environment, and its effects on the participants' emotional state. Previous studies have implemented flight-simulators (Takeuchi, 2000), drive-simulators (Li et al., 2009), or war video, game-like simulations (Izzetoglu, Bunce, Izzetoglu, Onarall, & Pourrezaeil, 2003), but there have been none that directly studied immersive reality settings.

In our study, we elaborated more on the methodology used in a previous study (Gamberini et al., 2008), in order to find a valid solution concerning correct signal acquisitions with fNIRS during an immersive VR task. Using a line bisection task, we expected that both the parietal lobe and the parieto-occipital junction would be activated (Weiss et al., 2000). By using PET, Weiss et al. (2000) asked participants to perform a line bisection task at two distances, 70 cm (nearby space) and 170 cm (space that is farther away; see Figure 3.2.1.). Lines were presented in the center of a monitor. Participants performed bisection using a laser pointer. Weiss et al. (2000) found that when lines were bisected in near space, the dorsal visuomotor stream was activated (i.e., the dorsal occipital cortex and the parietal cortex along the intraparietal sulcus). In contrast, when lines were bisected in the space that was farther away, the ventral visuoperceptual stream was activated (i.e., the bilateral ventral occipital cortex and the

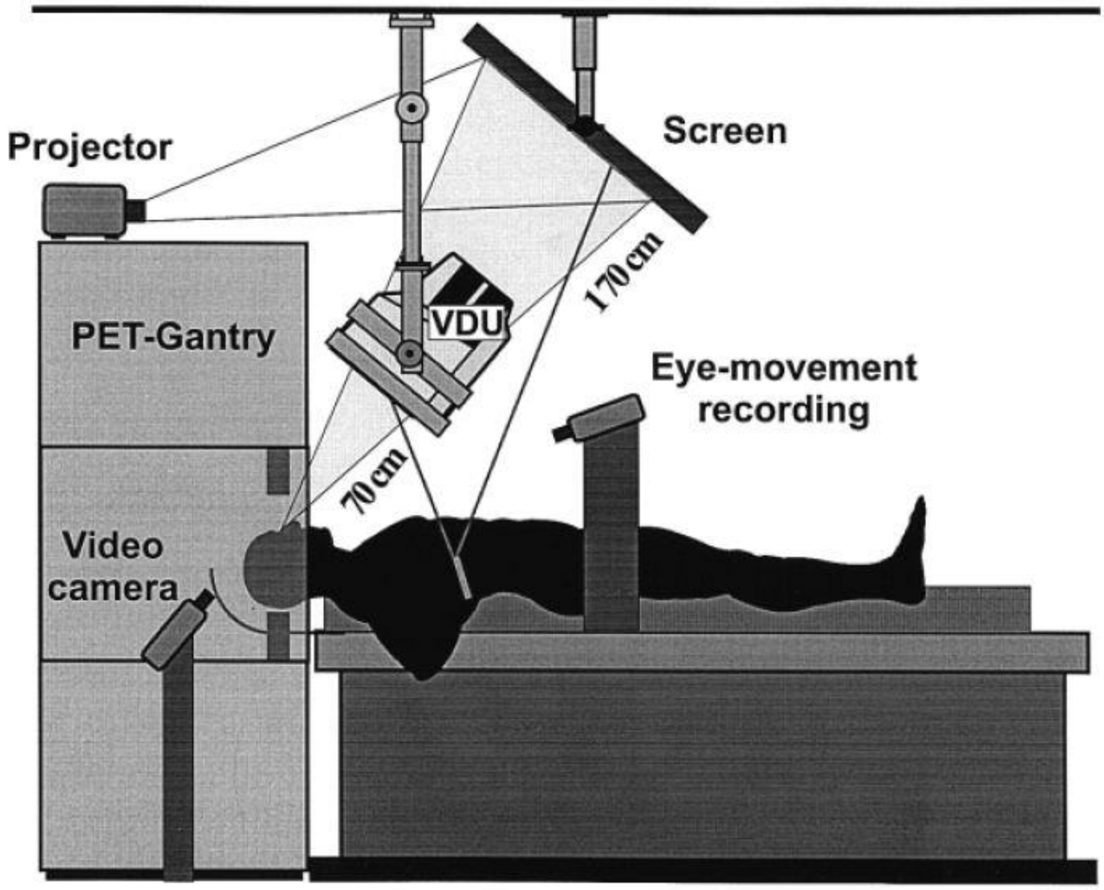


Figure 3.2.1. A schematic representation of the experimental setting in the research of Weiss et al. (2000).

right medial temporal cortex). As we stated before, one of the advantages in using fNIRS is that it could allow a full immersion into the virtual environment, a feature that is not found in other brain imaging techniques (e.g., fMRI or PET).

In the present study we investigated the possibility to implement fNIRS while participants experienced immersive VR. Our solution involved the use of a modified VR helmet to allow fNIRS optical fibers to be placed correctly over the scalp. Therefore, the aim of the study was to investigate whether this technical apparatus is suitable for correct signal acquisition with fNIRS. We employed the line bisection task in order to produce an efficient and valid paradigm to test brain-area activation during spatial attention deployment. The line bisection task is a widely used one. Although this is a relatively simple task, it gives remarkable results in terms of visuospatial attention and perception. It is widely accepted and several studies have reported similar results, in many of its variations (Jewell & McCourt, 2000 for a review; Ferber & Karnath, 2001; Longo & Lourenco, 2006; Rorden et al., 2006). Very few studies have simulated the line bisection task in an immersive virtual environment (Baheux et al., 2006; Garrison & Ellard, 2009). Gamberini et al. (2008) reported similar results when participants performed live bisection in a real environment and in a virtual one. Therefore, the aim was to employ this paradigm to test the feasibility of the technical proposal for registering fNIRS signals in an immersive VR environment.

3.2.2. Method

Participants

Eight right-handed students at the University of Padua (7 males; M = 27.6 years, S.D. = ±3.35 years, range = 24–36 years) with normal or corrected-to-normal vision participated in the experiment after providing their informed consent. None of the participants reported a prior history of neurological or psychiatric disorders, and none was under medication at the time of testing. One participant was excluded from the data analysis because his fNIRS signal was too noisy.

Materials

Participants saw the virtual environment through an adaptation of a V8 Research HMD (Head Mounted Display; Dual 1.3” diagonal Active Matrix Liquid Crystal Displays; 800x600 resolution; 60° diagonal Field Of View; 200:1 Contrast ratio). V8 Research HMD LCDs were taken from the original helmet and attached to a modified bike helmet that was modified in order to reach brain areas from the fNIRS optical fibers. A Velcro belt was attached at the back of the helmet in order to counterbalance the effect of the LCDs’ weight in front of the helmet. This belt was subsequently secured to the participants back through a thoracic belt. An Intersense tracker was

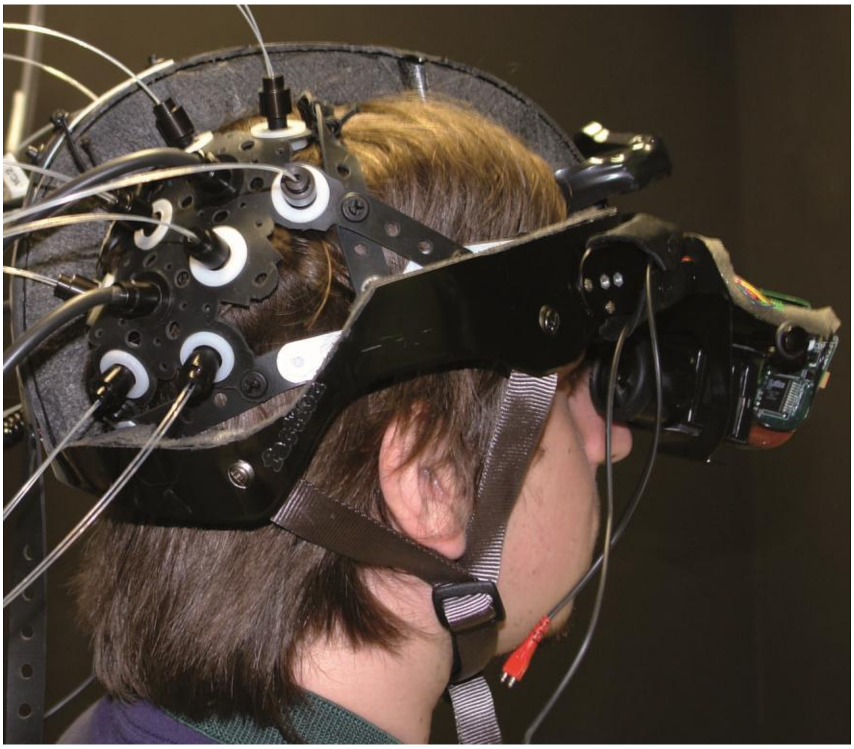


Figure 3.2.2. The adapted virtual reality helmet. The helmet was created by attaching the LCDs removed from a V8 Research Head Mounted Display to a modified bike helmet. The fNIRS optical fibers were applied to the parietal and occipital areas. A Velcro belt was attached at the back of the helmet in order to counterbalance the effect of the LCDs' weight in front of the helmet. The belt was subsequently secured to the participants back through a thoracic belt.

mounted above the LCDs, in order to allow the participants to completely immerse into the environment (see Figure 3.2.2. and Figure 3.2.3.).

The virtual environment was created using 3DStudio Max 8.0 for the development of three-dimensional objects and Virtools 3.5 for the interaction with them. A virtual room was created with a “wooden” table in the centre. Above and aligned with the table's centre, there was a white panel (50 x 50 cm) for displaying horizontal lines. In the panel's centre there was a bracket; on the left of the panel there was a telephone, while on the right there were some books (see Figure 3.2.4.).

There were two viewer-line distances: 60 cm and 120 cm. Line were 4- and 8-cm-long at the distance of 60 cm, and 8- and 16-cm-long at the distance of 120 cm (subtending a visual angle of 3.82° and 7.54° for each line pair 4-8 and 8-16, respectively). In front of the table there was a mobile chair with wheels that served for the participant, as he was instructed that, once he was seated, he could move along the two distances through that chair. Virtual lines were planes (i.e., a type of 3D object primitive used in computer graphics) that were 2-mm thick. To guarantee high precision in the response acquisition each centimeter of each line was subdivided in 4 segments, (0,25 mm each) . To decrease normal aliasing provoked by three-dimensional lines, line textures of the same dimensions were superimposed above the virtual lines. To simulate the laser pointer, a Nintendo Wiimote® was used. The Wiimote® operates as a normal mouse throughout the software GlovePie (http://glovepie.org/). In the virtual environment the Wiimote® moved a 2.5 mm red dot as a simulation of the same one represented by a real laser pointer.

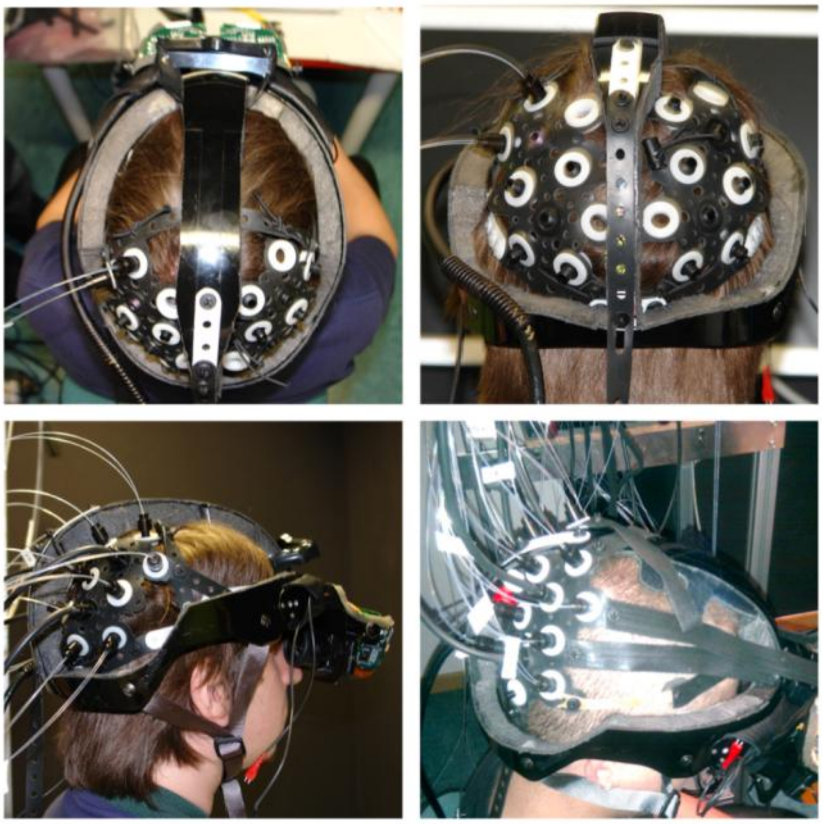


Figure 3.2.3. Different views of the adapted virtual reality helmet (see also Figure 3.2.2.).

Figure 3.2.4. The virtual environment. On the left, a panoramic view of the virtual room is presented; the mobile chair with wheels was created to simulate and motivate the movement along the distances of line presentation, 60 and 120 cm. On the right the participants' point of view of the virtual environment is presented; lines were presented over the white panel and could be bisected moving a red dot through the manipulation of a Wiimote® controller.

The virtual red dot was represented by a 3D cone whose tip could collide with the lines, giving the point of contact over them (i.e., the bisection point). The A button on the Wiimote® served to memorize the response (the last point of contact over the line) and to switch to another line and/or distance. The virtual environment was perceived stereoscopically as two points of view. That is, two cameras outdistanced by 2 cm were created as a simulation of the left and right eyes: The left camera for the left LCD and the right camera for the right LCD. The task was divided in two blocks: The experimental block and the control block. The experimental block comprised 72 stimuli in which the participant had to bisect the lines. The control block comprised 36 stimuli in which only the right extremity of the lines had to be reached. The inter-trial interval between each line presentation (onset) was 12 sec. in order to register a correct hemodynamic response. Lines and distances presentation was randomized. The order of blocks was counterbalanced across participants.

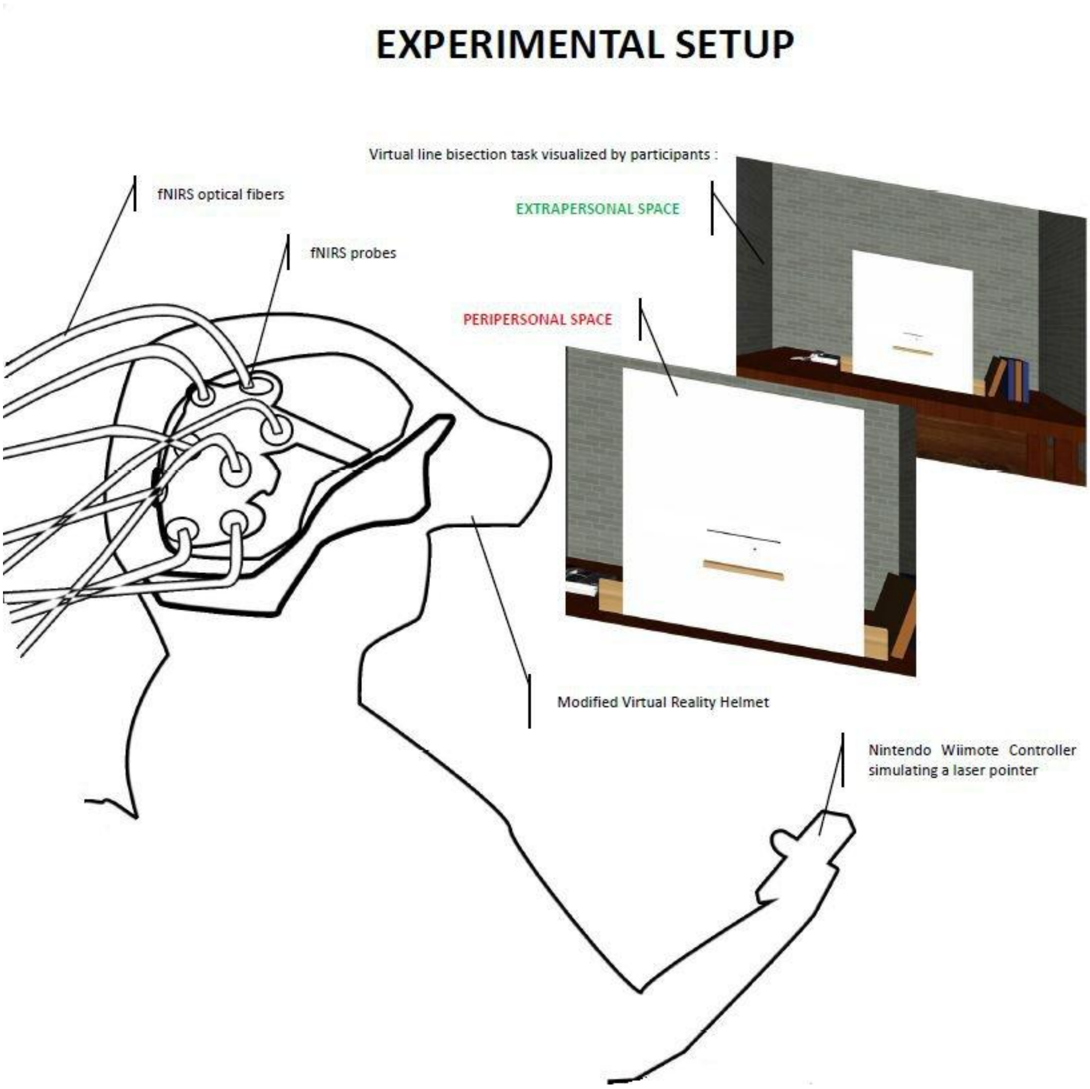


Figure 3.2.5. A schematic representation of the experimental setup. The participant sat on a chair wearing the adapted virtual reality helmet and the fNIRS optical fibers. The participant had to perform a virtual line bisection task . Lines were presented within a virtual peripersonal (60 cm) or extrapersonal (120 cm) space, and could be bisected through the manipulation of a Wiimote® controller (right hand).

Procedure

After having compiled the informed consent (see Appendix 1A – 1B), each participant read the instructions in order to complete the experimental task (see Appendix 4). Then the participant was invited to seat in a comfortable chair placed inside a sound-attenuated and dimly-lit room, where the virtual reality helmet and the fNIRS optical fibers were placed on his/her head. The average time to apply the helmet was approximately 20’. Before starting the experiment the participant was instructed to remain steady as much as possible, during the experiment, and to avoid repetitive movements; the experimenter highlighted this instruction to be sure that the participant was aware of the fact that each single movement could interfere with signal registration. The participants performed a training task in which 16 lines were presented (8 for the experimental block and 8 for the control block). The overall duration of the experiment was 20’ (see Figure 3.2.5.).

fNIRS data acquisition

The recording optical unit was a multi-channel frequency-domain NIR spectrometer (ISS Imagent™, Champaign, Illinois), equipped with 32 laser diodes (16 emitting light at 690 nm, and 16 at 830 nm) modulated at 110 MHz. The diode-emitted light was conveyed to the participant's head by multimode core glass optical fibers (heretofore, sources; OFS Furukawa LOWOH series fibers, 0.37 of numerical aperture) with a length of 250 cm and a core diameter of 400 µm. Light that scattered through the brain tissue was carried by detector optical fiber bundles (diameter 3 mm) to 4 photo-multiplier tubes (PMTs; R928 Hamamatsu Photonics). The PMTs were modulated at 110.005 MHz, generating a 5 KHz heterodyning (cross-correlation) frequency. To separate the light as a function of source location, the sources time-shared the 4 parallel PMTs via an electronic multiplexing device. Only two sources (one per hemisphere) were synchronously ($t=4$ ms) active (i.e., emitting light), such that the resulting sampling frequency was $f=15.0625$ Hz, due to the 64 ms sampling period required to cycle through the 16 multiplexed channels. To stabilize the optical signal, a dual-period averaging was performed, resulting in a final sampling period of 128 ms ($f=10^3/128=7.8125$ Hz). Following detection and consequent amplification by the PMTs, the optical signal was converted into alternating current (AC), direct current (DC), and phase (Φ) signal for each source-detector channel, considering separately each light wavelength. These values were then converted into estimates of absorption coefficient variations ($\Delta\mu\alpha$) using the differential-pathlength factor (DPF) method.

Temporal variations (Δ) in the cerebral oxy-hemoglobin (ΔHbO) and deoxy-hemoglobin (ΔHbR) concentrations were calculated based on the values of Δμα at the two wavelengths (Franceschini, Toronov, Filiaci, Gratton, & Fantini, 2000; Sevick, Chance, Leigh, Nioka, & Maris, 1991).

The spatial arrangement of source/detector pairs on the scalp was determined using a recent probe placement method (Cutini, Scatturin, & Zorzi, 2011b). Sources and detectors were held in place on the scalp using a custom holder with velcro straps. Each source was composed of two source optical fibers (one for each wavelength). The distance between each source/detector pair (i.e., channel) was 30 mm. This probe arrangement included 20 channels, providing 20 measurements for HbO and 20 for HbR. The holder covered partially both the occipital and the parietal lobes, as in a previous fNIRS study adopting the same probe placement criteria (Cutini et al., 2011a). An illustration of the regions covered in the present study is provided in Figure 3.2.6 (for details, see Cutini et al., 2011a, b).

fNIRS data analysis

Individual hemodynamic responses were baseline-corrected on a trial-by-trial basis by subtracting the mean intensity of the optical signal recorded in the interval 2 s – 0 from the onset (i.e., the presentation of the to-be-bisected line) from the overall hemodynamic activity (12 s) (Schroeter, Zysset, Kupka, Kruggel, & Cramon, 2002). Trials contaminated by artifacts were eliminated using the outlier removal algorithm proposed by Devaraj (2005). The mean value and the difference between the maximum and minimum values (range) were calculated considering all trials in a given condition. The mean value and range were also calculated for each single trial. Single-trial mean and range values were then compared with the mean values of all trials in that condition. Trials with a range or mean value greater than the condition mean ±3 standard deviations were discarded from analysis. Signal averaging of all remaining trials in each condition was then performed. Noisy channels (with standard deviation > 700nM) were discarded from further analysis (less than 5%). The averaged hemodynamic signal was smoothed with a Savitzky and Golay’s (1964) filter with polynomial order equal to 3 and frame size equal to 39 time-points (i.e., 5 s).

Subsequently, the mean ΔHbO and ΔHbR signal intensities during the vascular response (i.e., the peak value reached during the temporal window between 5 and 9 s from onset) were calculated for each participant and condition. The analysis performed on the data recorded in the trials using the individual optical maps aimed at verifying the channels showing a significant activation increase relative to the baseline.

3.2.3. Results

Although a specific functional dissociation between extrapersonal and peripersonal space was not observed, we were able to verify the reliability of the measurements in terms of a significant hemodynamic activity with respect to the baseline. To this scope, we performed a series of t-tests on the individual ΔHbO concentrations observed during the hemodynamic response vs. baseline (pooled activity of peak amplitudes during extrapersonal and peripersonal bisection conditions). We observed statistically significant HbO activity in most of the occipital and parietal channels, whereas no significant HbR decrements were observed, mainly because of the poorer signal-to-noise ratio with respect to that of HbO. In particular, we observed a pronounced ΔHbO activation in the right parietal channels (see Fig. 3) during virtual line bisection (e.g., right parietal channel 1 (PR1): t(6)=2.26, p=.032; right parietal channel 2 (PR2): t(6)=2.12, p=.037; one-tailed t-tests (see Fig. 3.2.6. for the location of those channels).

The activity observed in PR1 seemed to be a reliable task-related hemodynamic response; nevertheless, such activity might have been contaminated by physiological components unrelated to the task (i.e., skin blood flow, Takahashi et al., 2011), although the event-related design should have limited this influence. In order to provide a further proof in regard to the reliability of PR1 hemodynamic response, we compared the activity of PR1 with that of the symmetrical channel on the left hemisphere (i.e., PL1;

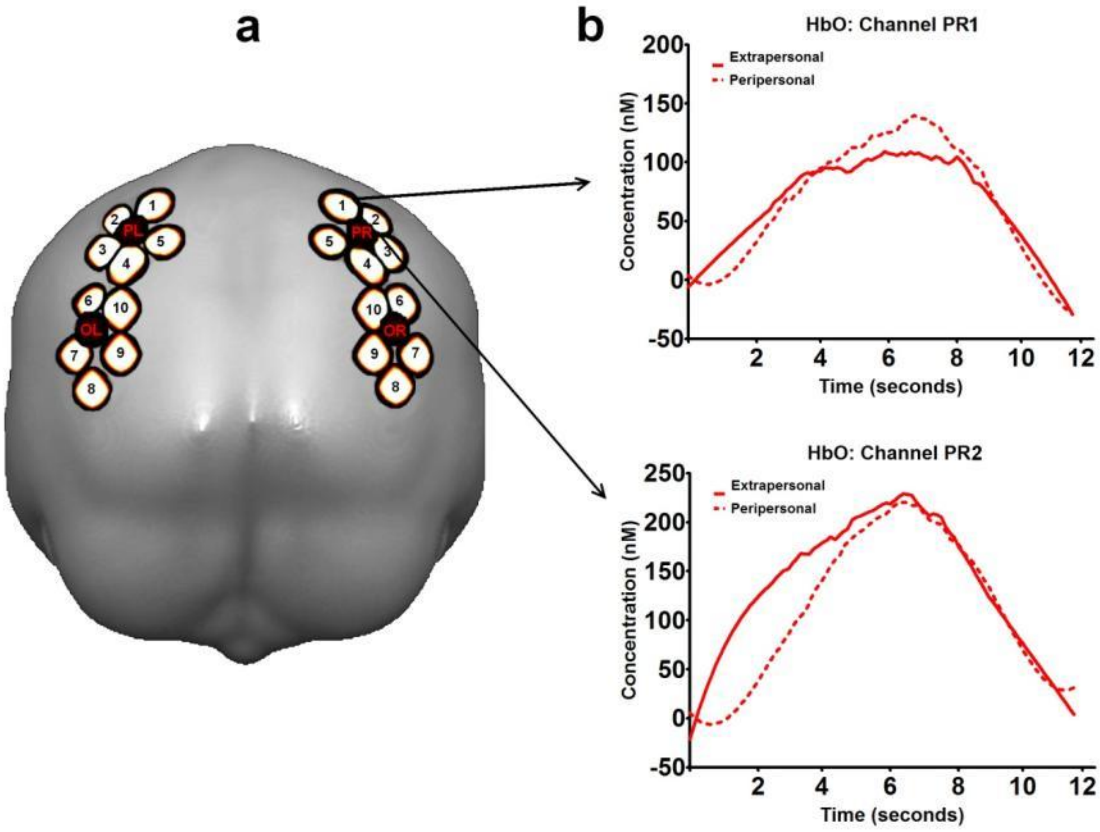


Figure 3.2.6. a) Location of the regions investigated in the present study. Cerebral projections of detectors (black) and channels (white). The letters of the detectors indicate the lobe (P: parietal; O: occipital) and the hemisphere (L: left; R: right). The number indicates the source. Channels are named according to the source-detector pair: for instance, detector OL and source 5 created the channel OL5. Further details can be found in Cutini et al.(2011a, b). b) Hemodynamic response profile in channels PR1 and PR2 (i.e., right parietal lobes) during virtual line bisection. The classical hemodynamic response profile can be clearly recognized in both conditions (i.e., peripersonal space and extrapersonal space).

see Fig. 3.2.7.). Interestingly, we observed a difference between PR1 and PL1 activity that was very close to significance (p=.077, t(6)=1.628, one tailed t-test). The real version of the line bisection task was found to activate the right parietal areas in several previous studies (Fink et al., 2000; Fink, Marshall, Weiss, & Zilles, 2001; Fink, Marshall, Weiss, Toni, & Zilles, 2002; Hurwitz, Valadao, & Danckert, 2011; Foxe, McCourt, & Javitt, 2003). Given the exploratory nature of the present investigation, data analysis shown here was meant to represent only a broad verification of the

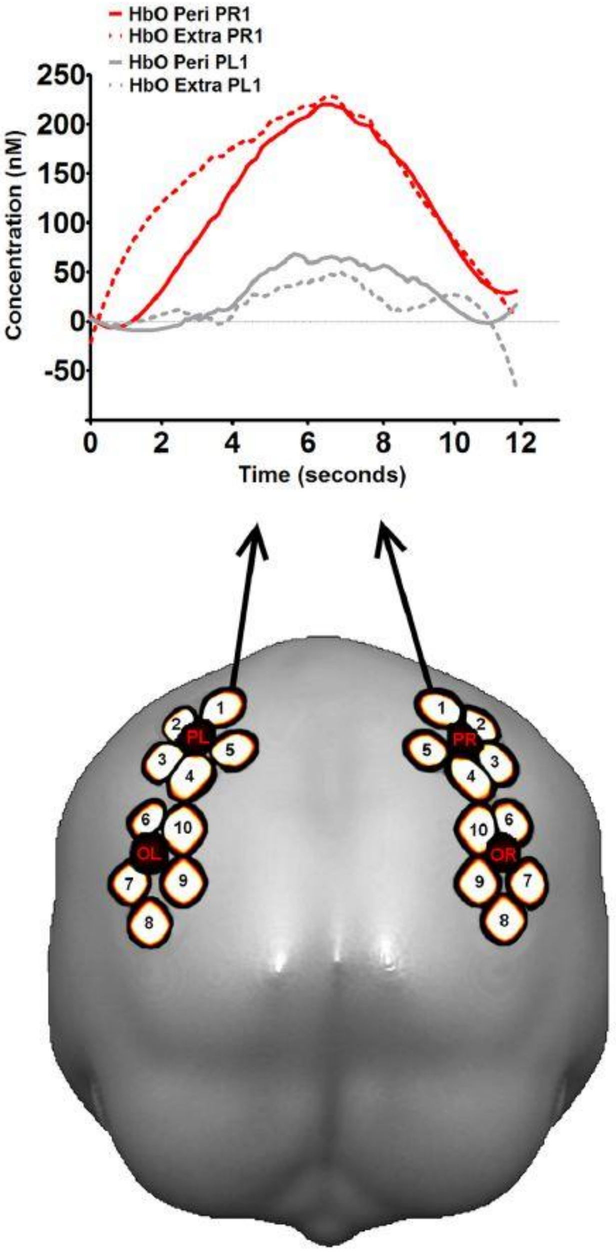


Figure 3.2.7. The fNIRS recording. In the bottom part of the figure, the location of the regions investigated in the present study, with cerebral projections of detectors (black) and channels (white) superimposed on a template brain (occipital view). The letters of the detectors indicate the lobe (P: parietal; O: occipital) and the hemisphere (L: left; R: right). The number indicates the source. Channels are named according to the source-detector pair: for instance, detector OL and source 5 created the channel OL5. Further details can be found in Cutini et al. (2011a, b). In the top part of figure, hemodynamic response profile in symmetrical channels PR1 and PL1 (i.e., right vs. left parietal lobe) during virtual line bisection. A visual inspection of the response profiles in the two channels suggests a marked difference for what concerns the presence of task-related hemodynamic activity in the two parietal lobes.

feasibility of our methodology. Nevertheless, further analysis as well as tests on the methodology used should be performed to completely assess the potential and the limitations of the proposed methodology.

Behavioral results of the virtual line bisection task showed a significant difference in the bisection error in the comparison between the performance in peripersonal and extrapersonal space. Although an overall error to the left of the true midpoint was present (M=-2.49), participants' performance showed a greater error to the left in virtual peripersonal space than in virtual extrapersonal space, t(6)=-2.112, =.039, one-tailed t-tests (see Fig. 3.2.8.). The discrepancy between the behavioral results, in which a dissociation between peripersonal and extrapersonal space is revealed, and the fNIRS results, in which a dissociation between peripersonal and extrapersonal space is not revealed, could be ascribed to the different nature of the present study and that of Weiss et al. (2000). As stated above, further testing and validation of the system need to be done to completely assess its potential and limitations.

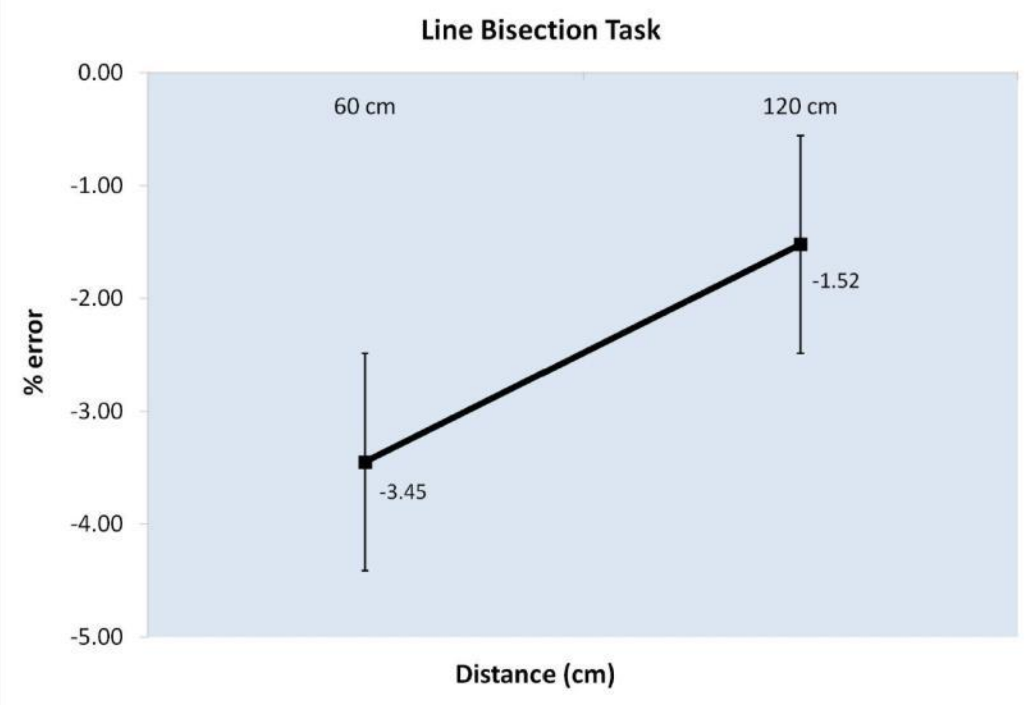


Figure 3.2.8. Graph of the behavioral results. The graph shows the mean percentage error (Y axis) along the distances of line presentation, 60 and 120 cm (X axis). Negative values indicate an error on the left the lines midpoint; positive values indicate an error on the right of the lines midpoint. Error bars represent the standard error ±SE.

3.2.4. Discussion

Results show an activation of the parietal and occipital lobes both when the lines were bisected at 60 cm and at 120 cm. These areas are implicated in visuomotor tasks, in the case of this study in which participants had to perform hand movements (i.e., using the simulated laser pointer), while they were visually focused in finding the centre of the lines. Several researchers have found parietal activation during attention, space perception and visuospatial tasks, and the frequent paradigm used was the line bisection task (Fink et al., 2000; Fink et al., 2001; Fink et al., 2002; Bjoertomt et al., 2001; Hurwitz et al., 2011; Foxe et al., 2003; Waberski et al., 2008; Thiel, Zilles, & Fink, 2004; Pisella et al., 2011; Peers et al., 2005; Azañón, Longo, Soto-Faraco, & Haggard, 2010); in particular, a right parietal lobe predominance was found (Fink et al., 2000; Fink et al., 2001; Fink et al., 2002; Hurwitz et al., 2011; Foxe et al., 2003). On the other hand, there is little evidence to prove that visuospatial tasks are performed during virtual reality simulation (Baumgartner et al., 2006; Hribar et al., 2009; Maguire et al., 1998; Jeong et al. 2006). Moreover, no fNIRS and virtual reality studies have reported similar results. The inability to find dissociation in neural activation for the two distances presented, as mentioned in the study of Weiss et al. (2000), could be ascribed to the virtual component of the task. In the present study, we used V8 Research LCDs attached on a bike helmet in order to have as much as possible the same conditions of the study by Gamberini et al. (2008). The aim of this exploratory investigation was to study the possibility of implementing the fNIRS brain imaging technique in the study of immersive virtual reality experience. Using a virtual line bisection task, a cerebral activation was observed to be present in the parietal and occipital lobes. Further investigation is needed to confirm the validity and reliability of our results. Although the experiment was not flawless, it represents a good starting point in the implementation of the fNIRS in investigating virtual reality interactions: in this regard, we hope that our results trigger further research in the field.

A major problem arose upon the application and assembly of the adapted helmet on each participant. As the helmet was not adjustable and each participant had a different head circumference, we had to use Velcro to fix the fNIRS on the head and on the helmet, and had to add several pieces of rubber to fit the helmet onto the participant in a correct and comfortable way. Moreover, in this solution only BOLD in parietal and occipital brain areas can be measured because in the other ones there was no space to place fNIRS probes. Solving these problems will be the goal of our future studies.

The implementation of less cumbersome HMDs (i-Trek 3D PC, Virtual Visor, Sensics xSight; www.vrealities.com) could solve the problem of the space on the head needed to place the NIRS patch more correctly and comfortably. On the other hand, those HMDs suffer from less resolution and FOV (Field of View) and in some cases they lack stereoscopic vision. Another more effective way might be to adopt stereoscopic and auto-stereoscopic 3D displays, although it would be detrimental for VR immersion.

The use of fNIRS has resulted in considerable benefits for cognitive neuroscience studies. The procedure is noninvasive and capable of not constraining the participant to be in huge machineries such as those for positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). It allows a natural position rather than the horizontal position assumed within the PET or fMRI. Therefore, fNIRS can allow the investigation of classic neuropsychological disorders in a way not previously possible.

The implementation of fNIRS in the analysis of the cerebral functions that subtend VR experiences represent another important goal. The exploration and the in-depth examination of different methodologies and solutions for VR applications will be the most important topic of future studies . In conclusion, fNIRS has the potential of opening up new frontiers in brain research and VR applications.

3.3. EXPERIMENT 3: The influence of the body position

3.3.1. Introduction

Visuospatial attention studies mainly address themselves to the identification of stimuli located in the visual space. On the other hand, the physical actions performed by the body play a crucial role in the planning and executions of visuospatial behaviors. Body position and visual information are integrated when actions have to be performed in response to the different situations that an individual has to face. The perceptual and attentional human systems automatically and adaptively work to constantly face occurring events (Previc, 1998). The term ‘visuospatial attention’ refers to the cognitive process involved in the selection of certain visual stimuli to the detriment of others based on their spatial location (Marshall & Fink, 2001). Basically, spatial attention functions to locate stimuli and places in the surrounding environment that are pertinent for the actual or future actions of an individual (Bouma & Bouwhuis, 1984). Interaction with the environment is made possible by the orientation of the attention to relevant events. Spatial attention serves as a filter by which to identify the salient information, and helps perceptual processing with the augmentation of the stimuli presented in a specific location (Bouma & Bouwhuis, 1984; Braun, Koch, & Davis, 2001).

However, the various positions of the body and limbs represents reference frames for the actions to be performed, and operate to assist the identification of relevant perceptual information. Few researches have investigated the role of the body and limbs influence in the processing of space. The body directly influences and modulates the representation of nearby visual stimuli. Body parts constantly constrain movements and update the visual configuration of the space, allowing the distribution of attention within the environment. Even when the body is fixed, its position within the environment should influence attentional processing.

Often, the position of the body during the performance of visuospatial attention tasks is not monitored accurately. The body, specifically the part of the trunk to which is attached the head, the arms and the legs, plays a fundamental role in the execution of reaching and grasping movements of surrounding objects. Consequently, the orientation and configuration of the trunk of the body received during a task of attention can influence sensory processing and motor activity during the execution of specific actions (Guerraz, Caudrona, Thomassin, & Blouin, 2011; Guerraz, Navarro, Ferrero, Cremieux, & Blouin, 2006), influencing the distribution of the attentional resources allocated in the surrounding space (Reed, Garza, & Roberts Jr., 2007). Normally, the head, and hence our eyes, are pointing in the direction in which the body moves, therefore, demonstrating that the trunk is almost always aligned with the most salient portions of the behavioral space. During a locomotion movement, attention and gaze are directed towards the path, in order to avoid obstacles. However, it is possible to proceed through the environment focusing attention in other directions. The alignment of the gaze with the body is, indeed, useful when objects become accessible. Peripersonal space in front of the body is manipulable with one or both hands.

In spatial neglect patients the influence of body position on the attentional space showed interesting results. Spatial neglect, following a brain lesion that usually affects the right parietal and temporal regions, is a syndrome which prevents those affected from perceiving and exploring the contralesional portion of space (Halligan et al., 2003). Researchers have shown that when the body is rotated toward the contralesional space, neglect patients ability to explore and interact with the objects in that part of space increases (Karnath, 1994; Karnath, Christ, & Hartje, 1993; Karnath, Schenkel, & Fischer, 1991). Even the implementation of specific procedures for amending attentional orientation towards the contralesional portion of space have produced positive results in neglect patients. Rubens (1985) implemented the caloric irrigation of the ear to train neglect patients to orient toward the affected hemifield. Karnath (1994), dealing with neglect patients, concluded that vestibular stimulation and neck muscle proprioception are relevant factors in elaborating our body position in space. Moreover, after the administration of a line bisection task with a horizontally moving background, a displacement of the subjective midpoint was induced in neglect patients, with positive effects on the syndrome (Pizzamiglio, Frasca, Guariglia, Incoccia, & Antonucci, 1990).

When the body is rotated towards the unregistered portion of space, improvements in the elaboration of the stimuli on the neglect portion of space are observed.

Otherwise, the procedures described above were not found to have the same influence on healthy participants (Karnath et al., 1991; Karnath et al., 1993); in addition, the administration specific spatial tasks together with caloric irrigation or neck muscle vibration did not show significant changes in normal participants (Rorden, Karnath, & Driver, 2001). Body orientation showed influence in a study where participants were requested to respond as quickly as possible to targets presented on their right or left side. When the body was oriented on the right or left side , participants were faster in detecting the stimuli presented respectively on the right or left side (Hasselbach-Haitzeg & Reuter-Lorenz, 2002). The influence of body orientation was present also in a covert orienting paradigm where participants turned on the left side were faster to detect invalidly cued targets on the left and slower to detect invalidly cued targets on the right (Grubb & Reed, 2002).

Hands' actions are influenced by the body in the way that the movement through the environment is characterized by different in relevance regions of space affected by the arm position. Avoiding an obstacle is a behavior that acquire relevance especially when an individual is standing and walking to a specific location. The bias generated by the action of walking both introduce and is affected by additional motor and cognitive processing demands. Neglect patients shows additional deficiencies when the position of the body is changed during the fulfillment of visuospatial attention tasks because their attentional resources decrease (Robertson, Mattingley, Rorden, & Driver, 1998; Heilman, Schwartz, & Watson, 1978; Hjaltson, Tegner, Kerstin, Levander, & Ericson, 1996). On the other hand, in normal adults these effects were not found, probably because the experimental tasks were designed not to induce an high mental workload.

Nevertheless, body position can alter how healthy humans perceive the surrounding space and the space beyond the arm reaching distance. Based on the results obtained in the studies of Longo and Lourenco (2006) and Gamberini et al. (2008), the next two studies aimed to verify if the feeling of having the body blocked or free to move during an attention task, this has implications in terms of how the perceptual transition from peripersonal to extrapersonal space is modulated. The experiments have investigated if the presence (Gamberini et al., 2008) or absence (Longo & Lourenco, 2006) of a chinrest has implications in a real line bisection task performed in peripersonal space and extrapersonal space. According to the different experimental procedure, Study 1 replicated in part the real version of the line bisection task used in Gamberini et al. (2008), where participants used the chinrest and were seated during the experiment. When using a laser pointer (i.e., a device that does not expand the peripersonal space), it is assumed that the presence of the chinrest would lead to an abrupt shift in the bisection error from the left to the right of the true centre of the lines in the transition from peripersonal to extrapersonal space (Gamberini et al., 2008). The absence of the chinrest would lead to a gradual shift (Longo & Lourenco, 2006). When using wooden sticks (i.e., a device that expands the peripersonal space), it is assumed there is no influence from the implementation or not of the chinrest, having a leftward bias of the true centre of the lines for all the distances. Study 2 replicates in part the experiment of Longo and Lourenco (2006), where participants did not use the chinrest and were standing during the experiment. Only the laser pointer was used.

Study 1

Participants

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

Materials

Apparatus and stimuli were the same used for the first experiment in Gamberini et al. (2008). There were two viewing distance for peripersonal space (30 and 60 cm) and two viewing distances for extrapersonal space (90 and 120 cm). Lines measured 2, 4, 8, 16 and 32 cm (height: 1 mm). Each line was centered on a white sheet of paper (width: 33 cm; height: 24 cm). Each sheet of paper was positioned in the centre of a 50 by 50 cm white panel. Participants used four wooden sticks (length: 49.2, 78.6, 104.3, and 121.8 cm) to perform line bisection at the four viewing distances (30, 60, 90, and 120 cm, respectively). In order to indicate the midpoint of each line, sticks had a point at the endpoint opposite the grasped one. The laser pointer was attached on the head of a tripod (height: 10 cm) in order to avoid the effects of natural handshaking. The tripod was located in front of the chin rest. The laser pointer projected a red point (diameter: 1 mm) to indicate the midpoint of the line.

Procedure

After the completion of the informed consent module (see Appendix 1A), the Edinburgh Handedness Inventory (Oldfield, 1971; see Appendix 2) and after have read the instructions (see Appendix 3), participants were invited to seat sit in front of a table (length: 180 cm; width: 60 cm). There were two main blocks: in one block participants performed line bisection without the chinrest, in order to keep the body free to move (see Figure 3.3.1.a); in the second block participants performed line bisection using a chinrest in order to keep the body blocked (see Figure 3.3.1.b). Within each main block there were other two sub-blocks: in one sub-block participants performed line bisection with the laser pointer; in the second sub-block participants performed line bisection with the wood sticks. On each trial, the participant was asked to indicate the midpoint of a single line, that was displayed at one of four viewing distances (i.e., 30, 60, 90, or 120 cm). There was no time limit to perform the task. Before the beginning of the experiment, there was a practice block (i.e., 5 trials using the stick and 5 trials using the laser pointer). Each experimental sub-block comprised 40 trials for a total of 80 trials. Each main blocks comprised 80 trials for a total of 160 trials. Order of stimuli and order of viewing distances were randomized. Order of blocks (no chinrest vs. chinrest and stick vs. laser pointer) was counterbalanced among participants. On half the trials participants performed bisection starting from the right endpoint of the line, while on the other half participants performed bisection starting from the left endpoint of the line.

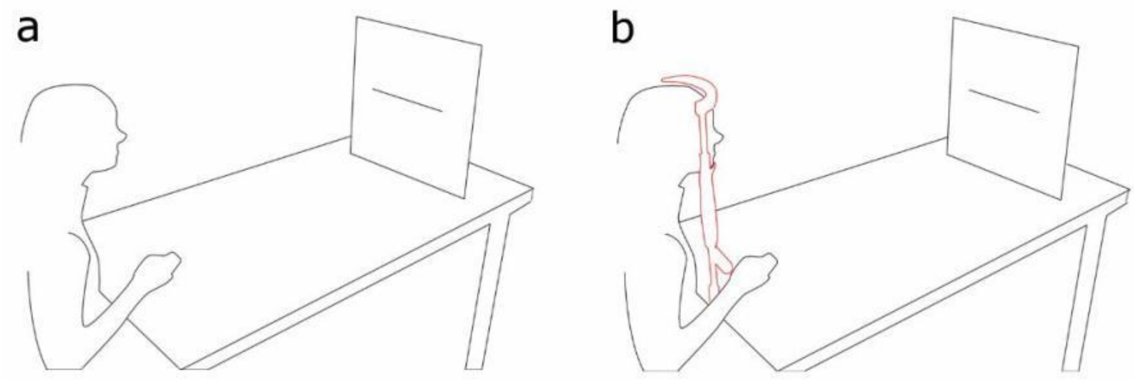


Figure 3.3.1. Representation of the two experimental main blocks: a) without the chinrest, b) with the chinrest.

Participants handled and moved the stick or the laser pointer with their dominant hand. Whenever the participant indicated the midpoint of the line, the experimenter marked it on the sheet and the next trial started.

Results

Statistical analysis was performed using the Statistical Software Package SPSS 17.0. There were three independent variables (i.e., chinrest [two levels: no chinrest, chinrest], device [two levels: stick, laser pointer] and viewing distance [four levels: 30, 60, 90, 120 cm]). The dependent variable was the mean difference (as error percentage) between the observed midpoint (i.e., the midpoint indicated by the participant) and the true midpoint of the line. Positive values of the dependent variable indicate shifts to the right of the true midpoint, whereas negative values indicate shifts to the left of the true midpoint. A three-way analysis of variance (ANOVA) for repeated measures was conducted with Chinrest (no chinrest vs. chinrest), Device (laser vs. sticks) and Distance (i.e., 60, 30, 90, 120 cm) as factors. No main effect of Chinrest was present (see Figure 3.3.2. and Figure 3.3.3.).

There was a significant main effect of Device F(1,14) = 5.23, p = 0.038, indicating, in the ‘chinrest’ condition, a mean bias to the left of the midpoint when the stick was used (M = -0.423 % error) and when the laser pointer was used (M = -0.023 mm % error). In the ‘no chinrest’ condition, results show a mean bias to the left of the

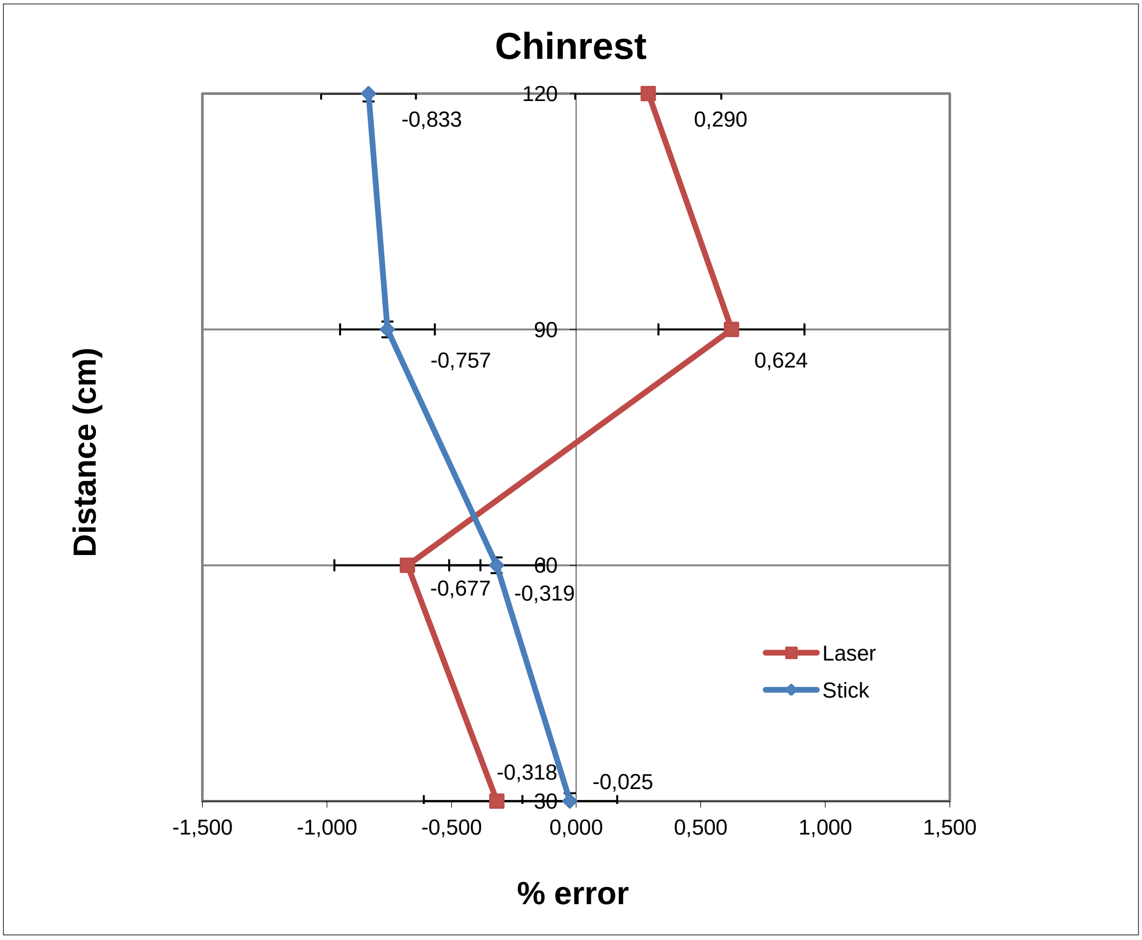


Figure 3.3.2. The graph shows the mean percentage error (X axis) along the distances of line presentation (Y axis) for the device used (i.e., laser vs. sticks) in the ‘chinrest’ condition. Negative values indicate an error on the left of the lines midpoint; positive values indicate an error on the right of the lines midpoint. Error bars represent the standard error ±SE.

midpoint when the stick was used (M = -0.273 % error) and a mean bias to the right when the laser pointer was used (M = 0.252 % error). The main effect of Distance was also significant, F(3, 42) = 3.34, p = 0.028, showing a left to right shift when the laser pointer was used, during the transition from near to far space (‘chinrest’: 60 cm = -0.66 vs. 90 cm = 0.48; ‘no chinrest’: 60 cm = -0.31 vs. 90 cm = 0.71). The interaction Device by Distance was significant, F(3, 42) = 9.52, p = 0.000. Paired comparisons revealed a significant difference between 60 and 90 cm, for the laser pointer, in the ‘chinrest’ condition t(17) = -5.11, p = .000 and in the ‘no chinrest’ condition t(17) = -2.72, p = .014, whereas this difference was not significant for the sticks (see Figure 3.3.4.).

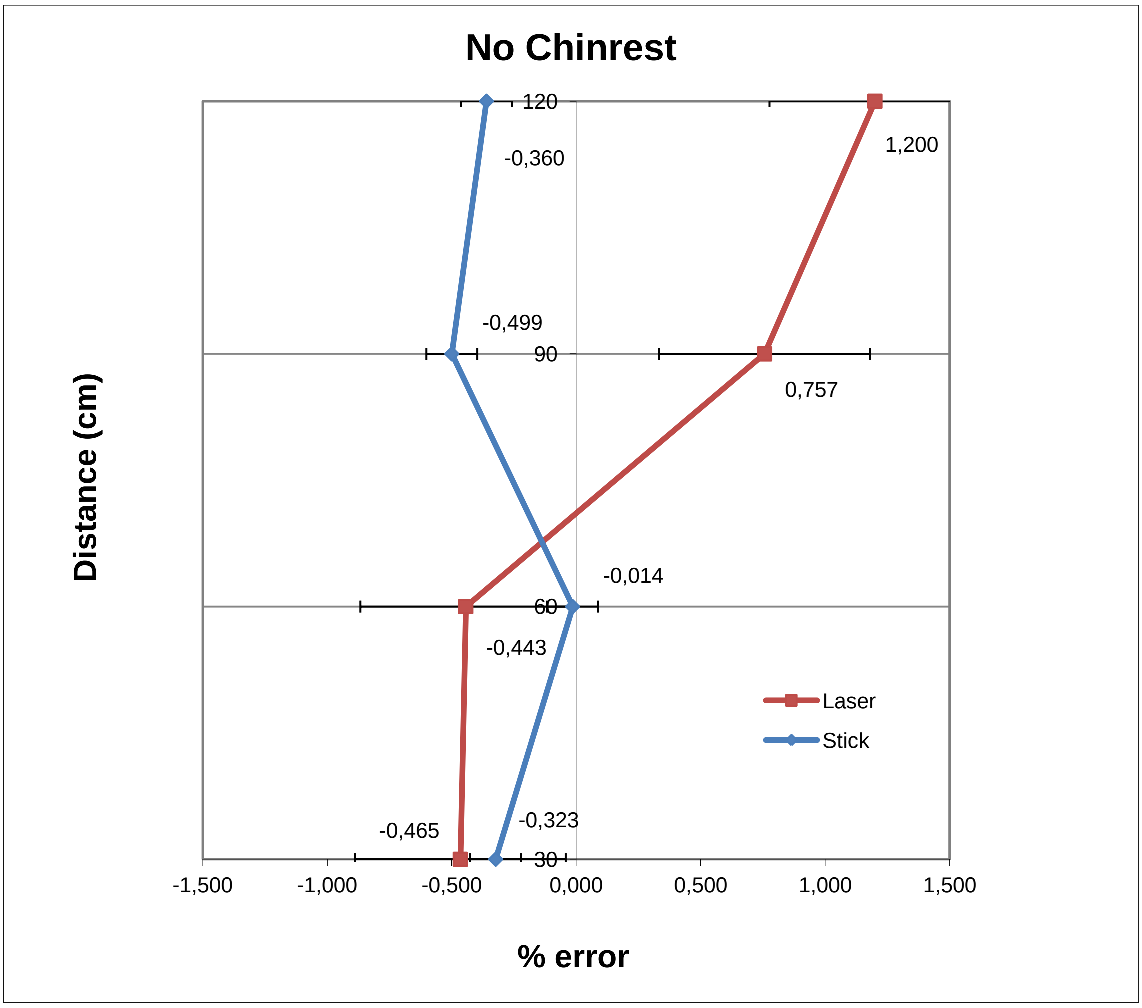


Figure 3.3.3. The graph shows the mean percentage error (X axis) along the distances of line presentation (Y axis) for the device used (i.e., laser vs. sticks) in the 'no chinrest' condition. Negative values indicate an error on the left of the lines midpoint; positive values indicate an error on the right of the lines midpoint. Error bars represent the standard error ±SE.

Study 2

Participants

24 participants with normal or corrected-to-normal vision took part in the experiment (13 males; M = 27.87 years, S.D. = ±6.65 years, range = 21–49 years). All participants gave their informed consent to participate in the study. Results from the Edinburgh Handedness Inventory (Oldfield, 1971), showed a majority of right-handed participants (M = 68.69 , S.D. = ±46.25).

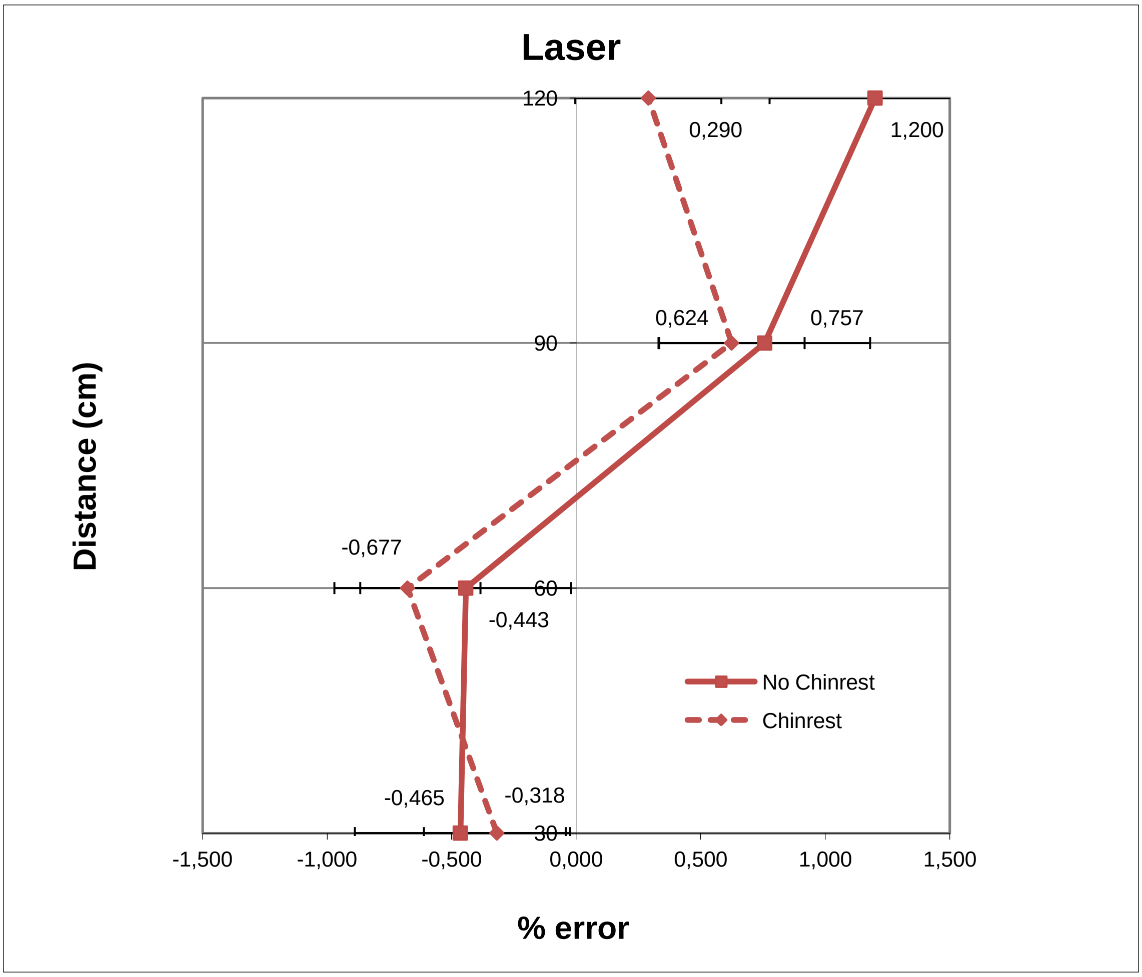


Figure 3.3.4. The graph shows the mean percentage error (X axis) along the distances of line presentation (Y axis) for the chinrest condition (i.e., no chinrest vs. chinrest) in the 'laser' condition. Negative values indicate an error on the left of the lines midpoint; positive values indicate an error on the right of the lines midpoint. Error bars represent the standard error ±SE.

Materials

There were two viewing distance for peripersonal space (30 and 60 cm) and two viewing distances for extrapersonal space (90 and 120 cm). Lines measured 5, 10, 15 and 20 cm (height: 1 mm). Each line was centered on a 19" LCD monitor (1024x768 resolution) positioned over a table at ~ 160 cm height from the ground. Lines presentation occurred randomly using an adaptation of the software implemented in Gamberini et al. (2008) and Experiment 2 (see Section 3.2.2. Material). There were four main blocks, two with and two without the chinrest. The chinrest was adjustable according to the participants' height. To bisect the lines only the laser pointer tool was used, that was simulated through a Nintendo Wiimote® controller (see Section 3.2.2. Material) and attached to a tripod (height: ~ 120 cm) in order to avoid the effects of natural handshaking. The tripod was located on the side of the hand used to bisect the lines. The simulated laser pointer moved a red dot (diameter: 1 mm) over the monitor to indicate the midpoint of the line. There were four red dot starting position (i.e., up-left, up-right, down-left, down-right).

Procedure

Participants completed the informed consent module (see Appendix 5), the Edinburgh Handedness Inventory (Oldfield, 1971; see Appendix 6), the CLQ, Claustrophobia Questionnaire (Radomsky, Rachman, Thordarson, McIsaac, & Teachman, 2001; see Appendix 7), and a set of Ponzo stimuli (see Appendix 8) centered each one on A4 papers. The CLQ is a self-report measure with 26 items (2 subscales: suffocation and restriction). Each item corresponds to a specific situation (suffocation: e.g., ‘‘using an oxygen mask’’; restriction: e.g., ‘‘in a crowded train stopped between stations’’). Participants rated each item in terms of how anxious they would feel in that situation. Items were rated on a scale of 0–4, with 0 indicating ‘‘not at all anxious’’ and 4 indicating ‘‘extremely anxious’’. Typically, the Ponzo illusion figure is represented by two parallel bars located between two converging lines (Newman & Newman, 1974). The bar near the apex of the context lines looks longer than the bar farther from the apex. In the present version, only one bar was located between the two converging lines, in four different vertical position (up, middle-up, middle-down or down; 3 or 6 cm in length). Participants were requested to bisect the bar with a pencil. There were a total of 48 stimuli randomly presented.

Then, the experimenter instructed orally the participant on the line bisection task and after 10 lines of practice the experiment starts. The participant was standing and moving along the distances during each of the four blocks (two with and two without the chinrest). Participants performed the line bisection task with the simulated laser pointer. On each trial, the participant was asked to indicate the midpoint of a single line,

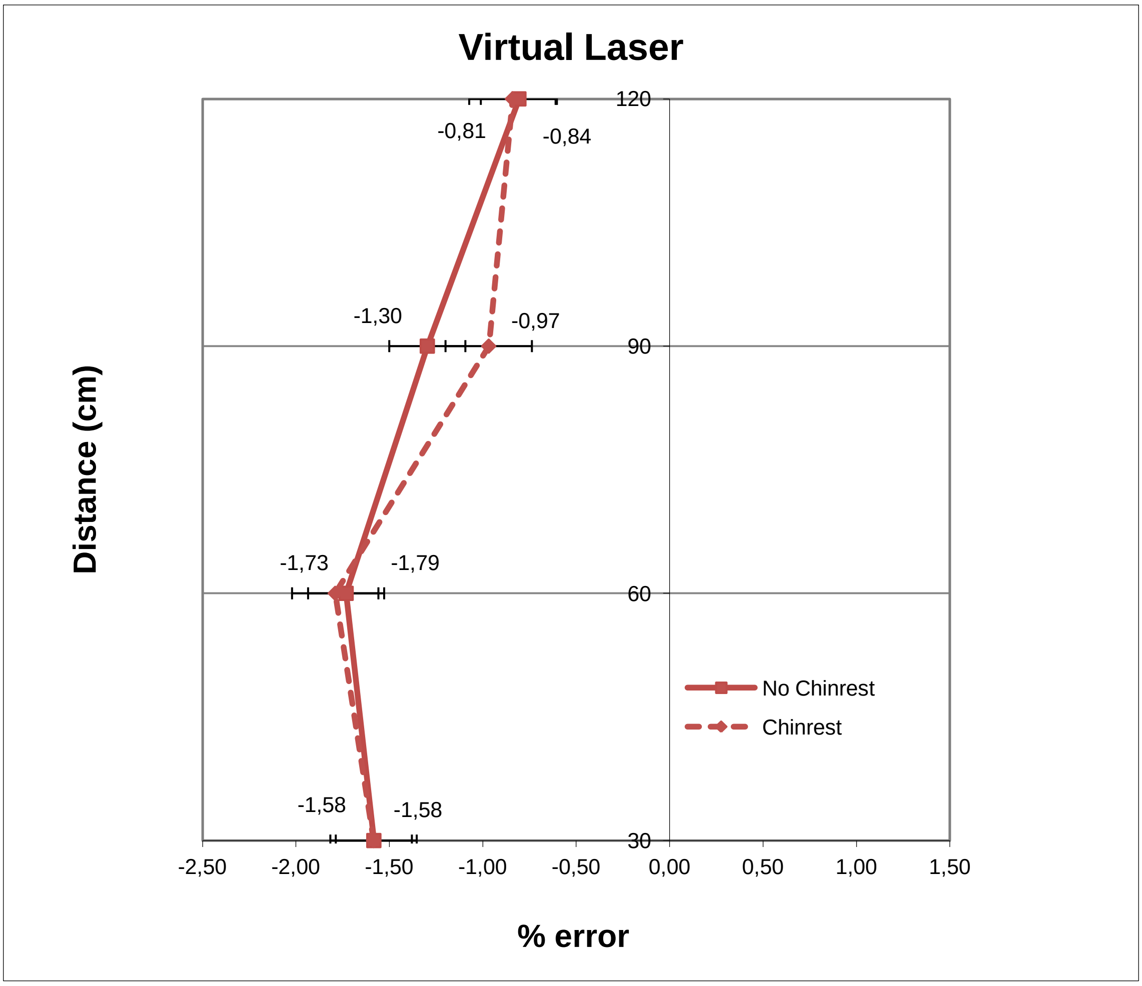


Figure 3.3.5. The graph shows the mean percentage error (X axis) along the distances of line presentation (Y axis) for the chinrest condition (no chinrest vs. chinrest) in the 'virtual laser' condition. Negative values indicate an error on the left of the lines midpoint; positive values indicate an error on the right of the lines midpoint. Error bars represent the standard error ±SE.

that was displayed at one of four viewing distances (i.e., 30, 60, 90, or 120 cm). There was no time limit to perform the task. There were 96 lines for each block for a total of 384 stimuli (i.e., 192 with chinrest and 192 without chinrest). Order of stimuli and order of viewing distances were randomized. Order of blocks (no chinrest vs. chinrest) was counterbalanced among participants. Participants handled and moved the simulated laser pointer with their dominant hand. Whenever the participant indicated the midpoint of the line, he/she took off the hand from the tripod, as a signal for the experimenter to memorize the response on the computer and proceed to the next trial.

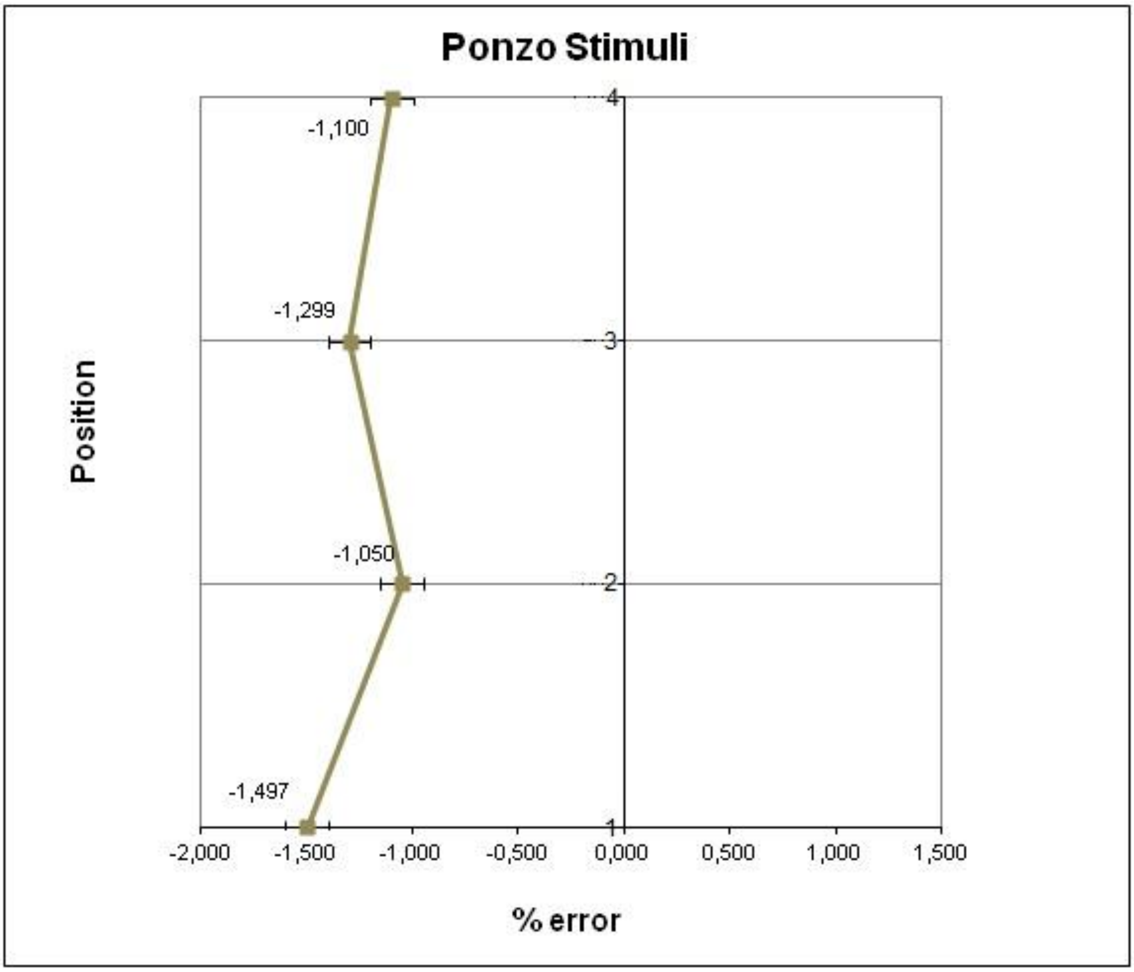


Figure 3.3.6. The graph shows the mean percentage error (X axis) along the four position of presentation (Y axis) for the Ponzo stimuli. Negative values indicate an error on the left of the true centre of the line; positive values indicate an error on the left of the true centre of the line. Error bars represent the standard error ±SE.

Results

Statistical analysis was performed using the Statistical Software Package SPSS 17.0. There were two independent variables (i.e., chinrest [two levels: no chinrest, chinrest] and viewing distance [four levels: 30, 60, 90, 120 cm]). The dependent variable was the mean difference (as error percentage) between the observed midpoint (i.e., the midpoint indicated by the participant) and the true midpoint of the line. Positive values of the dependent variable indicate shifts to the right of the true midpoint, whereas negative values indicate shifts to the left of the true midpoint.

two-way analysis of variance (ANOVA) for repeated measures was conducted with Chinrest (no chinrest vs. chinrest) and Distance (i.e., 60, 30, 90, 120 cm) as factors. No main effect of Chinrest or the interaction between Chinrest and Distance was present. There was a significant main effect of Distance F(3,69) = 14.41, p = 0.000, indicating, in the 'chinrest' condition, a mean bias to the left of the midpoint (M = -1.3 % error) also present in the 'no chinrest' one (M = -1.35 % error). Paired comparisons revealed a significant difference between 60 and 90 cm, in the 'chinrest condition' t(23) = -3.87, p = .001; in the 'no chinrest' condition a significant difference was found between 60 and 90 cm t(23) = -3.96, p = .005, and 90 and 120 cm t(23) = -2.37, p = .026 (see Figure 3.3.5.). No main effect of the laser pointer starting position was present.

Scores on the CLQ were comparable to existing normative data (Radomsky et al., 2001). The mean total score was 36.79 (SD = 16.4), with mean scores of 15.1 (SD = 7.7) for the suffocation subscale (SS) and 21.71 (SD = 9.84) for the restriction subscale (RS). The CLQ total score was implemented to investigate the relation between the size of near space and claustrophobic fear. Results did not show any correlation. For the Ponzo stimuli a mean leftward bias was observed (M = 1.23) with no overall effect of the Position factor. (see Figure 3.3.6.).

3.3.2. Discussion

In Study 1, either when participants perform the line bisection task with or without the chinrest, a shift from the left to the right of the midpoint of the line, when using a laser pointer (i.e., a device that does not expand the peripersonal space), is present only for the 60 vs. 90 cm distances. In contrast, no significant differences are present for the 30 vs. 60 cm distances and for 90 vs. 120 distances. Those results indicate that an abrupt perceptual change, not gradual, occurs when healthy humans perform an attention task within peripersonal and extrapersonal space. The feeling to have the body blocked or free to move has no implication in how the two different spaces are perceived. Moreover, when using a tool (i.e., a device that expands the peripersonal space), the use or not use of the chinrest has no implications too; a constant shift to the left of the midpoint was present in peripersonal space (30 and 60 cm) also observed in the expanded peripersonal space (90 and 120 cm). The tool extends peripersonal space representation to the limit of the tool handled. A clear influence during the experiment could be ascribed to the sitting position, that, undoubtedly constrain the body much more than if the body was in a standing position.

In Study 2, where only the laser pointer tool was implemented, we do not observe a shift from the left to right of the lines midpoint in the transition between near and far space. The left to right shift is present, confirming a modulation on the task by the distance factor, but the bias remains constant on the left. The reason could be ascribed to the tool (the simulated laser pointer) used, that was technically different from that of Study 1. Since the real laser pointer of Study 1 projected directly the red dot onto the white panel over which the lines were presented, in the case of the present study, with the simulated laser pointer, there was no correspondence between the position of the tool (in the specific the Wiimote® over the tripod) and the position of the red dot over the screen. For example, the randomly appearance on the right of the red dot over the screen could be associated with the previous left positioning of the laser pointer. Once a line was bisected the laser pointer was left in the resulting position, immediately after the hand was took off. Although this issue represents a relevant methodological bias that has to be corrected in future works, interestingly did not affect the influence of the distance on the task. On the other hand, another explanation could be possible. The left to right shift with a constant error on the left could also indicate an influence of the task difficulty. Since the error (relative to the true centre of the line) is greater in the near space than in far space, this could indicate that far away the task was too simple, participants were more accurate in the line bisection. During the experiment, looking at the lines over the screen and manipulating the Wiimote® on the tripod far away could represent a more natural and intuitive set of actions, undoubtedly with a grater red dot – Wiimote® position correspondence, than standing close or, at 30 cm, in front of the monitor. Regard the presence or not of the chinrest, we did not find a clear main effect. An abrupt shift was present in the ‘chinrest’ condition, confirmed by the unique significant difference between 60 and 90 cm. On the other hand, in the ‘no chinrest condition we observe a significant difference between 60 and 90 cm and 90 and 120 cm, that could account for a gradual shift in the bisection bias. Contrary to Study 1, participants were standing during the task. This condition could explain the gradual transition observed for the farther distances. No correlation was found between the CLQ score and the size of near space as in Longo et al. (2011). They found a correlation because a gradual shift was present over the distances used. The bisection error rate for each participant along the distances strongly depended on the CLQ single score. For the Ponzo task we observe a clear leftward shift for all the position between the two converging lines, then indicating a normal pseudoneglect not affected by the presence of lateral influencing factor in the line bisection.

In conclusion, both the studies seem to indicate and abrupt shift in the transition from near to far space. On the other hand, the standing position in Study 2 has to be further investigated. Moreover, the experimental paradigm used in Study 2, since it was implemented for the first time, will be modified and adapted the for future investigations.

3.4. EXPERIMENT 4: The influence of the arm position

3.4.1. Introduction

During everyday life, we may encounter situations in which we are forced to avoid, due to defensive instinct or fear of bumping into, objects that invade our peripersonal space. This kind of situation can be either caused intentionally by another person or be the result of serious or trivial incidents. During our automatic interaction with this kind of situation, the current position of the hands and arms affects the speed and success with which an object can be grabbed or moved aside. These types of natural and instant reactions are the result of the integration between visual information and information arising from body parts, in response to a dynamic environment that continually stimulates the spatial attention system (Goodale & Haffenden, 1998). Our hands and our arms act mainly within functional regions of space to achieve our objectives. Following a selection of different degrees of priority from the brain with a specific configuration of the sense organs and effectors, the actual actions are performed. For example, the planning of the possibility of reaching and grasping a visually located object requires an evaluation of the distance between the eye and the object and the distance between the hand and object. The successful execution of this simple action is obtained by carrying out an operation in which the sensorimotor information on the position of the hand and arm in relation to the position of the eyes is integrated (Biguer, Prablanc, & Jeannerod, 1984; Bottini, et al., 2001). These assumptions explain how the role of the arms and hands can influence the mechanisms of spatial attention. The position of the limbs and hands influences the perception of an object or a region of space since more attention is placed in the area close to the hand, thereby increasing the relevance of the adjacent stimuli. Thus, the vision of the hand can change the spatial distribution of attention, influencing the perception of near stimuli. As described in Chapter 1, the space close to the body, peripersonal space, is represented differently from other regions of space, and the presence of the limbs affect the relative salience of specific near space regions (Vallar & Maravita, 2009). An object placed close to the hand or arm may change its functional implications and potential interactions with it. Attention is then further affected when the stimuli are presented in the space near or distant from the hand. The neural mechanism responsible for this difference is partly due to existence of bimodal neurons that integrate visual and tactile processing in the same time. The approach of the hand to the object and the resulting active manipulation arise from simultaneously visual and tactile representations (Graziano & Gross, 1994; Graziano & Gross, 1995; Graziano et al., 1994). This fact suggests that visuotactile bimodal neurons are involved in reaching and grasping actions, and also in avoidance behaviors potentially dangerous stimuli (Cooke & Graziano, 2004). Several studies with monkeys have identified populations of neurons that respond both to tactile stimuli on the hand is so close at hand to visual stimuli presented in peripersonal space (Fogassi, et al., 1992; Fogassi et al., 1996; Gentilucci, Fogassi, Luppino, Matelli, Camarda, & Rizzolatti, 1988; Graziano & Gross, 1993). Often, these neurons are activated when stimuli are presented close to a specific body part, such as the hand, coding the space according to a specific coordinate system on the part of the body (Grefkes & Fink, 2005). That is, these populations of neurons are differently activated regardless of when the stimulus is perceived relative to the hand or in relation to the surrounding space. In addition, when the stimuli are presented away from the body, in extrapersonal space, the response of the bimodal neurons gradually decreases. However, if a tool is used, such as a rake, to interact in extrapersonal space, the same neurons are activated, showing how the instrument becomes an extension of the arm and how an expansion of peripersonal space occurs to include the extrapersonal one (Iriki et al., 1996). Stimuli and objects located around the hand could gain relevance from the attentional cues given intrinsically by the sight of the hand. The visual environment provides predictive evidences of upcoming events or situations. Thus, the spatially distributed attention could be affected by the functional capacity connected with the perception of the hand. Moreover, hand position can influence the expectation that an event will occur in a given region of space. Consequently, this event expectation, by increasing the degree of relevance of a given region of space, reduces the attentional capacity for the regions of space where certain events are not expected. In humans the existence of bimodal neurons has been demonstrated through studies of cross-modal extinction in patients with lesions of the right parietal lobe (di Pellegrino et al., 1997; Farnè & Ladavas, 2000; Farnè et al., 2000; Ladavas, 2002; Ladavas et al., 1998; Ladavas, Zeloni, & Farnè, 1998). Recent studies on healthy adults have shown that the different limbs' positioning may improve or otherwise modify the perceptual and attentional processing of certain regions of space (Reed, Grubb, & Steele, 2006; Grubb & Reed, 2002). It has been suggested that limbs positioning during visuospatial attention tasks can affect the attentional system in terms of spatial prioritization and shifting of attention. A covert orienting task was used to test this hypothesis (Reed et al., 2006). The task required the subject to respond as quickly as possible to stimuli that appeared to the left or right of a fixed point after they were anticipated by a cue stimulus in the same or opposite position. Independently of the apparent cue position, reaction times were found to be faster when the hand was located close to the target stimulus compared with when the hand was in a neutral position. Moreover, when the hand was replaced by another object this facilitation did not occur showing that the hand was responsible for this phenomenon. The effect appears to be multimodal because it also occurred after the removal of visual or proprioceptive input. In summary, the space near the hand was attentionally prioritized. The existence of bimodal neurons may explain the reason behind this phenomenon, since the perception of target stimuli could be amplified by the increased visual- and tactile-dependent activity of these neurons. Bimodal neurons properties suggest that, in addition to occipital visual neurons typically activated to perform visuospatial tasks, the activation in the frontal and parietal areas in responding to tactile or visual stimuli could be involved in the detection of stimuli close to a part of the body (Graziano & Gross, 1993; Graziano et al. 1994).

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

3.4.2. Method

Participants

Thirty participants with normal or corrected-to-normal vision took part in the experiment (15 males; M = 22.83 years, S.D. = ±6.65 years, range = 20–29 years). All participants gave their informed consent to participate in the study. Results from the Edinburgh Handedness Inventory (Oldfield, 1971), showed a majority of right-handed participants (M = 56.68 , S.D. = ±43.43).

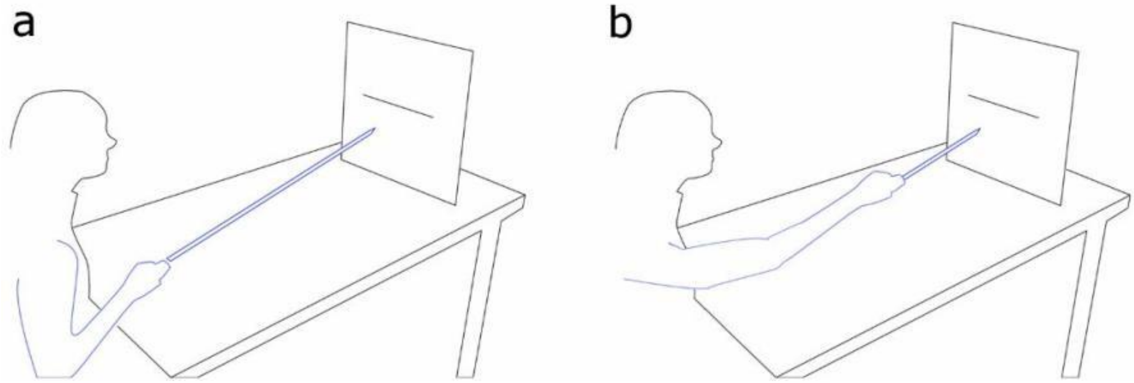


Figure 3.4.1. Representation of the two experimental main blocks: a) arm stretched, b) arm bent.

Materials

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

Procedure

After the completion of the informed consent module and the Edinburgh Handedness Inventory (Oldfield, 1971), participants were invited to seat in front of a table (length: 62 cm; width: 100 cm) and to position their head in a chinrest, in order to guarantee that the distance between the participant's eyes and the displayed line was maintained constant. There were two main blocks: in one block participants performed line bisection using the wood sticks with the arm bent (see Figure 3.4.1.a); in the second block participants performed line bisection using the wood sticks with the arm stretched (see Figure 3.4.1.b). On each trial, the participant was asked to indicate the midpoint of a single line, that was displayed at one of four viewing distances (i.e., 30, 60, 90, or 120 cm). There was no time limit to perform the task. Before the beginning of the experiment, there was a practice block (i.e., 5 trials using the stick and 5 trials using the laser pointer). Each experimental block comprised 40 trials for a total of 80 trials. Order of stimuli and order of viewing distances were randomized. Order of blocks (bent vs. stretched) was counterbalanced among participants. On half the trials participants performed bisection starting from the right endpoint of the line, while on the other half participants performed bisection starting from the left endpoint of the line. Participants handled and moved the stick with their dominant hand. Whenever the participant indicated the midpoint of the line, the experimenter marked it on the sheet and the next trial started.

3.4.3. Results

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

A two-way analysis of variance (ANOVA) for repeated measures was conducted with Arm (bent vs. stretched) and Distance (i.e., 60, 30, 90, 120 cm) as factors. There was a significant main effect of Arm F(1,26) = 16.25, p = 0.000, indicating a mean bias to the left of the midpoint in the 'bent' condition (M = -0.555 % error) and in the 'stretched' condition (M = -0.172 % error). No main effect of Distance was present. The interaction Device by Distance was not significant. Paired comparisons revealed a significant difference between 'bent' vs. 'stretched' conditions at 30 cm, t(29) = -2.63, p = .013, and at 120 cm, t(17) = -2.58, p = .015 (see Figure 3.4.2).

3.4.4. Discussion

Results show an influence of arm position in the modulation of space perception when performing a visuospatial attention task. The tool (stick) extends peripersonal space representation to the limit of the tool handled, both when the arm is bent and when the arm is stretched, with a constant bias to the left of the midpoint of the line along all the distances as reported in previous studies (Gamberini et al., 2008; Longo & Lourenco, 2006). When the arm is stretched, we assist to a greater leftward bias in the very near space (30 cm) and in the very far space (120 cm). Although a significant difference was not find for all the distances investigated but only at 30 cm (very near space) and 120 cm, the study partially confirms the initial hypothesis.

The two distance were the extreme ones regards this experimental procedure, and represent the exact opposite position in the stretched condition. At 30 cm the arm was

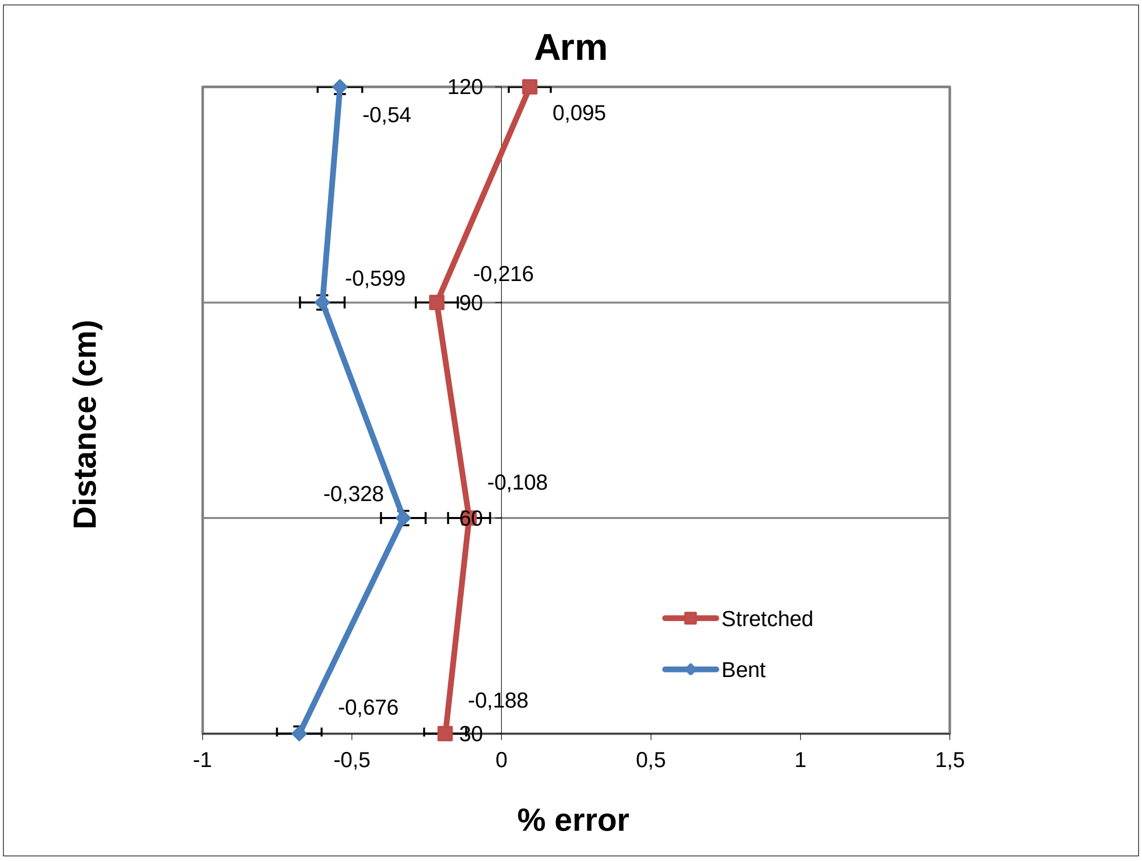


Figure 3.4.2. The graph shows the mean percentage error (X axis) along the distances of line presentation (Y axis) for the arm condition (i.e., stretched vs. bent) in the 'stick' condition. Negative values indicate an error on the left of the lines midpoint; positive values indicate an error on the right of the lines midpoint. Error bars represent the standard error ±SE.

not stretched but only not leaned on the participant' side; on the other hand, at 120 cm the arm was totally stretched. It is possible that arm position in the middle distances (60 and 90 cm) was not sufficiently perceived differently during the experiment. Evidences of the arm position influence in the perception of visual stimuli comes from crossmodal extinction researches with brain damaged patients. If peripersonal space is processed in terms of visuotactile representation and if an injury to the right hemisphere affect this representation, then peripersonal visual stimuli in the right hemi-space should interfere in the detection of tactile stimuli on the left hemi-space. Di Pellegrino et al. (1997) found a complete extinction of simultaneous left tactile stimulation following visual stimulation in the same side. When the arm was positioned behind the patients' back or when visual stimuli were presented far from the right hand, the recognition of tactile stimulation significantly increased. Moreover, with crossed arms, visual stimulation near the right hand caused the extinction of left hand tactile stimuli (Mattingley et al., 1997). Visuotactile spatial interactions are centered on the hand and are relative to the hand position changes in space, confirming that visuotactile peripersonal space is represented in a coordinate system centered on body parts. Also in the studies on individual neurons in the monkeys' premotor and posterior parietal cortex there were evidences of such peripersonal space representation (Graziano & Gross, 1995; Graziano et al., 1997b). Research with crossmodal extinction other important aspects. Visual stimuli presented in the right side near the right and visible elicited a greater extinction crossmodal than those presented far from the hand (Ladavas et al., 2000).

Moreover, the stimulation in the same position, but with the hand hidden from view, causes the same amount of extinction when the stimuli were presented out of the right hand (Mattingley et al., 1997). This finding is consistent with that of Halligan et al. (1996) who studied a patient who did not recognize normal tactile stimulation on her left arm, the vision of his arm touched by the experimenter, however, induced a tactile sensation (Haggard et al. 2003; Rorden et al., 1999). Similarly, di Pellegrino and Frassinetti (2000) studied a patient with right temporal-parietal lesions, in which the perception of a visual stimulus was facilitated when the left hand of the patient was positioned close to the screen where the stimulus was projected. Finally, the combination of tactile stimulation of a part of the body and the visual stimulation near that part of the body can improve both visual and tactile perception deficits.

3.5. EXPERIMENT 5: An investigation on virtual peripersonal space

3.5.1. Introduction

Previous studies has have implemented different tools in real environments in order to try to expand peripersonal space, as it is believed that the different ways in which those tools are manipulated (to touch or to move the objects) leads to the phenomenon of peripersonal space expansion. A device, like a laser pointer, that only indicates a spatial region doesn’t have this ability. It seems that it is the ability to actively manipulate the space which is the essential feature to induce peripersonal space expansion. But, as observed by Garrison and Ellard (2009), it is also the visual continuity from the hand to the region of space manipulated a fundamental feature to modulate peripersonal space expansion. To test this hypothesis we implement a virtual line bisection task in which the tools, virtual wooden sticks, used to bisect the lines can be either totally visible or partially visible (only the end of the wooden stick). If the visual continuity represents the essential feature for expanding peripersonal space, we expect a bias to the left of the midpoint for all the distances using the totally visible tool, with a shift from the left to right of the midpoint in the transition from peripersonal to extrapersonal space when using the partially visible tool. If it is the ability to actively manipulate the space which is the essential feature to induce peripersonal space expansion, then we expect a bias to the left of the midpoint for all the distances, using both tools.

3.5.2. Method

Participants

24 students of the University of Padua, Department of Psychology, participated to the experiment (12 males; M = 23.2 years, S. D. = ±3.2 years, range = 20–30 years).

All participants were right handed, as reported by the Edinburg Handedness Inventory, with normal or corrected to normal vision. 10 participants were short-sighted while 6 were astigmatic.

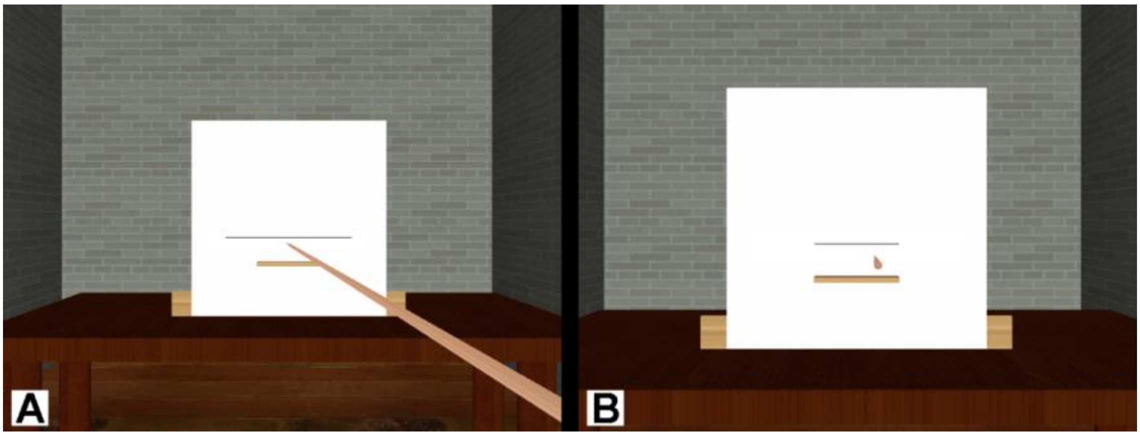


Figure 3.5.1. The virtual environment. The participants' point of view of the virtual environment is presented: a) in virtual extrapersonal space with the totally visible virtual stick; b) in virtual peripersonal space with the partially visible virtual stick.

Materials

The virtual environment was created with 3DS Max 8.0 software, while for the interaction with it Virtools 3.5 was used. The virtual environment was a 3x5x2 m room with a 180x60 cm wood table on the centre and a chair in front of it. On the wood table a 50x50 cm vertical white panel was positioned upon which lines were presented. The environment could be explored only moving and rotating at 360° the head. The shift of the point of view along the distances was computerized. There were 4 different lines presentation distances: 30, 60 cm, peripersonal space, and 90, 120 cm, extrapersonal space. There were 5 different in length lines: 2, 4, 8, 16, 32 cm. Line bisection was made possible through the manipulation of 2 different tools: the first tool was a virtual wood stick whose entire shape (totally visible) could be seen (see Figure 3.5.1.a); the second tool was a virtual wood stick whose only the upper extremity (partially visible) could be seen (see Figure 3.5.1.b). Each virtual wood sticks length was modified automatically by the software according to the line distance presentation. The manipulation of the tools was made possible through the use of a Wiimote® controller, a wireless controller able to detect hand movements, synchronizing them with the virtual wood sticks movements. The signal emitted by the controller was detected by an infrared Sensor Bar positioned in front of the controller at 50 cm, and then transferred to the computer via Bluetooth. Virtual environment was visualized by participants through a Virtual V8 Head Mounted Display (HMD), 800x600 resolution, upon which an Intersense tracker was mounted for the head movements detection.

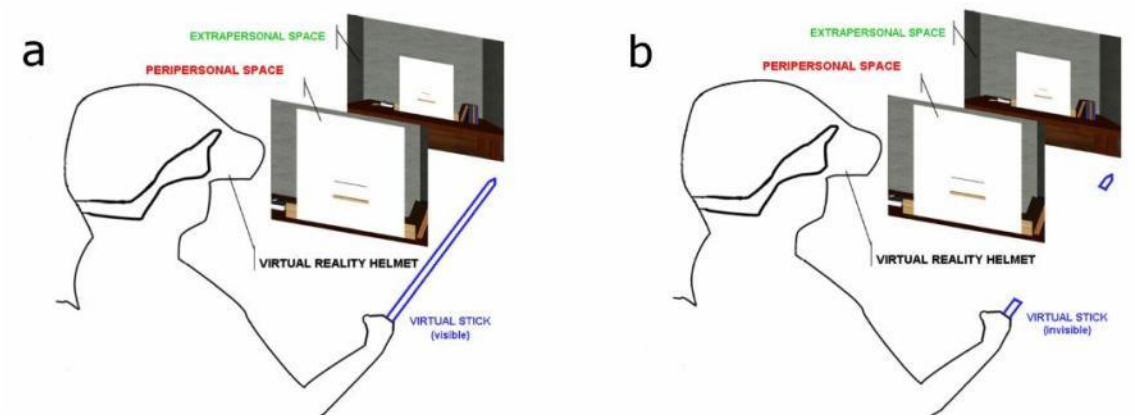


Figure 3.5.2. Representation of the two experimental main blocks: a) manipulating the totally visible virtual stick, b) manipulating the partially visible virtual stick.

Procedure

Once in the experiment room, participants were invited to sit in front of a monitor. After having compiled the informed consent (see Appendix 1A – 1B) and the Edinburgh Handedness Inventory (Oldfield, 1971; see Appendix 2), participants read the instruction for the experiment (see Appendix 9). Instructions were also repeated orally by the experimenter, making sure the experiment was clearly understood. The participants' wrist was blocked on the armchair support with an elastic rubber stripe, in order to prevent excessive arm movements and to ensure that the Wiimote® controller was guided mainly by the wrist movement. A first training session with 8 lines presented in front of the monitor was performed. The same training was repeated after the participants having worn the HMD. Then, the experiment started and the experimenter sat on the right side of the participant watching the task on the monitor.

Participants could bisect the lines moving the virtual wood stick toward the lines centre, through the manipulation of the Wiimote® controller (see Figure 3.5.2. a, b). Once they were sure of the position selected they pressed with the thumb the Wiimote® controller A button to save the response (with a precision of 0,25 mm). After few seconds the next line was presented and the virtual wood stick was automatically re-located to the initial position. This procedure was repeated until the end of the experiment. Each participant completed 2 main blocks of 40 lines, one with the 'totally visible' tool and one with the 'partially visible' tool. Each of the 5 lines was presented one time for all the 4 distances of presentation, for a total of 20 observations. This subset of lines was repeated two times for each block varying the starting position of the tools that could be on the right or left lower portion of the white panel. Order of distances and lines presentation was randomized. Order of tools and starting position was counterbalanced across participants. Each participant performed each experimental condition, for a completely within subject experimental design. Independent variables are represented by the tool used (2 levels, 'totally visible' and 'partially visible'), and by the distances of presentation (4 levels: 30, 60 cm, peripersonal space, and 90, 120 cm extrapersonal space). The dependent variable is represented by the position indicated by the participants as the centre for each line. It is calculated subtracting the numeric value of the position indicated and the numeric value of the true centre of the lines. Negative values represent a leftward error compared to the line centre, while positive values represents a rightward error.

3.5.3. Results

A two-way analysis of variance (ANOVA) for repeated measures was conducted with Stick (invisible vs. visible) and Distance (i.e., 60, 30, 90, 120 cm) as factors. The main effect for Stick as well as for Distance was not significant. There were a mean bias to the left of the midpoint in the 'invisible' condition (M = -3.322 % error) and in the 'visible' condition (M = -4.816 % error; see Figure 3.5.3.).

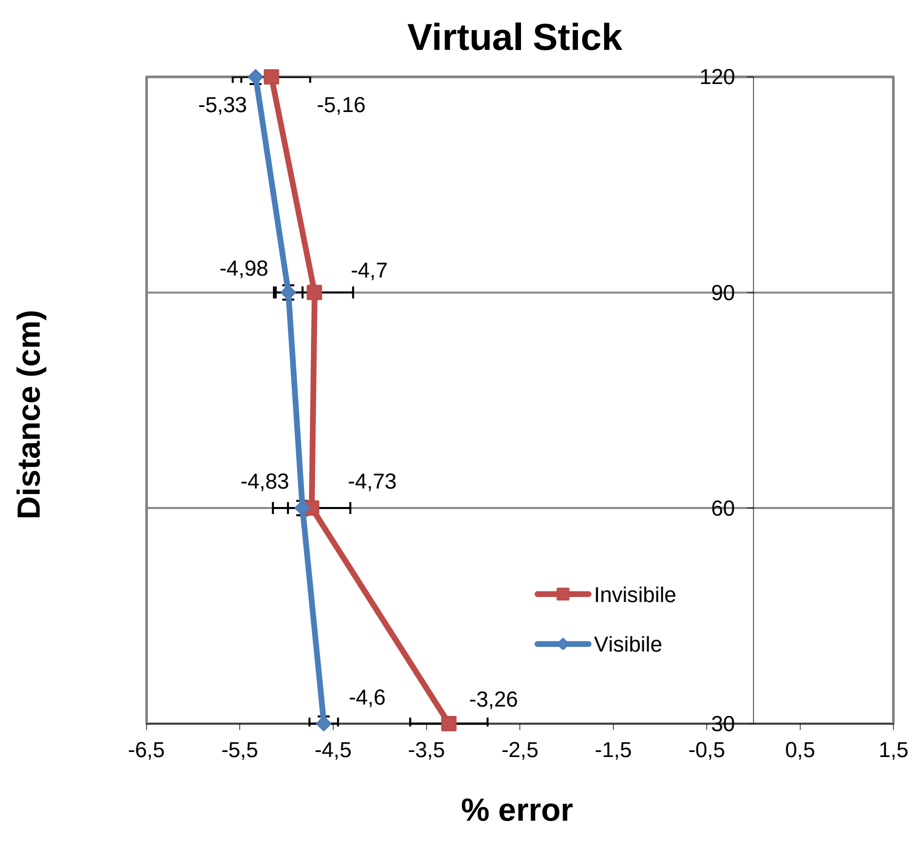


Figure 3.5.3. The graph shows the mean percentage error (X axis) along the distances of line presentation (Y axis) for the virtual stick condition (i.e., invisible vs. visible). Negative values indicate an error on the left of the lines midpoint; positive values indicate an error on the right of the lines midpoint. Error bars represent the standard error ±SE.

3.5.4. Discussion

Results show that having or not a visual continuity from the hand to the region of space manipulated leads to an expansion of peripersonal space as demonstrated by a constant bias to the left of the midpoint of line. In this case, we can conclude that only the active portion of the object manipulated in the space is responsible of the expansion of peripersonal space. The results reported allow to formulate two important observations.

First, the presence of a constant left bias in the bisection error with the entirely visible tool, indicates an extension of peripersonal space in agreement with previous studies of Longo and Lourenco (2006) and Gamberini et al. (2008). In addition, the same bias pattern found with the partially visible tool, revealed by the similar left errors means combined with the absence of significant differences between the tools performance, allows to advance the hypothesis about what is the fundamental aspect of the tool-use for the peripersonal space expansion. Since the partially visible tool offers the same possibilities of interaction with the environment as for the entirely visible tool, but lacks of the visual connection with the hand, it is reasonable to assume that the latter factor plays a minor role in the peripersonal space expansion. Thus, the findings show a convergence with the previously analyzed studies in animals and patients suffering from neglect and give support to the recent line of research that investigates the peripersonal space plasticity (Iriki et al., 1996a; Berti & Frassinetti, 2000; Maravita et al., 2002).

In addition, the use of a VE draws a parallel between the subjects' performance in real and virtual scenarios, testifying the validity of this methodological approach. Several researches provide the points of view about this peripersonal space expansion, suggesting that only the active side of the tool manipulated in the extrapersonal space is responsible for the same performance obtained in the peripersonal one (Holmes et al., 2007; Holmes, Spence, & Calvert, 2007; Collins et al., 2008; Yue et al., 2009). The expansion of the peripersonal space following the tool-use seems now a consolidated figure (Berti & Frassinetti, 2000; Longo & Lourenco, 2006; Gamberini et al., 2008; Garrison & Ellard, 2009). Further research is however necessary to clarify this phenomenon.

Holmes et al. (2004; 2007) have proposed such a different interpretation of the results discussed. According to these authors only the portion of the instrument needed to perform the tasks (usually the distal end) could be incorporated into peripersonal space. In their experiment, the visuotactile interactions measured at the handle, the middle and the end of a stick differed depending on the task, that could be done with one of these three different portions of the tool. Both interpretations are in agreement with the experiments discussed and further investigations are required to definitely validate the hypothesis of peripersonal space expansion induced by the entire instrument.

Also, these results could be also important to determine whether the transition from peripersonal space to extrapersonal space happen gradually or rather abruptly. In any case, this step seems to be systematically related to the length of the upper limbs. Longo and Lourenco (2007) in a bisection task by means of a laser pointer found a larger peripersonal space for participants with greater arms-length.

Finally one may wonder whether the peripersonal space plasticity is symmetric. That is, if the ability to reach longer distances through the use of an instrument can expand peripersonal space, it is also possible that preventing or making it still more difficult for individuals to act within the range of extension could reduce limbs representation. Recent studies, both with monkeys and humans, seem to indicate that symmetry in the plasticity of the peripersonal space (Caggiano et al., 2009; Longo & Lourenco, 2009). For example, Longo and Lourenco (2009) have shown that the usual right error shift, detected using a laser pointer in a line bisection task, takes place at shorter distances (within peripersonal space) if weights are applied to the participants' wrists, making the task more challenging.

Such peripersonal space plasticity of revealed also by the present experiment, points to the importance of the concept of affordances of Gibson, that the action opportunities dynamically provided by the surrounding environment. This concept seems to be deeply rooted in the human brain, and the plasticity of peripersonal space represents a clear demonstration.

CHAPTER 4

4.1. GENERAL DISCUSSION

The present work is part of that field of research that deals with investigating the multisensory representation of peripersonal space and extrapersonal space. Moreover this representation is influenced and modulated when an individual (human or animal) manipulates a tool. The research presented has included visuospatial attention experiments conducted in real environments and in virtual environments, the latter trying to simulate the same real environment conditions. Few studies in this area have set up experiments in a real environment and have then replicated using virtual reality. Increasingly, scientific research has shown that VR is an important resource in a variety of fields, from medicine to engineering and psychology, hence the interest to assess whether the results obtained in a virtual environment can be compared or even overlapped with that obtained in a real environment. Different topics were investigated and will be separately analyzed and discussed. On the other hand, a common thread connected together the different studies presented, that is the adoption of the same experimental paradigm: the line bisection task. The task was administered to normal healthy volunteers. Generally, when participants are requested to bisect lines in their peripersonal space, a bias on the left of the lines midpoint is observed, an asymmetry in spatial attention known as pseudoneglect (Bowers & Heilman, 1980; Jewell & McCourt, 2000). On the other hand, when line are bisected in extrapersonal space with a common laser pointer, the bias shifts to the right of the lines midpoint. Furthermore, when line are bisected manipulating a wooden stick the bias remains constant to the left of the lines midpoint both in peripersonal and extrapersonal space, showing that the use of a tool effectively represent an extension of peripersonal space into extrapersonal space. Although several studies have found no effect of distance in pseudoneglect (Cowey, Small, & Ellis, 1999; Weiss et al., 2000) or have found only inconsistent effects (Cowey et al., 1994; Wilkinson & Halligan, 2003), other recent studies reported a constant error to the right of the line in the transition from space to space near the far (Bjoermont et al., 2002; McCourt & Garlinghouse, 2000, Varnava et al., 2002; Longo & Lourenco, 2006; Lourenco et al., 2011).

The reason why the distance modulates line bisection performance is due to the fact that the activation of both cerebral hemispheres, particularly the regions in and around the intraparietal sulcus, interfere contralaterally with the attentional system (Corbetta, Shulman, Miezin, & Petersen, 1995), a tendency stronger in the left hemisphere than in the right one (Kinsbourne, 1987; Ladavas, Del Pesce, & Provinciali, 1989). Near space processing activates similar areas, particularly in the right parietal cortex (Bjoertomt et al., 2002, Fink et al., 2000). Therefore, the presentation of stimuli in near space may activate the right hemisphere parietal mechanisms for directed attention, shifting attention to the left and leading to pseudoneglect. In this way, the rightward shift in line bisection tasks indicates the degree of activation of near space representations of the right posterior parietal cortex. When using a laser pointer, representations of near space gradually become less active when the subject begins to move away from the stimulus, leading to a gradual shift from left to right, since, basically, the tendency of the left hemisphere orientation (right) is greater than the right hemisphere (left). When a tool is used, on the contrary, the representations are more activated at any distance, and a constant shift to the left is observed. Tool-uses represents a class of complex sensorimotor behaviors that probably cannot be attributed to the operation of a particular brain region (Johnson-Frey, 2004). Visuotactile bimodal neurons showing responses with overlapping receptive fields were discovered in the putamen, premotor cortex, intraparietal sulcus and in the superior colliculus. These cortical and sub-cortical areas play an important role in generating visuotactile behavioral interactions. These behavioral interactions could be traced to contribute neural plasticity which is quick, task-dependent and transient. This can be put in a different context from other forms of plasticity, such as the invasion of deafferent areas of the somatosensory cortex by afferent input in the nearby regions (Kaas, 1991). Research on the effects of the use of plastic instruments, particularly at a neural level, is still at a speculative stage and are premature for a possible neural mechanism underlying this plastic behavior (Schaefer, Rothemund, Rothemund, & Rotte, 2004; Johnson-Frey, 2004).

The first study aimed at verify the limit distance to which peripersonal space can be expanded when manipulating a tool. Moreover, using very long distances, we wanted to understand how stimuli presented in extrapersonal space modulate visuospatial attention . Thus, we were able to report that, manipulating a tool, peripersonal space can be expanded up to a distance of 240 cm. When manipulating a wooden stick, the line bisection performance revealed a bias on the left of the midpoint both in peripersonal space and extrapersonal space (240 cm), thereby extending peripersonal space representation to the limit of the tool handled. Neppi-Mòdona et al., (2007), using a longer distance (300 cm), were the only group of research that find similar results and observing the same tendency. On the other hand, when using a common laser pointer, participants’ performance to the line bisection task differs in the transition from peripersonal to extrapersonal space (480 cm). As for the tool manipulated, in near space a bias on the left of the lines midpoint was observed. On the contrary, a bias on the right of the lines midpoint was observed when acting in far space. Therefore, these findings confirm the results of previous studies with normal adults (Bjoermont et al., 2002; McCourt & Garlinghouse, 2000, Varnava et al., 2002; Longo & Lourenco, 2006; Lourenco et al., 2011) and neuropsychological patients (Berti & Frassinetti, 2000). Furthermore, the bias on the right of the lines midpoint is constant for the three extrapersonal space distances, excluding the possibility of a gradual shift as a function of the incrementing distance. This result is relevant for the discussion and analysis of the third study. Future studies will try to extend the distance within which participants can manipulate tools, designing and developing special and usable tool with different materials, as in the research of Neppi-Mòdona et al. (2007). Moreover, the same experiment will be simulated in VR, as, unlike for the real setting, it allows the potential investigation of very long distances and different in shape tools.

The second experiment had two main objectives: first, to investigate which brain areas are responsible in the different peripersonal and extrapersonal space processing; second, to find a valid solution for a correct signal registration with the fNIRS brain imaging technique when used during a VR experiment. The first objective was partially reached. The simulation through VR of nearly the same Weiss et al. (2000) experimental conditions, has shown an activation of the parietal and occipital lobes both when the lines were bisected in near and far space. Instead, Weiss et al. (2000) found activation of the parietal lobe in near space and parieto-occipital lobe in far space. The reasons for that difference could be of various nature. The neural dissociation between peripersonal and extrapersonal space is clearly demonstrated (Bjoermont et al., 2002; Weiss, Marshall, Zilles, & Fink, 2003; Quinlan & Culham, 2007). In the present study, the areas found to be active are, indeed, implicated in visuomotor tasks, as for the virtual line bisection task administered to participant in which they manually had to indicate the lines midpoint with the Wiimote®/laser pointer. Parietal activation during attention, space perception and visuospatial tasks was observed in various recent and past experiments, where the same experimental paradigm was used (Fink et al., 2000; Fink et al., 2001; Fink et al., 2002; Waberski et al., 2008; Thiel et al., 2004; Peers et al., 2005); in particular, a right parietal lobe predominance was found (Fink et al., 2000; Fink et al., 2001; Fink et al., 2002; Hurwitz et al., 2011; Foxe et al., 2003). The inability to find a dissociation in neural activation for the two distances presented, could be ascribed to the virtual component of the task. In the present study, a modified HMD was used in order to have as much as possible the same conditions of the study by Gamberini et al. (2008). Behavioral results, although not similar to that of Gamberini et al. (2008) experiment, reveal, indeed, a different processing of the two virtual space presented; the difference can be ascribed to the small number of participants. Also, the neuroimaging technique used, the fNIRS, could be still premature in the investigation of VR space processing. On the other hand, the second main objective was reached. Being an exploratory research on the possibility to implement the fNIRS brain imaging technique in the study of immersive VR experience, the ability to acquire a reliable and valid cerebral activation, observed in the parietal and occipital lobes, represents a good starting point. Further investigation is needed to confirm the validity and reliability of the present results. The use of fNIRS has resulted in considerable benefits for cognitive neuroscience studies. There is still little evidence that demonstrate the implementation of VR visuospatial tasks during cerebral registration (Baumgartner et al., 2006; Hribar et al., 2009; Maguire et al., 1998; Jeong et al. 2006). Furthermore, no fNIRS and VR studies are yet reported. The several advantages the fNIRS has in respect to positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) can allow the investigation of classic neuropsychological disorders in a way not previously possible. The implementation of fNIRS in the analysis of the cerebral functions that subtend VR experiences represent another important goal. The exploration and the in-depth examination of different methodologies and solutions for VR applications will be the most important topic of future studies.

The third study analyzed how the perceptual transition from near to far space occurs, in the specific if in a gradual or abrupt way. In most studies with neuropsychological patients, the stimuli were presented only at two different distances, not allowing to formulate any hypotheses about the transition between near and far space. Two exceptions are the studies by Berti et al. (2002) and Cowey et al. (1999). The first researchers have used three different distances, identifying a more severe neglect at 1.5 and 3 m (far space) rather than within the area of arm reach (0.5 m). There were no significant differences in performance between 1, 5 and 3 m, supporting, therefore, an abrupt transition between the near and far space. Instead Cowey et al. (1999) examined five patients with more severe neglect in near space rather than in that far, at six different distances, not experiencing an abrupt transition within the arm reaching distance. This difference may be due to the fact that the extension of the receptive fields that code peripersonal space varies widely. Fogassi et al. (1996), for example, found that the extent of visual receptive fields varies from 5 to 35 cm compared to the tactile receptive fields. However, these visual receptive fields remain within the area of arm reaching, as evidenced in a study conducted on monkeys (Fogassi & Gallese, 2004). So, although there seems to be a graduality in the neural response, for the objects processed within the reaching space, however, this may terminate abruptly at the edge of this space. Longo and Lourenco (2006; 2011) explain the gradual shift in the line bisection task performance, based on the freedom movement of the arms and body that can influence the actions of the subject at far distances, making these actions more effective. In fact, the abrupt transition between near and far space observed in several neuropsychological experiments, could be due to the fact that the monkeys used as experimental subjects, were locked in their seats during the experimental stage and therefore unable to act beyond the arm reaching distance, despite the effort to extend beyond (Fogassi et al. 1996; Rizzolatti et al., 1981). To test this hypothesis, in the first part of Study 3, participants were requested to bisect line in a seating position with or without the implementation of a chinrest. In the second part of Study 3, participants were requested to bisect line in a standing position with or without the implementation of a chinrest. The first part of Study 3 clearly confirm the abovementioned tendency; participants were seated and the only significant difference was observed between 60 and 90 cm, confirming an abrupt shift. The second part of revealed no gradual difference within the two peripersonal space distances. Instead, a gradual shift from left to right in the transition between 60 and 90 cm, and 90 and 120 cm was observed, while participants were standing during the task. It seem that the presence, feeling to have the body blocked, or absence, feeling to have the body free to move, of the chinrest has no influence in the task performance. Instead, the position of the body, seating or standing, modulated the line bisection performance. According to these findings, it can be true also that the intensity of peripersonal space representations may be inversely proportional to the level of effort required to act, and rather than being encoded as the space of arm reaching, near space could be graduated according to the length of the arm (Longo & Lourenco, 2007).

The fourth study has explored how limbs positioning in the space can affect human representation of the surrounding space and of the space beyond the arm reaching distance. The hypothesis tested aimed at verify if having the arm bent or stretched during an attention task, has implications on how the perceived peripersonal and extrapersonal space are modulated. In the specific, the experiment explored the influence of a tool when manipulated with the arm stretched or bent it the perception of peripersonal and extrapersonal space. The 'stretched arm' condition would lead to a greater attention shift that the 'bent arm'. Results show an influence of arm position in the modulation of space perception when performing a visuospatial attention task. The tool (stick) extends peripersonal space representation to the limit of the tool handled, both when the arm was bent and when the arm was stretched, with a constant bias to the left of the midpoint of the line along all the distances as reported in previous studies (Gamberini et al., 2008; Longo & Lourenco, 2006). Moreover, in the 'stretched arm' condition, a greater leftward bias in the very near space (30 cm) and in the very far space (120 cm) was observed. Although a significant difference was not find for all the distances investigated but only at 30 cm (very near space) and 120 cm, the study partially confirms the initial hypothesis. These results demonstrate that a simple relationship between the behavior effects and the properties of individual neurons recorded in the experiment with anesthetized animals may not be possible (Iriki et al., 1996a). Behavioral influences in attention, response preparation and stimulus-response compatibility, for instance, could be of particular importance to the literature on the consequences of visuotactile tool-use (Creem & Proffitt, 2001; Handy, Grafton, Shroff, Ketay, & Gazzaniga, 2003; Iriki et al., 1996a, 1996b; Riggio, Gawryszewski, & Umiltà, 1986). Automatic processing and preferential multisensory stimuli that come from different regions of space when using tools, could help the perceptual processing by the brain of the stimuli connected to the instrument (Handy et al, 2003), facilitating the selection of appropriate actions, and, in particular, the hand-eye-tool movement coordination required for the proper use of objects (Creem & Proffitt, 2001; Riddoch, Humphreys, Edwards, Baker, & Wilson, 2003; Tucker & Ellis, 1998). Regarding the perception and movement of the limbs, several experiments have been conducted (Clark & Horch, 1986; Jones & Hunter, 1992) in locating the position of a target by pointing the finger, the speed direction and range of motion, as well as the position of the target, are all factors that may affect the accuracy of the response. Kinesthetic space have been reported in several psychophysical phenomena, such as the perception of distance and anisotropic orientation, the apparent curvature of straight lines and the measurement of non-Euclidean distances between two points (Fasse, Kay, & Hogan, 1990; Hogan, Kay, Fasse, & Mussa-Vivaldi, 1990; Loomis & Lederman, 1986). Future research will allow to understand how behavioral findings derived from psychological studies of human participants, can be linked to neuropsychological neural recordings in premotor and posterior parietal cortex of macaque monkeys.

The final study has highlighted an important topic regards the understanding of the cognitive mechanism involved in the expansion of peripersonal space when a tool is manipulated. Specifically, the results do not seem to be consistent with the assumption that peripersonal space extends completely within the area, or region of space, occupied by a tool. The similarity of results removes any doubt about the expected and hypothesized differences attributable to the different cognitive functions of the two instruments analyzed. Both for the completely visible and partially visible tools, the bias to the right of the line midpoint is constant. Moreover, this result confirms that tool-use remaps extrapersonal space to include the peripersonal one, in real environments (Holmes et al., 2007; Holmes, Spence, & Calvert, 2007; Collins et al., 2008; Yue et al., 2009) and virtual ones (Gamberini et al., 2008; Garrison & Ellard, 2009), excluding the visible part of the tool as responsible for this phenomenon. On equal terms, both visuotactile and motor, having or not a visual continuity, influences in a similar way the performance to the line bisection task. The active manipulation of the instrument in a given region of space, and consequently the actions done by the individual in that region of space, seems to be responsible of brain remapping for changing perceptively and attentively that particular region. As well as for studies of Iriki et al. (1996a, b), it is possible that the brain areas involved in this perceptual remapping are the right posterior parietal cortex and premotor cortex. This result can explain the reasons connected to the reprocessing of the perceptual space while using an instrument. One of the main limitations of this experiment, similar to the problems encountered with the laser tool of the Experiment 3 second study, is the correspondence relation between the real movement of the arm and the virtual movement observed by the participant during the experiment. Again, alternating the starting point of the instrument (right / left), while contemporary specifying for each line to reposition the hand longitudinally, may be experiencing that particular phenomenon. The locked position of the wrist can still perceived to have reduced the influence of this type of mismatch. But as already mentioned, the similarity of results removes any doubt about the differences expected due to the presence or absence of a visual continuity between the hand and the region of space manipulated. Future work in the virtual version on the line bisection task will focus on the arm position control as for the Experiment 4. The task can be done in virtual reality with the arm bent or stretched. Even the analysis of the position of the arm, in the 'stretched' condition, from lateral to central will be taken into account.

Together these result could help the design and development of haptic interfaces. The term haptic refers to the acquisition of information and manipulation of objects through touch. The term covers all aspects of manual handling, from the exploration performed by people and machines, to the interaction between real, virtual and teleoperated environments. Haptic interfaces allow users to touch, feel and manipulate objects in a virtual environment, and simulate them through teleoperative systems (Salisbury & Srinivasan, 1992). Keyboard and mouse are passive haptic interfaces that detect the user's hand movements. Although a certain amount of force is experienced by the user's hand, through contact, consequently providing a tactile sensation, the force is not under a programmed control. Recently the use of the mouse was found to expand peripersonal space (Bassolino, Serino, Ubaldi, & Làdavas, 2010). Active haptic interfaces, such as robots, virtual Data Gloves or exoskeleton, which have force feedback, are tools that implement more sophisticated sensors and actuators. To simulate the sensation of touch or manipulation made possible by the force feedback, a two-way communication is necessary between the user and the computer. In contrast to vision and hearing, haptic is the only sensory mode that allows this kind of bi-directionally information between the user and the VE. The development of haptic interfaces is important in several areas (Srinivasan & Basdogan, 1997):

- *Medicine*
    - simulators for surgical operations, useful for training;
    - micro and macro robots for invasive surgery;
    - telemedicine for remote diagnosis;
    - assistance for disabled persons;
    - haptic interfaces for blind or amputated limbs.
- *Education*
    - tools for the students to experience the sensation of different in size scenarios or experiment complex data sets;
- *Industry*
    - haptic tools capable of giving designers the ability to freely manipulate the components of a mechanical assembly in an immersive environment.

According to this view, active haptic interfaces are indeed required for some tasks and can also increase the sense of presence of the user as illustrated by the development of dedicated software: Ghost Toolkit for the Phantom (http://www.sensable.com/) and immersion Studio for the FeelIt mouse (http://www.immersion.com/). In the real world, when a person touches an object, a feeling of power is transmitted to the skin, this feeling along with posture and movement of the legs are communicated to the brain as kinesthetic (or proprioceptive) information, through multiple receptors located on joints, tendons and muscles. A tactile image, then, is composed of both tactile kinesthetic sensory information, and, moreover, is controlled by motor commands based on the user's intentions. The haptic interfaces in VE or teleoperative systems receive voluntary motor commands and return the user tactile images, the main input-output interface variables are represented by position and strength, together with their spatial and temporal distribution. The consistency between the free movement of the hand and the moment of contact is achieved adequately by observing the position and movement of the hand as a control variable, and the resulting vector of forces along its distribution within the regions of contact (Stanney, 2002). For example, to discriminate the length of a rigid object held in hand with the thumb and forefinger (Durlach, Delhorne, Wong, Ko, Rabinowitz, & Hollerbach, 1989), kinesthetic information is essential, while the touch is superfluous; on the contrary, in recognition of the composition of a surface, the tactile information is fundamental, while the kinesthetic information is superfluous (Srinivasan, Whitehouse, & LaMotte, 1990). A wide variety of devices is under development in several companies and universities (Stanney, 2002):

- *Desktop Devices*
    - Joystick, mouse, steering wheel, joystick for flight, range instrumentation (pens, tools);
- *Devices based the shape of the body*
    - Flexible (gloves and suits worn by the user) exoskeleton (sensors attached to the joints of the body), tactile display

In conclusion, the understanding and comprehension of the mechanism involved in the processing of near and far space could help the development of innovative methods of neuropsychological rehabilitation. Two recent studies (Kuttuva & Burdea, 2005; Kuttuva et al., 2005) have demonstrated the possibility to create new interfaces to provide upper limb amputees a virtual hand that can manipulate objects in a virtual environment with sensory stimulation. The interface keeps track of the specific myokinetic activity of the residual limb, and encodes the intention of the voluntary movement that takes place in the movement of the virtual hand. The system called MKI-VR (Virtual Reality-Myokinetic Interface) consists of a set of pressure sensors placed in a prosthetic arm built for the amputee, sensors for movement of the shoulder and elbow and a virtual hand built with Java 3D (a free software for creating three-dimensional objects). Users could manipulate objects such as spheres and cylinders in a three-dimensional training environment, while the performance is evaluated according to different difficulty degrees. Preliminary tests showed that amputees have learned in a satisfactory way to grasp and release virtual objects, allowing us to propose the MKI-VR system as an assessment tool for rehabilitation, and the incentive for amputees to exercise and, therefore, to maintain their residual motor ability. The second study (Kuttuva et al., 2005) proposes a rehabilitation system for people affected by stroke. It consists of a device called the Rutgers Arm, composed of a special table, a three-dimensional detector, a Java library for virtual reality exercises and a dedicated telerehabilitation system. The device was tested on a patient's chronic condition using the local telerehabilitation for over five weeks. The results show an improvement in motor control of arm and shoulder as shown by the scores in the Fugl-Meyer test. The telerehabilitation training showed that exercise duration, difficulty level and motivation were maintained by the patient. After a week from the end of the tests it was found that the most improvement, regard the subject motor skills, had been maintained and even increased.

Appendices

Appendix 1-A

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Dichiarazione di Consenso Informato

Nome: ____

Cognome: _____________________________________

Data di Nascita: ________________________________

Residente in: ___________________________________

Città: ________________ Provincia: ____________________

Desidero la protezione del mio anonimato e di quello delle persone o enti a cui io mi sia eventualmente riferito/a nel corso della sessione. Sì ☐ No ☐

Acconsento all'utilizzo, per i soli fini della ricerca, dei dati personali riportati nelle righe soprastanti ed alla registrazione (audio/video) dell'intera sessione sperimentale. Questo può comportare la successiva pubblicazione di parte del materiale così raccolto in riviste o convegni.

Firma

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Appendix 1-B

L'interazione con un ambiente di realtà Virtuale può essere paragonata all'interazione che si ha con un videogioco per computer.

Tuttavia, la stimolazione sensoriale indotta da questa tecnologia, specialmente se sperimentata a lungo (da 10 minuti in su) e in modalità immersiva (indossando un casco), può provocare in soggetti sensibili effetti collaterali come:

- lacrimazione;
- nausea;
- mal di testa;
- vomito.

Per questo motivo è sconsigliato l'uso della realtà virtuale a soggetti che abbiano avuto in passato crisi epilettiche, che abbiano problemi cardiaci o vestibolari e a persone che abbiano appena consumato pranzi sostanziosi.

E' altresì sconsigliato l'uso della realtà virtuale immersiva senza l'uso di occhiali, a soggetti con forte miopia o astigmatismo in un solo occhio. Alla fine dell'esperimento si consiglia vivamente di rimanere all'interno del Dipartimento meglio ancora se seduti per un certo periodo di tempo.

Ho letto la seguente dichiarazione e accetto di partecipare all'esperimento consapevole dei possibili effetti collaterali legati all'impiego della Realtà Virtuale. Sono consapevole del fatto che posso interrompere in qualsiasi momento la partecipazione all'esperimento senza fornire alcuna spiegazione.

Firma

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Appendix 2

TEST DI DOMINANZA EMISFERICA
(Test di Edimburgo)

DATA_________________

COGNOME________________NOME____________SESSO_______SCOLARITA’_______________________

FAMILIARITA’ MANCINISMO________________ EVENTUALE MANCINISMO CORRETTO ____________

PROBLEMI VISTA____________________________________

CON QUALE MANO

1) DISEGNI? D S A
2) SCRIVI? D S A
3) DISTRIBUISCI LE CARTE (INDICA LA MANO OPPOSTA A QUELLA CON CUI TIENI IL MAZZO)? D S A
4) LANCI UN SASSO PER COLPIRE UN BERSAGLIO? D S A
5) USI IL MARTELLO? D S A
6) USI LO SPAZZOLINO DA DENTI? D S A
7) USI UN CACCIAVITE? D S A
8) USI UNA RACCHETTA DA TENNIS? D S A
9) USI LE FORBICI? D S A
10) TIENI IL FIAMMIFERO PER ACCENDERLO? D S A
11) APRI UNA LETTERA? D S A
12) CHE MANO TIENI IN CIMA AL MANICO DELLA SCOPA SPAZZANDO? D S A
13) TI PETTINI? D S A
14) USI IL COLTELLO? D S A
15) USI IL CUCCHIAIO? D S A
16) USI IL COLTELLO (CON LA FORCHETTA)? D S A
17) IMPUGNI IL BASTONE DA CRICKET? (MANO PIU’ BASSA) D S A
18) IMPUGNI LA MAZZA DA GOLF? (MANO PIU’ BASSA) D S A
19) APRI UNA SCATOLA DI CERINI? D S A
20) USI IL RASTRELLO? D S A

PIEDE

1) CON QUALE PIEDE CALCI LA PALLA? D S A
2) SE DEVI SALIRE SU UNA SEDIA QUALE PIEDE VI POGGI PER PRIMO? D S A
3) SE DEVI ALZARE UN SASSO CON LA PUNTA DEL PIEDE, QUALE PIEDE USI? D S A
4) QUALE PIEDE USERESTI PER SCHIACCIARE UN INSETTO? D S A

OCCHIO

1) CON QUALE OCCHIO GUARDERESTI ATTRAVERSO IL BUCO DI UNA SERRATURA? D S A
2) SE DOVESSI GUARDARE DENTRO UNA BOTTIGLIA SCURA PER VEDERE SE E’ PIENA, QUALE OCCHIO USERESTI? D S A
3) QUALE OCCHIO USI PER PRENDERE LA MIRA COL FUCILE? D S A
4) QUALE OCCHIO USI PER GUARDARE CON IL TELESCOPIO? D S A

ORECCHIO

1) IN QUALE ORECCHIO METTI L’AURICOLARE DI UNA RADIO? D S A
2) SE VOLESSI ASCOLTARE UNA CONVERSAZIONE CHE HA LUOGO DIETRO UNA PORTA CHIUSA, QUALE ORECCHIO POGGERESTI ALLA PORTA? D S A
3) SE VOLESSI ASCOLTARE IL BATTITO CARDIACO DI QUALCUNO, QUALE ORECCHIO POGGERESTI AL SUO TORACE? D S A
4) IMMAGINA UNA PICCOLA SCATOLA SU UN TAVOLO. LA SCATOLA CONTIENE UN PICCOLO OROLOGIO. QUALE ORECCHIO POGGERESTI SULLA SCATOLA PER SCOPRIRE SE L’OROLOGIO FA TIC-TAC? D S A

Appendix 3

Istruzioni

In questo esperimento ti verranno presentate delle linee, su fogli di carta, di diversa lunghezza e a distanze diverse. Il tuo compito sarà quello di segnalare con precisione il centro di ogni linea; potrai fare questo attraverso due modalità differenti: in una avrai a disposizione un puntatore laser montato su un treppiede regolabile che proietta un punto luminoso di colore rosso, nell'altra avrai a disposizione delle aste di legno di diversa lunghezza che utilizzerai impugnandole nella mano di tua preferenza. Quando avrai trovato quello che secondo te è il centro della linea lo segnalerai allo sperimentatore il quale procederà a marcarlo con una matita sul foglio di carta.

Grazie per la partecipazione

Appendix 4

Istruzioni

Quando indosserai il casco virtuale visualizzerai una stanza all'interno della quale sono presenti un tavolo di legno marrone e un pannello di colore bianco posizionato su di esso; sul pannello ti verranno presentate delle linee di colore nero di diversa lunghezza e a distanze diverse. Il tuo compito è quello di segnare con precisione il centro di ogni linea. Potrai eseguire questo compito attraverso l'utilizzo di un Wiimote® (controller/telecomando della console Nintendo Wii) che simula un puntatore laser tramite il movimento di un punto di colore rosso. L'esperimento è diviso in quattro blocchi segnalati dai titoli 'Controllo' o 'Bisezione' prima dell'inizio di ognuno. Il tuo compito sarà quello di segnalare l'estremità destra della linea durante il blocco 'Controllo', mentre dovrai segnalare il centro della linea durante il blocco 'Bisezione'. Quando avrai trovato quello che secondo te è la risposta corretta premi il tasto 'A' del Wiimote® per memorizzare la risposta e passare alla linea successiva..

Grazie per la collaborazione.

Appendix 5

DEPARTMENT OF PSYCHOLOGICAL SCIENCES

BIRKBECK UNIVERSITY OF LONDON

Title of Study: Personal Space and the Body

Name of researcher: Bruno Seraglia / Matthew Longo

Dear participant

The study is being done as part of research in the psychology department, Birkbeck University of London. The study has received ethical approval.

This is a study of how people perceive the centre of various lines. You are free to stop the study and withdraw at any time, without having to give a reason.

A code will be attached to the data so it remains totally anonymous. Your data will be used for research purposes only, and will be stored on a computer in a locked laboratory accessible only to the researchers.

The results of the study may be published in professional psychology journals. You will not be identifiable in the write up or any publication wich might ensue.

The study is supervised by Dr. Matthew Longo. If you wish to contact the supervisor, contact details are:

Email: m.longobk.ac.uk

Department of Psychological Sciences, Birkbeck University of London, Malet St, London WC1E 7HX TEL: 020 7079 0868

Appendix 6

CLQ

How anxious would you feel in the following places or situations? Circle the most appropriate number:

Not at all anxious	Slightly anxious	Moderately anxious	Very anxious	Extremely anxious
1	2	3	4	5

1.	Swimming while wearing a nose plug	1	2	3	4	5
2.	Working under a sink for 15 minutes	1	2	3	4	5
3.	Standing in an elevator on the ground floor with the doors closed	1	2	3	4	5
4.	Trying to catch your breath during vigorous exercise	1	2	3	4	5
5.	Having a bad cold and finding it difficult to breathe through your nose	1	2	3	4	5
6.	Snorkeling in a safe practice tank for 15 minutes	1	2	3	4	5
7.	Using an oxygen mask	1	2	3	4	5
8.	Lying on a bottom bunk bed	1	2	3	4	5
9.	Standing in the middle of the third row at a packed concert realizing that you will be unable to leave until the end	1	2	3	4	5
10.	In the centre of a full row at a cinema	1	2	3	4	5
11.	Working under a car for 15 minutes	1	2	3	4	5
12.	At the furthest point from an exit on a tour of an underground mine shaft	1	2	3	4	5
13.	Lying in a sauna for 15 minutes	1	2	3	4	5
14.	Waiting for 15 minutes in a plane on the ground with the door	1	2	3	4	5

closed

15. Locked in a small DARK room without windows for 15 minutes 1 2 3 4 5

16. Locked in a small WELL LIT room without windows for 15 minutes 1 2 3 4 5

17. Handcuffed for 15 minutes 1 2 3 4 5

18. Tied up with hands behind back for 15 minutes 1 2 3 4 5

19. Caught in tight clothing and unable to remove it 1 2 3 4 5

20. Standing for 15 minutes in a straitjacket 1 2 3 4 5

21. Lying in a tight sleeping bag enclosing legs and arms, tied at the neck, unable to get out for 15 minutes 1 2 3 4 5

22. Head first into a zipped up sleeping bag able to leave whenever you wish 1 2 3 4 5

23. Lying in the trunk of a car with air flowing through freely for 15 minutes 1 2 3 4 5

24. Having your legs tied to an immovable chair 1 2 3 4 5

25. In a public washroom and the lock jams 1 2 3 4 5

26. In a crowded train which stops between stations 1 2 3 4 5

Appendix 7

Edinburgh Handedness Inventory

Age ______

Please indicate your preferences in the use of hands in the following activitie by placing an "x" in one of the five boxes.

	Strong left preference	Left preference	No preference	Right preference	Strong right preference
Writing					
Drawing					
Throwing					
Scissors					
Toothbrush					
Knife (without fork)					
Spoon					
Broom (upper hand)					
Striking match (match)					
Opening box (lid)					
Which foot do you prefer to kick with?					
Which eye do you use when using only one?					

Appendix 8

3 CM LINE

6 CM LINE

Appendix 9

Istruzioni

Quando indosserai il casco visualizzerai una stanza all’interno della quale sono presenti un tavolo di legno marrone e un pannello di colore bianco posizionato su di esso; sul pannello ti verranno presentate delle linee di colore nero di diversa lunghezza e a distanze diverse. Il tuo compito è quello di segnare con precisione il centro di ogni linea. Potrai eseguire questo compito attraverso l’utilizzo di un Wiimote® (controller/telecomando della console Nintendo Wii) che simula, a seconda della condizione:

- un asta di legno virtuale intera (strumento 1)
- l’estremità finale di un asta di legno virtuale (strumento 2)

all’interno dell’ambiente muovendo il Wiimote®, vedrai spostarsi gli strumenti sopra citati. Per ogni strumento, l’esperimento è suddiviso in 2 blocchi, a seconda che il punto di posizionamento iniziale dello strumento sia a destra o a sinistra.

Quando hai segnato quello che secondo te è il centro della linea, posizionandoti sopra di essa, premi il tasto ‘A’ del Wiimote® per memorizzare la risposta e passare alla linea successiva. Ricorda, inoltre, di visualizzare sempre la mensola virtuale di legno posta sotto le linee. Lo sperimentatore è a disposizione per qualsiasi domanda.

Grazie per la partecipazione!

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