A NEW VIDEOGAME FOR THE REHABILITATION OF ATTENTION AND EXECUTIVE FUNCTIONS FOLLOWING TRAUMATIC BRAIN INJURY

Direttore della Scuola: Ch.ma Prof.ssa Clara Casco
Coordinatore d’indirizzo: Ch.ma Prof.ssa Francesca Peressotti
Supervisore: Ch.mo Prof. Marco Zorzi

Dottorando: Veronica Montani
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Overview

The most common consequences of traumatic brain injury (TBI) include impairment of attention and executive functions. Thus, TBI patients can be affected by psychomotor slowness and by difficulties in dealing with distraction, maintain a cognitive set for a long time, processing different simultaneously presented stimuli, and planning purposeful behavior. The aim of this study was to develop and test a computerized procedure to support the rehabilitation process of TBI patients. There is some evidence that action videogames could enhance a variety of cognitive skills. Therefore, we created a new videogame that activates attention and executive functions. Our videogame users have to plan the way to achieve a goal within a maze, to actively maintain the cognitive set representing the goal, and to monitor for errors. In different sessions, our users are required to perform two tasks alternatively (i.e., task switching) or to perform the two tasks simultaneously (i.e., divided attention). The videogame has a self-adaptive algorithm that calibrates task difficulty on-line, according to the user’s performance.

In the first study, we validated the videogame with unimpaired participants, to confirm the involvement of the abilities it was conceived to improve. In the second study we administered a rehabilitation protocol to TBI patients. TBI patients were assigned in a controlled way to two treatment groups: the experimental group, that received the videogame treatment, while the control group, that received a standard treatment. Attention and executive functions have been assessed with a comprehensive neuropsychological test battery, twice before the treatments and twice after the treatments. We expected that our videogame could lead to better treatment outcomes given that it is more cognitively demanding and motivating for TBI patients than
traditional treatments. Results partially confirmed the hypothesis but further investigation is necessary.
Le conseguenze cognitive del trauma cranico (TC) sono varie ma con grande frequenza includono deficit delle funzioni attentive e delle funzioni esecutive. Infatti, i pazienti con TC possono presentare disturbi quali lentezza psicomotoria, difficoltà a contrastare la distrazione, difficoltà a mantenere un set cognitivo per un tempo protratto, difficoltà a portare a termine due compiti cognitivi contemporaneamente e infine difficoltà a pianificare comportamenti finalizzati.

Lo scopo di questo studio è di sviluppare e testare una procedura computerizzata che possa essere utilizzata come supporto nel processo di riabilitazione dei pazienti con TC. Ci sono evidenze che l’utilizzo dei videogiochi di azione potenzia una varietà di abilità cognitive. Di conseguenza, abbiamo creato un nuovo videogame con caratteristiche simili a quelle dei videogiochi commerciali ma nello stesso tempo ideato con l’intento di attivare specificatamente alcune funzioni attentive ed esecutive. L’utente deve pianificare il modo di raggiungere lo scopo, mantenere attivamente il set cognitivo relativo a quel particolare scopo e monitorare gli errori. In differenti sessioni, all’utente è richiesto di eseguire due compiti in maniera alternata (task switching) o di eseguirli contemporaneamente (dual task). Inoltre, il videogame è controllato da un algoritmo adattativo che calibra la difficoltà dei compiti in funzione della prestazione corrente del giocatore.

Nel primo studio abbiamo validato il videogame con partecipanti sani per verificare che effettivamente il suo utilizzo richiedesse l’uso delle abilità ipotizzate. Nel secondo esperimento abbiamo somministrato un protocollo di riabilitazione a pazienti con TC. I pazienti sono stati assegnati a due gruppi di trattamento: al gruppo sperimentale
veniva somministrato un trattamento con il videogame, al gruppo di controllo un trattamento più tradizionale. Veri aspetti delle funzioni attentive ed esecutive dei partecipanti sono state valutate con una ampia batteria di test neuropsicologici, due volte prima del trattamento e due volte in seguito al trattenimento. Avevamo ipotizzato di riscontrare un miglioramento significativamente maggiore nel gruppo trattato con il videogioco dal momento che esso è cognitivamente più impegnativo e allo stesso tempo più motivante rispetto al trattamento tradizionale. I risultati hanno confermato le ipotesi solo parzialmente ma ulteriori indagini sono necessarie.
1. Cognitive deficits in traumatic brain injury

1.1 Introduction

The cognitive impairments following traumatic brain injury (TBI) can be various and involve many different abilities and a combination of specific function deficits (Cattelani, 2006). Nevertheless, the mechanics of injury makes some brain areas more susceptible to damage and some impairments more common than others. The acceleration-deceleration mechanism makes the frontal and temporal lobes as the most frequent damaged sites, with a subsequent wide range of high function impairments (Povlishock & Katz, 2005). In particular, frontal lobe damage is associated with dysexecutive syndrome and attentional deficits. Attentional neural networks are disrupted also by diffuse axonal injury and the same shearing mechanism leads to a general impact in mental slowness (Chan, 2001). Impairments in attention and executive functions can profoundly affects an individual’s daily functioning, making the managing of very simple daily activities difficult. Accordingly, patients often report problems with concentration, distractibility, forgetfulness and the ability to do more than one thing at a time (Sohlberg & Mateer, 2001). Because of the related disabilities and the increasing number of people suffering of this pathology, the development of effective rehabilitation strategies should be considered of high priority.

One of the basic assumptions of the rehabilitation practice is to have a theoretical foundation for the treatment itself (Sohlberg & Mateer, 2001; Chan, 2001). This means to conceptualize the cognitive process in order to understand deficits. Model or taxonomy of cognitive process making possible to have a clinical models helping to organize the
assessment and the treatment practice. Cognitive functions have many dissociable components that can be identified using both experimental paradigms on normally functioning individuals and clinical observations. Then, a useful model should emerge from the overlapping perspectives of cognitive psychology and neuropsychology.

Executive functions have been traditionally defined as “integrative cognitive processes that determine goal-directed and purposeful behaviour and are superordinate in the orderly execution of daily life functions” (Cicerone et al., 2000). In particular they include the ability to formulate a goal, to plan and organize behaviour, to monitor and adapt behaviour accordingly with the context. TBI patients often show dysexecutive syndrome with disability in processes such as planning, problem solving, organising. Problems could arise for example because the patient is unable to generate alternative solutions, to solve a new problem. In other case, the patient cannot predict the consequence of some actions or organise the sequence of steps necessary to achieve a goal. They often are also unable of inhibiting automatic response.

Attention and executive functions are two concepts strongly related and interdependent from both a functional and anatomical point of view. Baddely (2003) suggested a functional analogy between the central executive and the supervisory attentional system (Norman & Shallice, 1986) emphasizing the attentional nature of the central executive. Chan (2000) suggests to conceive executive function as the higher level of attentional control processing, the system for strategies allocation which modulates all the lower components of attention. For example, we exercise intentional executive control to select and implement the task-set (Monsell, 2003) in a task switching paradigm (see 1.2.3) through change in the allocation of attention between the two tasks. Indeed, task switching is a concrete example since it is depicted alternatively as part of the attention function (eg. Chan, 2000; Sohlberg & Mateer, 2001) or executive functions (eg. Monsell,
13 Stablum et al, 2007). In the next chapter I will focus on ”attention functions”, but it should be kept in mind that those functions can also be described as part of the central executive.

1.2 Attention

The construct of attention include a wide range of cognitive functions. The common ground is that the human brain has not sufficient processing power to fully analyze all the information it receives. The selection of where to allocate the cognitive resources depends on the attentional process. Indeed one of the first aspect that characterized the research about attention was the idea that it act as a filter (Broadbent, 1958). For many years the debate around attention was focused identifying on the stage of processing upon which this attentional filter acts, with rigid separation between those who argued for an early locus and those who argued for a later locus (Deutsch & Deutsch, 1963). During the past decades the results of many studies have led to the conceptualization of attention as a flexible function rather than a rigid bottleneck. For example, Lavie (1995) proposed the ‘load theory’ of selective attention that suggest the possibility to allocate cognitive resources in different ways according to task demands.

Another basic distinction since James’ (James, 1890) first description of attention was between two kinds of attentional processes: reflexive, involuntary, exogenous or automatic from one side and active, voluntary, endogenous or controlled from the other side. From one point of view this distinction concerns the use of processing resources. An automatic task requires minimal engagement of attention, which leads to the possibility to perform an other independent process at the same time. There is evidence that many processes can be carried out in automatic fashion, without ‘effort’ (Schenider et Shiffrin,
From another point of view, the same distinction points out that some processes are completed without ‘intention’, while others need a volitional engagement and allocation of cognitive resources. When something unexpected happens in our environment, there is a strong tendency to direct our attention towards the unexpected event (Wolfe & Horowitz, 2004). The evolutionary advantage of such a behaviour is clear: in an ever-changing environment with some potential dangerous event, being quickly responsive to any change allows to avoid many risks. On the other hand, attention can be directed according with the current goal of the subject in a more ‘controlled’ way (Noudoost et al, 2010). In this way, it is possible to manage novel situation that require a more flexible behaviour.

Attention is served by many brain regions. For example, visual attention seems to be controlled by two partially segregated neural systems dynamically interacting. One system is centred on the dorsal posterior parietal and frontal cortex, while the other relies on the temporo-parietal and ventral frontal cortex (Corbetta & Shulman, 2002). The first pathway seems to be primary involved in conveying ‘top-down’ signals, that is the volitional deployment of attention according to the context, the current goals and the internal status. The second pathway conveys ‘bottom-up’ signals and is responsible for the automatic deployment of attention driven by salient stimuli (Bushman and Miller, 2007).

Attention is strongly related with working memory. They are both related to the idea that the brain has a limited processing capacity. Attention is more related to the selective aspect of the information processing and subsequent response, whereas working memory is related to the temporarily maintenance of information to achieve efficient access and updating. The standard model considers working memory as a function arising from a specialized system that stores and permits to manipulate the information (Baddley,
1986). However, there is now much evidence suggesting that working memory is implemented in a distributed network. Working memory functions arise through the recruitment of brain system that accomplish sensory and motor representation, through the temporary activation of representation in long-term memory. The activation of this representation is achieved through attentional selection (Postle, 2006)

Attention may be described in terms of different components that can be located along a continuum from more basic elements to higher functions regulating the strategic allocation of attention. For example, in the domain of spatial attention, it is possible to isolate modality specific focus of attention. Chambers et al, (2004) showed that disruption with TMS of the right parietal cortex impaired spatial attention in vision but not in somatosensation. On the other side, there is strong evidence supporting a supramodal system (Spence et al, 2000; Macaluso & Driver, 2004)

Though the single components are not independent from each other, their distinction allows to investigate underlying the brain mechanisms and it helps to examine the impact of brain injury on everyday life. Moreover, restorative training focuses on improving a specific cognitive function (Sturm, et al., 1997).

The model of attention I have here adopted recognizes four main components: selective attention, sustained attention, divided attention, alternate attention. I will give a brief overview of such components, with special focus on divided and alternate attention, since these components are particularly relevant for the empirical studies presented in chapter 4 and 5.

1.2.1 Selective and sustained attention
The concept of selective attention is related to the managing of the information overflow that we experience in our daily living. Managing the daily activity require to select what kind of information has to be processed further and what has to be ignored accordingly with the context and the goals. The selective mechanism delivers a limited subset of information to the subsequent limited-capacity process (Evans et al, 2011). The inability to carry out this kind of process leads to higher distractibility and the inability to maintain a cognitive set in the face of other stimuli (Sohlberg & Mateer, 2001). Typically, selective attention has been studied with visual search paradigm that allow to measure the ability to detect a target among distracters. The Stroop test (Stroop, 1935) is another of the most common paradigm used to study selective attention and also to assess the ability to inhibit the interference of irrelevant information in patients. Deficit of selective attention in TBI patients are quite common but like for other component of attention functions there is no consensus on the mechanism underlying this deficit (Ben-David et al, 2011). The debate concerns the existence of a genuine inability to focus attention or inhibit irrelevant resources information, as proposed for example by Park, et al, (1999) as opposed to the view that ascribes selective attention deficits as a secondary effect to a general slowdown in speed of processing (Madigan et al, 2000; Mathias & Wheaton, 2007).

Sustained attention refers to the ability to maintain attention over time during continuous and repetitive activity (Sohlberg & Mateer, 1989). Often it is studied with vigilance tasks that require the participant monitoring a series of stimuli in order to detect infrequent and critical targets over a prolonged period of time (Parasuraman, 1984). Despite the fact that patients commonly report to have difficulties in concentration, the finding of impaired performance in vigilance test are not consistent (eg. Whyte et al, 1995; Buchtel, 1987).
Seignourel et al., (2005) proposed that the impairment of patients in selective attention arise more from the inability to maintain the context than to inhibit interference. They used a computerized variant of the Stroop task where trials were presented individually rather than as list and the task instructions (colour naming vs. word reading) randomly varied across trials (Cohen et al, 1999). This arrangement forced participants to update task instructions at every trial and shift from one task to another. They manipulated also the delay between task instructions and appearance of the stimulus creating two condition, one short with a delay of 1 second, and one long with a delay of 5 sec. With this setting they found that patients showed disproportionately greater error rates in the incongruent condition and overall slower RTs than controls specially in the long delay condition. A possible interpretation of the finding is that patients are unable to endogenously maintain the set.

Interestingly, Manly et al, (2003) arrived at similar conclusion with a completely different, and for some aspects, opposite, paradigm. They showed that it is possible to enhance the sensitivity of the Sustained Attention to Response test (SART), a task designed to assess sustained attention, by simplifying the task. The reduction of task demands made the task less engaging with the paradoxical effect to render it more difficult for the patients. Both the evidence may suggest that patients suffer in the ability to endogenously allocate attention (also see Stablam et al, 1994) as in the selective than in the sustained aspect.

1.2.2 Divided attention

It is possible to divide the available controlled processing capacity between several cognitive operations? This question has afronted interest far more than 100 years
to better understand human limits and also for some practical problems (Reinerman-Jones, et al, 2011). Usually divided attention has been studied with paradigms that involve the coordination of two simultaneous tasks (‘dual tasking’) or a task that involve multiple demands such as monitoring of more kinds of stimuli (Sohlberg & Mateer, 2001). Overall, the main finding of studies on healthy participants is that the performance in the dual task condition shows a cost relative to the performance in the single condition. However, there is no consensus about the mechanism underlying this cost. A capacity-shared explanation posits that processing resources can be divided in a flexible-way, also with complex task and as a consequence processing of the two task proceeds in parallel (Kahneman, 1973; Allport, 1972). In contrast, the “bottleneck” explanation posits that the interference between the two tasks is due to the impossibility to use of the same mechanism and the unavoidable rolling over of one task (Pashler, 1998).

One of the most common paradigms used to address questions around divided attention is the psychological refractory period (PRP) paradigms. In this paradigm the manipulation of the stimulus onset asynchrony (SOA) between two tasks allows to measure how the overlap affects the performance of the second task. Usually, the PRP effect consists in the lengthening of the reaction time (RT) for the second task in the condition of short SOA supporting the idea of a central bottleneck. In contrast, there is also evidence of specific interference linked to the particular task supporting the idea that in some cases the resources are sheared. A very recent work study, tested the hypothesis of a common attentional limitation in perception and response processing in multitasking settings using time-resolved fMRI (Tomba et al, 2011). They were able to identify some areas such as inferior frontal junction, that are involved in both conscious encoding of stimuli and in decision making based on these events. The finding suggests the existence
of an unified attentional bottleneck that temporally limits also operations as different as perceptual encoding and decision making.

Charron and Koechlin (2010), using brain imaging, observed that the medial and lateral frontal cortex divides under dual task conditions. One hemisphere encodes the reward driving one task, while the other hemisphere encodes the rewarding of the other task. The prefrontal and frontopolar regions of both the hemispheres control the serial execution of the two tasks alternating them. Over again, this finding disconfirms the sharing hypothesis suggesting a severe constraint bearing upon human higher cognition.

Divided attention deficit has been frequently diagnosed in patients after TBI and this difficulty has been found to be significantly correlated with the inability to return to work (Van Zomeren & Van den Burg, 1985; Vikky et al, 1994). However there is no consensus about the mechanism underlying impaired dual task performance. Some studies find no additional deficit in divided attention when speed of processing was controlled for (Dell’Acqua et al, 2006; Foley et al, 2010) while others show that TBI patients have significant dual task decrement also controlling for processing slowdown(eg. Serino, 2006)

For example, Azouvi et al, (2004) asked patients to alternatively put emphasis on one task or another. They found a preserved ability to preferentially allocate attentional resources to one task or the other despite the dual task decrement suggesting a reduction in available resources. Mathias & Wheaton (2007) in a meta-analytic review of research examining attention following severe TBI found that slowed processing largely accounted for the deficits in attention, as demonstrated by the largest effect size.

From the rehabilitation point of view, it is important to understand the mechanism underling the dual task cost to choose the appropriate training regimen. Indeed, it is
demonstrated that extensive training with dual task can greatly reduce multitasking cost (Schumacher et al, 2001, Tombu & Jolicoeur, 2004; Van Selst et al, 1999). But it is not clear what neural mechanism could account for such improvement. Dux et al, (2009) demonstrated that the reduction of the interference between the two tasks is not achieved by diverting the flow of information processing away from the prefrontal cortex as expected if the training leads to an automation of the two tasks. The multitasking improvement was achieved thanks to the shortening of a central capacity-limited stage of information processing in the prefrontal cortex. The effect of the training was to speed up information processing through the prefrontal bottleneck.

1.2.3 Alternate attention

Responding in a flexible way in a changing environment require the ability to switch rapidly from an activity to another (Miller & Cohen, 2001). The ability to switch has been extensively studied with paradigms that require to perform two tasks rapidly alternating between them. The typical result show a ‘switch’ cost that is RT are longer and there are more errors when a task follow a different task in comparison with trial where one task follows the same task. This cost is attributed first to the reconfiguration of the new task set, the appropriate configuration of mental resources. Giving in advance an appropriate time to prepare for the task, for example with a cue, usually reduces the switch cost but do not allow to avoid it completely. Therefore other factors such as the transient persistence of the activation of the prior task must contribute to the switch cost (Monsell, 2003).

Neuroimaging studies have identified various prefrontal cortex regions that contribute to task switching (for review see Sakai, 2008), and together with behavioural
evidence, they suggest the existence of multiple switching mechanisms. For example, Ravizza & Carter, (2008) identify two different types of switch: Perceptual switching that relates to the shift in visuo-spatial attention and rule switching that relates to the shift in the correct stimulus-response mapping. They implemented two possible arbitrary sets of response rules and manipulated the presence of two different sets of features. They found that when rule information remained relatively static, they could evoke the switch cost simply requiring the reorienting of attention from one set of features to another set of features of the task (perceptual switch). In contrast, the switch cost in the alternation of the two sets of rules was present also if stimulus interference from the other set of features was absent. Besides, the absence of a region activated from both the type of switch make them to conclude that task switching is not a top-down process indifferent from the type of representation on which it is working.

In a more recent work, Kim et al, (2011) arrive at different conclusions. They designed a paradigm that allows to selectively induce three different types of switching: stimulus (perceptual), response (stimulus-response mappings) and set rules (task rules) in the context of a common task and a common set of stimuli. They were able to distinguish discrete regions of the prefrontal cortex that are spatially dissociated and that contribute to domain-general and domain specific forms of switching with a rostrocaudal gradient across the lateral and medial PFC according to the degree of representational abstraction required by the task. In particular, they found prominent common activation in the inferior frontal junction (IFJ) and in the posterior parietal cortex (PPC) claiming that those areas could be the best candidate to contribute a generic switch process. Further, they suggest that IFJ is devoted to the updating of the task set (Brass and von Cramon, 2004; Derrfuss et al, 2004; Roth and Courtney, 2007) meanwhile PPC to the
representation of the same (Bunge et al., 2003; Cavina-Pratesi et al., 2006), two cognitive processes that contribute to all forms of switching (Mitake et al., 2000).

Accordingly, Gold et al. (2010) found that the strength of anatomical connectivity along the superior longitudinal fasciculus, that connect IFJ and PPC, is negatively correlated to with switch cost. Then, faster task switching seems associated with ‘more direct’ information flow between IFJ and PPC consistent with a view that these regions play a coordinated role during switching. In conclusion, despite the existence of different kinds of shift, there is evidence that they share a common mechanism.

Patients with TBI frequently show problems to switch between different activities. They have difficulty to change a task once a set has been activated or needs extra cue to initiate a new task (Sohlberg & Mateer, 2001)

Stablum et al. (1994) using a variant of task-switching paradigm compared performance of severe Chi patients and controls manipulating the possibility to predict the switch. CHI patients exhibited inflated switch costs when the task alternated every 2 trials but not when the tasks alternated every 10 trials. Since in the 2 trials condition participants have the possibility to plan the switch in advance, they argued that patients were not able use this information.

Schmitter-Edgecombe & Langill (2006) in contrast found that giving an additional preparatory time (200 msec. vs. 1 sec) and an external cue, switch cost was reduced suggesting that they are able to take advantage of time to prepare the switch (slowness of reconfiguration). Moreover, since the cost of the switch was limited to the switch trial and did not dissipate gradually over a run of trials they concluded that patients did not experience longer proactive task set inertia. They controlled also for the slowness and found that larger switch cost of patients did not simply reflect their slower processing speed. They individuate in the residual component one possible cause of the larger switch
cost. For example, the response selection is a kind of process that is triggered only by the appearance of the stimulus. Then they proposed that the larger switch cost of patients is due to inefficiencies in the response selection stage of information processing.

Other studies addressed the question of switch deficit in CHI patients using neuropsychological measures such as WSCT and TMT (Greve et al 2002; Rios et al, 2004). Unfortunately this kind of test do not allow to isolate cognitive process underlying switching (Miyake et al, 2000) since the task performance depends also on many other skills.

Finally, there is evidence that is possible to enhance the ability to switch between different task with training (eg. Berryhill & Hughes, 2009). Unfortunately the same question has been not addressed with patients. One exception is the work of Stablum et. al, (2007) that trained severe and mild patients with a switch task where an endogenous shift of attention was required. A significant reduction of the shift cost has found and moreover, this reduction remained stable at least for 4 months.

1.3 Conclusion

In conclusion, there is a large debate about the specific cause of the attentional deficits in TBI. Some evidence argue for a general slowing processing while other studies show that TBI are impaired in some specific mechanism. The question is not without worth, since the best understanding of the mechanism of cognitive process and deficit related may lead to a better design of rehabilitation tasks. At the moment is difficult to disambiguate between the two prospective. Nevertheless, there is evidence that using some paradigms such as dual task could improve impaired abilities of patients and the
quality of their life. To better understand if the results is due promoting a more speeded response, stimulating some more specific mechanism or through both the processes further investigation is necessary.
2. Videogame experience and cognitive abilities

2.1 Introduction

“A videogame is a game which we play thanks to an audiovisual apparatus and which can be based on a story” (Esposito, 2005). This very simple and short definition of what is a videogame veils a great variety of many type of different videogames. Newman (2004) identified at least seven quite different categories of videogame, for example there are action and adventure games, first person shooter, platform and puzzle games, games of strategy and simulation.

Despite videogames had belonged to our culture since more than 30 years ago, for long time academic world had ignored the study of their effect on our life. The only exception of this lack of interest were studies investigating the potentially damaging and antisocial effect of play (see Dill and Dill, 1999 for a review). Kostner (1999) claims that one possible reason can be that they are considered ‘mere’ entertainment and maybe also devoted only to children. Recently, interest around the cognitive processes involved in videogame play has grown and many researchers have reported positive effects of play. Indeed, during the last decade, technique and culture of videogame have made considerable progress with the results that today videogames have very sophisticated graphics and demanding environments. The awareness that those characteristics could affect cognitive ability in a strict way can explain the renewed scientific interest (Hubert-Wallander et al, 2010).

Most of the literature on the effect of videogame play is centred on ‘action’ videogame. Action videogame are those that: 1) have fast motion and sudden appearance of stimuli, 2) require vigilant monitoring of visual periphery, 3) require simultaneous
tracking of multiple targets, 4) require excellent sensory-motor coordination (Green & Bavelier, 2006; Hubert-Wallander et al., 2011). Since they are remarkably visually challenging and require stringent use of attention, the investigations were focused on visual skill changes revealing that videogame players (VGPs) outperform non videogame players (NVGPs) on a variety of visuo-attentional tasks. But there is also evidence that they enhance a variety of other cognitive skills (Dye et al, 2009; Green & Bavelier, 2003) and that more strategic videogames involve different cognitive processes than visuo-spatial ability with possible benefits (Colzato et al, 2010; Boot et al, 2008).

The used methodology consists of both cross-sectional and longitudinal approaches. The latter compares the performance of habitual players and non players on a particular task, while the former compares the performance of two groups of not players before and after a different practice training. Indeed, it could be the case that VGPs have some better skills before using videogames and their ability drove them to choose to play. Thought the longitudinal approach is less common it reveals that the benefits of play are trainable to a non-game player population allowing to rule out that those benefits are due to prior differences between players and non players.

There is also some evidence that this kind of learning is not specific of the trained task but there is some degree of generalization to untrained aspects (Green and Bavelier, 2006) and some transfer to a completely different and more 'ecological' domain (Gopher et al, 2004; Landsittel & Averch, 2005). Finally, we can also find some very recent studies that using imaging methodologies have highlighted the brain mechanism involved in the changes induced by extensive play (Bavelier et al, 2011; Voss et al 2011).
2.2 Cognitive processes involved in videogame playing

Many different studies have consistently observed that VGPs show better visual abilities than NVGPs from the basic level to high level processes of the visual system.

2.2.1 Basic visual skills.

Contrast sensitivity, the ability to detect subtle changes in stimulus contrast, is one of the most basic visual functions but also one of the most fundamental aspects of vision (Campbell, 1983) since it is a building block for other visual functions (Caplovits & Kastner, 2009). Li et al. (2009) found that action videogame players had increased contrast sensitivity at all but the lowest spatial frequency. They were also able to prove that it is possible to obtain this improvements after an appropriate training with such a game.

Action videogame practice enhances also the spatial resolution in the form of reduced crowding. Crowding is the deleterious effect of flankers on the target recognition (Andriessen & Bouma, 1976). In the classical crowding paradigm, VGPs were able to recognize the target when the distance between the flankers and the target, the critical distance, was narrower than the critical distance of the NVGPs. Moreover, they recognized better the target in isolation showing also better visual acuity (Green and Bavelier, 2007).

2.2.2 Spatial attention

Green and Bavelier (2003) compared attentional resources of VGPs and NVGPs with the ‘flanker compatibility’ task. In this task, participants have to ignore a distracter while they have to recognize the target in a six ring display. The effect of the distracter is measured using the compatibility effect: distracters compatible with the target results in faster RT relative to distracters that has a different response than the target (Eriksen &
Eriksen, 1974). The size of the distracter effect depends on the difficulty of the task: a strong effect when the task is easy but a small effect when the task is made difficult by increasing the number of shapes in the ring. A classic explanation (Lavie, 2005) is that in the easy trial, spare resources are distributed to other locations allowing the distracters processing. As the task becomes more difficult all the resources are devoted to the target task and are not available for the distracter processing. As expected, videogame players showed a greater effect of the distracters also in the difficult condition leading to the conclusion that they have more available attentional resources than NVGPs.

The same paradigm has used to study the distribution of attention in the visual field. In a subsequent work, Green and Bavelier, (2006) manipulated the position of the distracters putting them in a central or peripheral location relative to the six ring display. The question was to assess if VGPs distributed their attention in a different way than NVGPs, but similar to that observed in deaf individuals. The latter allocate more attention in the periphery, while hearing individuals are focused on the area around fixation (Proksch & Bavelier, 2002). It is possible that action videogames affect peripheral vision more than central vision. This idea was disconfirmed by the fact that VGPs do not have a larger compatibility effect for peripheral distracters. They processed central and peripheral items better than NVGPs but the spatial distribution of attention did not differ among the two groups. Then action videogame play seems to affect equally both central and peripheral vision.

The distribution of attention in the visual field has been studied by Green and Bavelier (2003, 2006) with an adapted version of the ‘useful field of view’ task, UFOV (Ball et al, 1988). In this task participants have to localize a very briefly presented stimulus among distracters. Manipulating the eccentricity of the target it is possible to measure the distribution of attention, while manipulating the presence of distracters allow
to measure the ability to select the proper information. VGPs were better than NVGPs to localize the target in all the conditions. Perceptual learning is often specific to the trained task (Sagi & Tanne, 1994; Fiorentini & Berardi, 1980), instead the finding that they are better also at 30° of eccentricity allowed to conclude that videogame experience enhances visual processing also in untrained locations, the zone outside the ‘playing zone’, leading to a generalization effect. They were also better than NVGPs in the distractor condition. This advantage in the ability to select the target among distracters could be not explained by perceptual learning but refers to an enhancement of visual selective attention (Carrasco, Williams & Yeshurun, 2002).

The improvements in the UFOV task after videogame practice was confirmed also with a training studies. While the experimental group was trained with an action videogame, the control group had practice with a game involving visuo-motor coordination but that did not require multitasking at fast pace. Both groups improved they performance but the benefits was greater for action trained participants (Green and Bavelier, 2003; 2006).

VGPs showed better ability to distribute their spatial attention and to select the right target also in the ‘Swimmer task’ (West et al., 2008), another task that require to detect a high-salience stimulus among distracters. Their better ability to detect the target among distracters was proved also with a visual search paradigm that included a more difficult search condition, without ‘pop up’ effect (Castel et al., 2005).

VGPs show also to be more accurate in subitizing and outperform non players in accuracy and RT measures in the enumeration task (Green & Bavelier, 2003, 2006), suggesting that they have an enchanced visual-short memory and they can attend more objects than NVGPs.
Dye et al. (2009) to further understand the improvement in the allocation of attentional resources in VGPs compared habitual VGPs and NVGPs, in the range of age between 7-22 years, on the Attentional Network Test (ANT). ANT provides measures of three fundamental components of visual attention: alerting, orienting and executive control (Posner & Petersen, 1988). ANT require subjects to discriminate the orientation of a target that could be cued, uncued or double cued (cue that informs on the onset but not on the location) and it could be flanked by congruent or incongruent distracters. VGPs were faster in general in every conditions than NVGPs. There was no evidence of any differences in the alerting efficiency and in orienting measure, but effects of videogame playing were found in the flanker compatibility measure. The authors interpreted their results as evidence that videogame playing changes the spread of attention over the visual scene. VGPs ‘suffer’ more interference from incongruent flankers (as in the ‘flanker compatibility task’) because their greater spread of attentional resources allows a better processing of the flankers. When the spatial cue focuses attention tightly on the location of target, the difference in the flanker effect diminishes and there is little difference between NVGPs and VGPs in terms of how they use the valid spatial cue to allocate their attention. The enhanced attentional resources of action video gamers were seen throughout the entire range of age studied.

2.2.3 Temporal dynamics of vision

There is evidence that benefits of action videogame practice is not limited to the spatial domain: the temporal distribution of attention improves after playing as well. Green and Bavelier (2003) investigated the temporal distribution of attention with a variant of the ‘attentional blink task’ (Shapiro & Raymond, 1997). Attentional blink task
is a common paradigm designed to study the processing of different stimuli in fast succession. The worse performance with the stimulus that comes after in the succession is considered as evidence that limited processing resources involved in the first stimulus processing are still not available to process the incoming stimulus leading to a performance decline. Green and Bavelier (2003) expected to find VGPs to be better at avoiding this temporal bottleneck of attention since videogames usually press to act very rapidly. Their variant of the task adds a further difficulty including a switching between two task: the identification of the first stimulus vs. the detection of the second stimulus. VGPs showed a better ability to process stimuli over time since the accuracy in the detection of the second stimulus was significantly better than the accuracy of the NVGPs group. The results could not be attributable to differences between the two groups, since they demonstrated that such increment in the temporal distribution of attention can arise also in a non gamer population after a training with an action videogame.

Evidence of fast temporal processing after playing comes also from a study about multisensory integration. Donohue et al, (2010) found that VGPs discriminate the non simultaneity of auditory and visual stimuli at smaller intervals of time separation than NVGPs and they were also able to detect in a more accurate way which kind of stimulus, visual vs. auditory, came first. Moreover, faster temporal processing of stimuli in the auditory domain suggest that benefits of playing generalize over visual processing.

The effect of lateral masking is another phenomenon determined by the combination of spatio-temporal factors including the processing time of the target (Polat & Sagi, 2006). In the task used by Li et al, (2010) participants had to decide in which of two temporal intervals, the first vs. the second, a central Gabor patch was presented. Lateral masking strength was obtained by the increment in the threshold of contrast from the condition of isolation to the flanckered condition. VGPs displayed overall reduced
lateral masking compared with NVGPs and the effect was most marked for backward masking. Backward masking but not forward masking is primarily centrally mediated (Saccuzzo et al, 1996). This is consistent with the idea that videogame play speeds up visual information processing changing the rate at which information is integrated. Then, VGPs are less susceptible to the interference from maskers (Li et al, 2010).

2.2.4 Divided attention

In their version of the UFOV task (see par.2.2.2), Green & Bavelier (2003, 2006) added a centred task to measure the impact of a second task on the performance of the visual search task. VGPs performance relative to those of NVGPs was not affected by the second task, in agreement with the other finding that they have more available attentional resources. They have also better ability to split their attention among moving objects as measured by the Multiple Object Tracking task (Trick et al, 2005).

The flanker compatibility task (see par.2.2.2) involves the ability to divide attention as well, in this case between different aspects of the display. The finding that VGPs ‘suffer’ of interference effect of the distracters also in the difficult condition suggests that they are able to divide their attention among elements in a more efficient way.

2.2.5 Transfer

There is evidence that videogame playing improvements can be transfered to more ecological domains. Gopher et al, (2004) trained cadets of the Israeli Air Force flight school with complex computer game. Flight performance scores of the cadets who
received the training were significantly better than those of a matched group without game experience. Rosenberg, Landsittel and Averch, (2005) showed that novice laparoscopic surgeons trained with videogames had better performance in laparoscopic tasks than those who were not trained.

2.2.6 Imaging studies

To further investigate the finding that action video game playing enhance selective attention, Bavelier et al, (2011) studied the recruitment of frontal and parietal areas during a visual search task using fMRI. Despite VGPs were faster at performing the search task than NVGPs, they showed significantly lesser recruitment of a network usually associated with control of top-down attention while the task became more difficult. Authors interpreted this result as evidence that VGPs have a more efficient allocation of attention that relies on an automation of the process. They manipulated also the presence of static-moving distracters and analyzed the activation of the visual motion-sensitive area. Again VGPS showed less recruitment of those area, suggesting that they may suppress irrelevant motion distracters in a more efficient way than NVGPs.

Voss et al (2011), compared functional brain organization before and after training using functional connectivity analyses of fMRI data. They were interested in examining the interactions among regions as a result of complex skill learning. Participants increased their performance in the game Space Fortress (Donchin et al, 1989). Interestingly, the practice regimen involved different brain systems. The variability of group improvement was associated to the interaction between a memory system and a fronto-parietal network implicated in attentional control e working memory.
Difference in the performance between VGPs and NVGPs was studied also using electrophysiological recording of Steady-state visual evoked potentials (SSVEPs) to flashing stimuli (Mishra, 2011). Frequency tagged SSVEPs is sensitive index of the allocation of visual attention (Muller et al., 1998). The task required both spatial and temporal selection. Participants have to attend to one of three rapid serial visual presentation sequences (RSVP) in three different spatial position, each of one flashing at different rate. Cortical processing of each flashing sequence was analysed by recording its steady-tagged neural response (SSVEP). In the behavioural measure, VGPs performed better in both speed and accuracy in target detection in RSVP. Recordings of the SSVEPs provided insight into the mechanism underlining this superiority. VGPs showed a greater suppression of the SSVEPs elicited by the sequence in the unattended location suggesting they have an enhanced ability to suppress the cortical processing of irrelevant, distracting visual information. Moreover, the P300 component was larger in amplitude to attended targets in VGPs than in NVGPs. Amplitude of P300 varies with the content of the stimulus and the confidence of the perceptual decision. Authors concluded that VGPs can make perceptual decision more accurately and confidently also under high load conditions.

2.2.7 Executive control

There is consistent evidence that action videogame playing allow to orient attention to relevant items more quickly and efficiently, discard distracting items, divide attention in a more efficient way, and they improve visual skills. Studies involving other kinds of videogame find that playing could enhance other cognitive functions such as executive control.
Colzato et al. (2010) investigated the effect on the cognitive system of another type of videogame, “First Person Shooter” (FPS). This kind of videogame requires to manage complex scenarios with sudden visual and acoustic events and to switch back and forth between different subtask. The investigators thought that FPS allow to develop a more flexible mindset with a better ability to reconfigure the cognitive task set. They compared VGPs and NVGPs performance in a task switch paradigm and found that VGPs suffered smaller task switching cost than NVGPs, suggesting that they have better cognitive control.

Another type of videogame, with a more strategic nature, was used to study the possibility to attenuate cognitive decline in older adults. Basak et al, (2008), compared the performance of two groups of older adults in a cognitive battery including a number of tasks that fell in to two general categories: executive control tasks and visuo-spatial attentional tasks. The control group was not trained while the experimental group was trained with Rise of Nation (RON). RON is a complex real-time strategy game that combines both speed of real-time gaming and frequent shifts in component task priority. As expected, significant transfer of training was found on most of the executive tasks, in particular in different types of task switching, but in only one of visuo-spatial task, that is mental rotation. They found also a correlation between the improvement in the speed measures of the game and change in the task switch cost.

Following the results of other studies on task switching, Karle et al, (2010) investigated what aspects of task switching and the related control process are selectively different in VGPs. They implemented two different task switch paradigms to examine VGP versus NVGPs differences. Each of this two paradigms was conceived to stress different factors that are known to influence task switch process. In the first one, they manipulated both the amount of time and information available prior (linked with set
reconfiguration, see chapter 1) but without overlap between the tasks. The reduced degree of overlap between the task set rules likely corresponds to less trial-to-trial interference. In contrast, in the second experiment they used a paradigm with strong overlap between the tasks leading to a great extent of proactive interference between the different tasks. VGPs show less switch cost in the first paradigm but there were no differences in the ability to manage the alternation of the task in the second paradigm. Authors argued that VGPs are able to prepare the task reconfiguration in a more efficient way likely because they have a superior ability to control selective attention (Meiran-Chorev et al., 2000). The absence of benefit in the second experiment seems to indicate that gaming expertise does not make better able to reduce the effects of proactive interference between task set representation. Hence, not every aspect of executive control seems enhanced by videogame playing.

Boot et al. (2008) tried to replicate and extend the results of Green and Bavelier (2003, 2006) to other cognitive abilities. They took both the cross-sectional and longitudinal approach comparing on one hand habitual players with non-players and on the other groups trained with different games or not trained. They chose three different games, expecting game specific effects based on the specific game features. The game types were: a fast-paced action game (visual attention skills), a slower-paced strategy game (executive control skills), or a puzzle game (spatial skills). Participants skills were assessed with a cognitive battery covering a broad range of memory, reasoning and executive control task in addition to visual attention tasks. They found videogame experts outperforming non-gamers in many tasks. In particular, gamers were better at tracking objects moving at greater speeds, they were more accurate in a visual short-term memory test, they were able to switch more quickly between tasks, to rotate objects more quickly and accurately. In contrast to previous finding (Green & Bavelier, 2003, 2006) no
differences reaches significance effect in the UFOV task, in the attentional blink task and in the enumeration task, although there were trends in the expected direction.

Instead, the non-gamers who practiced with the three different games improved their performance in the games they were trained on but they did not improve their performance in any of the test tasks. Practice was not effective in NVGPs. Since the schedule of the practice period was more spaced but also longer than in the studies of Green and Bavelier, the authors attributed their inability to observe transfer effect to task differences.

2.2.8 Exogenous and endogenous deployment of attention

There are not many findings concerning exogenous attention in gamers and the results are quite controversial. Castel et al, (2005) used a version of the classic ‘cuing paradigm’ with an uniformative cue presented in one of two location before the target presentation. In the valid conditions, the cue position correspond, with the position of the target, while in the invalid condition there is no correspondence between cue and target position. When the delay between the two events are brief there is a cost in the RT for detecting the target in the invalid conditions, but after a delay of 200 ms or more target detection becomes faster at the uncued location (inhibition of return effect, Posner et al, 1985). VGPs were not more efficient then NVGPs using the ‘valid’ cue at early delay and showed equal inhibition of return effect than NVGPs at long delay.

The same results were found by Dye et al. (2009) with the orienting cue measure of the ANT (see par.2.2.2). In contrast, West at al. (2008) demonstrated a larger effect of the cue for VGPs in a temporal order judgment task.
Therefore, it seems that videogame experience does not modify the capture of attention by a sudden, salient visual cue but the findings do not allow definitive conclusions.

Visual search task is a good measure of endogenous deployment of attention. VGPs outperformed NVPs in a variety of different paradigms of this type (see 2.2.2) In particular, Hubert-Wallander (2011) used the same type of visual-search of Castel et al.(2005) but collecting a different search rate measure. In the original study, analysis was carried out on traditional RT measures while in the latter they collected accuracy measures. Habitual VGPs demonstrated faster search rates as compared to those who were not and there was significant positive correlation between the two measures. Since faster motor execution implies only faster RT and not better accuracy, the finding supports the view that VGP advantage stems from a difference in the rate of information integration and cannot be solely accounted for by faster motor execution (stimulus response mapping).

In conclusion, the data about the dynamics of exogenous attention are controversial but it seems that there are no differences between the two populations, VGPs vs. NVGPs in exogenous orienting. The literature points to a dissociation in the videogame experience change, with little to no change on transient, automatic aspects of attention but change in the selective and controlled aspect of attention (Chisholm et al, 2010).

2.2.9 Just faster visual processing?
Studies comparing VGPs and NVGPs on many different tasks invariably show that VGPs are faster across a great range of tasks and they do not show speed-accuracy trade-off. The latter findings is important to rule out the hypothesis that VGPs respond quickly simply because they do not wait until enough information is available (i.e. impulsivity). RTs are reported to correlate with better performance on tests of high-level cognition (Conway, Cowen, Bunting, et al, 2002) and be responsible of the observed changes in cognitive performance across the lifespan (Kail & Salthouse, 1994). Action videogame training may therefore prove to be an helpful training regimen for providing a marked increase in speed of information processing for many population such for example in elderly (Clark, Lanphear, Riddick, 1987; Drew & Waters, 1986).

Dye et al, (2010) believe that the more parsimonious explanation for to the superior ability both in accuracy and RT is enhanced visual information processing rather than enhanced attentional resources.

Clark et al, (2011) suggest that this improvement can be due to two different but not mutually exclusive hypotheses. The bottom-up hypothesis suggests that VGPs have an increased capacity to process visual information because the exposure to videogame leads to low-level differences. The top-down hypothesis suggests that VGPs have higher-level abilities such as attentional control (Clark et al, 2011, Chisholm et al, 2010). Clark et al, (2011) to disambiguate if top-down strategies contribute to the improvements showed by VGPs, compared VGPs and NVGPs performance in the ‘flicker’ variant of the change detection task. In the change detection task, participants have to identify a visual change between two scenes temporally separated by a disruption (Simons & Rensik, 2005, for a review). Successful change detection requires to form an appropriate representation and to maintain it in memory for successive comparison. In general, VGPs required fewer exposures to the changing stimulus to detect the presence of the change.
The broader strategies of VGPs (larger moves from one localization to the next) is not due to encoding more visual information on a given fixation. Indeed, the ability to take more information on a given fixation leads to a lower number of unrealized correct localizations. They did not differ from NVGPs in the number of times they accidentally found a change and failed to realize that they had done so. This result offers evidence for a top-down strategy contribution, at least in addition to the bottom up better visual processing.

2.3 Conclusion

There is evidence that videogames enhance a variety of different skills. Most of the research found benefits, especially for visuo-spatial skills. In particular, VGPs seem to outperform NVGPs in the ability to distribute the attentional resources to select a specific item while ignoring distracters items. This is not surprising considering the nature of the videogames used for this study. They are characterized by an environment changing at a fast rate, they require the tracking of multiple objects at once, they require fast shifting between different tasks, they are particularly visually challenging. Other type of videogame, more strategic, are more useful to improve other kinds of abilities such as the ability to plan, to monitor the choice and to choose between different ways to achieve the same results according to the situation. Pulling together the appropriate features may allow to have a videogame that can improve the desired abilities.
3. Videogame “Labyrinth”

3.1 Introduction

Since videogames seem to enhance a variety of cognitive skills and appear to be a promising tool to train these skills, we decided to design a videogame to use it as support of rehabilitation practice. The aim of the study is to create a videogame that involve some aspects of attention and executive functions that often are impaired following traumatic brain injury (Levine et al, 2011).

In order to stimulate patients impaired abilities, we developed a game that implement a task switching and a dual task at the same time. The videogame is constituted by two different games everyone involving focused and selective attention and different strategy of planning. The alternation of the two tasks stimulates the alternating of the two cognitive sets. When a game follow a game of the other type it is necessary to activate the new set and at the same time to inhibit the set of the other task. If the gamer performance reaches a sufficient level of expertise in the single tasks, in some trials he/she have to manage the dual condition. The dual condition engages the divided attention abilities and it stimulates the same attentional bottleneck that limits our behaviour in many daily living situation. Moreover, we think that implementation of both task switching and dual task in the same paradigm constitutes a more demanding situation that better mirrors daily living demands.

A fundamental aspect of rehabilitation practice is the difficulty level of the task administered to the patient. On one hand, if the task is too easy, the effort is not enough to stimulate improvement. On the other hand, if the task is too difficult, the patient may not be able to manage it and may experience frustration. It is worth noting, patients
performance tends to be more variable and less consistent over time than controls (Stuss, 1989; Stuss, 1994). Therefore, it is not easy to organize the progression of practice in a way that promotes performance improvement while finding a balance between patient variability and the choice of optimal task difficulty.

A good solution may be to use “adaptive games” that have shown to be successful in remediation of dyslexia and language impairment in children (Wilson et al., 2006; Merzenich et al, 1996; Temple et al, 2003). The distinctive feature of this kind of games is the adaptive algorithm that regulates the game advancing. In particular, the algorithm has to maintain the task difficulty within the “zone of proximal development” (Vygotsky, 1978), the ideal level of cognitive stimulation. Although this concept comes from education science, it fits well in the rehabilitation context. The main idea is to minimize the failure and at the same time maintain an adequate level of task difficulty. The goal is achieved by adapting the task difficulty to the current level of performance of the patient.

3.2 The play ground

A little man moves along a maze to reach a goal. The game character is controlled by the gamer through a joystick. The walls that gave form to the maze are variable: both their quantity and their location change every six trials accordingly with the task difficulty. The only constrain in the random distribution of the walls is that the software avoids the appearance of closed areas since this can prevent the goal achievement.

The maze difficulty changes accordingly with the kind of task. Indeed, the game consists of two tasks, the ‘diamond’ task and the ‘snake’ task (see 3.3). Overall, every task has six difficulty levels, across a continuum ranging from the less demanding, the
(level 1), to the more demanding (level 6). In the ‘diamond’ task, the easier the maze is the one with less walls as possible (see 3.3) and the number of walls increases in conjunction with the improvement of the performance. On the opposite, in the ‘snake’ task, the easier maze is the one with more walls as possible and accordingly, the number of walls diminishes with the impairment of performance.

3.3 The tasks

The goal of the game character depends on the nature of the current task. In the ‘diamond task’, the man has to collect the diamonds that are randomly distributed across the play area. Accordingly with the difficulty level, the number of diamonds ranges from one, in the less demanding level, to six in the more demanding level. The achievement of the goal requires the participant to plan a route that allow to collect every diamond within the time limit. Usually the best strategy is to follow the shortest path passing through the

Fig. 2 “Snake task” (see 3.3)
In the ‘snake’ task, the man has to avoid to be caught by a snake and to reach a ‘shelter’ house that appears at a random location. The range of difficulty is enforced by controlling the running speed of the snake. The achievement of this task requires a very different strategy compared to the diamond task. The best strategy is sometimes the opposite: Indeed, if the man takes the shortest way to arrive at the ‘shelter’ house, it is likely that the snake will catch him. Avoiding to being caught often requires to choose a longer route, sometimes moving even in the direction opposite to the house location.

Likewise, depending on the location of the house and the disposition of the maze walls, another good strategy may be to stop for a while, in a strategic location, waiting for the snake to take a wrong route. In this way, reaching the house becomes possible provided that the gamer chooses the right moment and moves quickly. Basically, the task requires adopting complex strategies involving the ability to plan and sometimes also
inhibiting the most ‘automatic’ action.

3.4 Switching and multitasking

The two kinds of task, ‘diamond’ and ‘snake’, alternate between each other with a frequency that is adjusted according to the performance score. The difficulty of this ‘switch task’ has four levels ranging from a completely predictable switching, when one task follows the other, to a completely random switch. The two medium levels are a switch every two trials and a switch every three trials.

Fig. 3 Dual task (see 3.3)

The switch task should involve the cognitive processes necessary to alternate attention between the two tasks. The beginning of a new task requires configuring the correct rule set, turning the attention on the representation of the correct goal (see 1.2.3) and the sequence of action necessary to reach the goal. At the same time, it requires inhibiting the other task.
The alternation, predictable vs. unpredictable, taps both the endogenous and exogenous allocation of attention (see 1.2.3). In particular, random switch should be more demanding since it does not allow the preparation of the task in advance. However, there is consistent evidence that TBI patients suffer more of endogenous allocation of attention (Stablum et al, 2004). Therefore, it would be the case they find difficult the predictable as well as the unpredictable.

In some trials, the gamer has to perform the two task simultaneously. In these trials the participants has to avoid the snake and to collect the diamonds at the same time. Contrary to the single ‘snake’ task, in this case the ‘shelter’ house appears only after all diamonds are collected. Performing the two tasks simultaneously should act as a dual task. In this case, the task requires actively maintaining the two cognitive sets and dividing attention resources between the two goals (but see 1.2.2).

Overall, the successful performance consist to reach the respective goal, collecting every diamond or/and avoid the snake within the time limit. If the trial is performed correctly the player receives some points, whereas if the participant fails to reach the goal some points are subtracted from the score. Every six trials the gamer receives a feedback concerning his/her performance. The time limit gives a temporal pressure that may support processing speeding-up.

The type of practice, with alternation between two single task and dual task, may be seen also as a variable priority regimen of practice. Contrary to fixed priority, the variable priority (VP) emphasizes the sub-components of the task. Voss et al. (2011) showed that VP encourage the use of different brain networks and facilitates the formation of efficient, automatic higher-level schema. Moreover, VP seems to affect networks that implement higher-order relationship between goal and actions (Kantak et
al, 2010). Flexible or integrated training regimens, requiring constant switching of processing and continual adjustments to new task demands have also been argued to lead to greater transfer (Bherer et al, 2005).

3.5 Calibration of the difficulty

Following Wilson et al, (2006) we used a multidimensional learning algorithm to adapt constantly the task difficulty to the current performance of the gamer. Adaptation was implemented using three dimensions of difficulty:

1) Time limit: the time limit to perform the task. There are 10 different levels of difficulty ranging from 20 to 100 seconds. It is updated every trial.

2) Difficulty of the task: overall it has six levels but the kind of difficulty depends on the task. In the ‘diamond’ task, it is related in the number of diamond that have to be collected (from 1 to 6). In the ‘snake’ task, it is related to the snake speed. In both the tasks the difficulty consists also in the number of walls of the maze (see par.3.2). It is update every trial.

3) Switch task: the kind of switch, predictable vs. unpredictable. It has four levels (see par.3.4). This dimension is updated every 12 trials.

The combination of the three dimensions forms the ‘training space’. Wilson et al, (2006) described the “learning space” (that in this context corresponds to the ‘training space’) as a cube with the three dimensions of difficulty as sides. Every trial consisted in a point of this cube and every point is associated with a certain probability of success. Higher probability is associated with easy trials and the opposite for the hard trials. Every subject shows a different probabilities of success matrix. For example, a patient who is
more impaired inhibiting automatic responses and less impaired with updating will have a higher probability of success in the ‘switch’ dimension and lower probability of success in the ‘difficulty’ of the snake task dimension.

The task of the algorithm is to estimate the ‘space of performance’ of the subject accordingly with the current performance. After sampling points within the space, the algorithm uses the response of the subject to build an interpolated model of the entire performance space. Then, it select a point in the space which it estimates that corresponds to the level required to maintain performance at 75% of accuracy. Moreover, with the game advancing, the algorithm update the ‘space of performance’ accordingly with the success or failure of the gamer.

The dual task condition is administered only if the percentage of successes is more than 60%. When the gamer achieves this performance level, the probability to have a dual task is 30%. In this way, the subject can reach enough expertise in the two single tasks before managing the more difficult dual task condition.

3.6 Conclusion

After positive evaluating of the algorithm with a mathematical simulation, we decided to test the game in two different studies. The aim of the first studies was to validate the game and confirm that it involves the cognitive abilities that it is supposed to train. The aim of the second studies was to evaluate the possibility of using it as rehabilitation tool. Therefore, we carried out a pilot study testing a rehabilitation protocol with TBI patients.
4) Study 1: Validation

4.1 Introduction

The videogame “Labyrinth” has been conceived as a tool for the enhancement of specific skills. The main goal is to use it in supporting the rehabilitation process of TBI patients. The game should involve specific abilities such as alternate attention and divided attention beyond selective and sustained attention, planning and inhibiting automatic responses. Before testing the game in a rehabilitation protocol with TBI patients we decided to validate the game with unimpaired participants to ensure that the game practice involve those skills. The ‘validation’ consists in the administration of a play session to unimpaired participants and the analysis of the performance to assess the presence of specific effects. In particular, we were interest to find the effects of dual task and the effects of the task switch in the different dependent measures of the game.

The game consists of two different tasks, the ‘diamond’ task and the ‘snake’ task. If the alternation between the two tasks works as switch condition we expect to find that the participants’ performance will show a cost when one task is followed by the other task relative to when it is follow by the same task (Monsell, 2003). Usually the cost consists in worse accuracy in the new task relative to the repeated one and/or in slower RTs in the new task relative to the repeated one. Likewise, performing the two tasks at the same time should be more difficult than performing one task at once, showing the cost of the dual task condition. If this is the case, accuracy should be worse and RTs slower in the dual task condition.

Videogame output is quite different from the output of the classical experimental paradigms. We have therefore to devise other types of dependent measures compared to
classical accuracy and RT ones. The videogame performance is scored with four different measures that became the dependent variables of our analysis. The four types of score are:

1) Accuracy: whether the task is completed with success or not, within the time limit;

2) Overall time: the time taken to complete the task;

3) Timer D: the time to collect the first diamond.

4) Space S: the distance from the snake after 3 sec.

In addition, in the same session, participants had to perform two other independent tasks. One task was a ‘classical’ switch task, commonly used to tap the alternate attention. The other was a ‘classical’ dual task, used to tap divided attention.

The idea was to evaluate the possible correlations between the costs in the videogame tasks and the costs in the two standard experimental paradigms. For example, one participants might suffer, less of the cost of dual task condition compared to another subject because he/she is able to divide attention in a more efficient way between the two concurrent task. If the ‘classical’ dual task and the dual task condition in the videogame are tapping the same skills, then the participant’s performance will be high in both paradigms and it should be correlated.

Therefore, a positive correlation would be a further evidence that the videogame tasks require the involvement of attention-executive functions as studied with the experimental paradigms. However, there is also evidence that both alternative and divided attention are not a single factor but instead they consist of different subcomponents (see 1.2). If this is the case, it should be possible to find dissociation between single
components with individuals with better skills in some of them and not in the others. Then we can also value if three completely different tasks conceived to tap the same cognitive skills correlate between them or this skills could have other dissociations.

4.2 Method

Participants

Twenty nine healthy adults (mean age 22.5; 10 females, 19 males), recruited from the University of Padua, participated in the study. They had normal or corrected-to-normal vision, 27 were right-handed and 2 were left-handed preference.

Apparatus

The experimental paradigms were controlled by E-Prime 1.1 software (Schneider, Eschman, & Zuccolotto, 2002). Stimuli were presented on a 33”, 75 Hz monitor screen. Each subject viewed the display from approximately 60 cm in a diminished lit room.

Procedure and stimuli

Each participants had to perform three different tasks. The order of the task were counterbalanced between the participants.

Dual task. Every session began with a brief block of practice. The experimental part was divided in two blocks, one of single task and one of dual task. The order of the task was counterbalanced between participants. In the single task, at the beginning of each trial, a fixation dot was presented at the center of the screen. After 1000 ms the fixation dot was replaced by a letter. The stimulus was randomly chosen between one of the vowels A,E,I,U or one of the consonants C,L,M,P with each letter presented the same number of times. The participant made a decision about wheter the letter was a consonant
or a vowel pressing the ‘z’ or the ‘m’ button on the keyboard (the stimulus-response button by mapping was counterbalanced between participants). After the recording of the response there was a 1000 ms long blank screen before the beginning of the new trial. The dual task condition was identical to the single task condition but at the same time of the consonant/vowel judgment participants had to count backward aloud, starting from 100 and carrying on in the reverse order. The complete experiment consisted of 240 trials.

*Task switching.* Each session began with a brief block of practice. The experimental part was divided in three blocks, one block of 96 trials consisting in a letter task, one block of 96 trials consisting in a number task, and one block of 160 trials comprising both tasks alternating between each other in a random way. The order of the blocks was counterbalanced between the participants. The complete experiment consisted of 380 trials. Every trial began with a 1000 ms long fixation dot replaced by the stimulus. After the response collection with the keyboard there was a 1000 ms long blank screen before the new trial. In the letter task, the stimulus consisted of a letter randomly chosen between the vowels A,E,I,U or the consonants C,L,M,P, with each letter presented the same number of times. Participants had to make a decision about whether the letter was a vowel or a consonant by pressing the ‘m’ or the ‘z’ button of the keyboard. In the number task, the stimulus consisted of a number randomly chosen between 2,3,4,5,6,7,8,9. Participants had to make a parity judgment, deciding if the number was even or odd number, pressing the ‘m’ or the ‘z’ button of the keyboard (the stimulus-response button mapping was counterbalanced between participants).

*Videogame.* For this study we used a slightly different version of the videogame described in the Chapter 3. The main difference between the patients version (see chapter 3) and the present version was that the maze walls were removed. This was done to avoid the variability of the environment, which would introduce a possible confound. The
session began with a block of trials controlled by the adaptive algorithm. The level of difficulty reached in this part was selected for the remaining blocks. Then, the level of difficulty was kept at the same level for the rest of the experiment. There were three blocks, each of 60 trials, presented in a fixed order. The first block had 20 ‘diamond’ tasks, 20 ‘snake’ tasks, and 20 dual tasks presented in a fixed order. The second block had the ‘diamond’ and the ‘snake’ tasks alternating each other in a random way. The third block was constituted by the two single task adding the dual task (30% of the trials). The single task conditions and the dual task condition in the last block alternated each other in a random way.

4.3 Results

Data were analysed employing mixed-effect multiple regression models (Baayen, Davidson & Bates, 2008) using lme4 package (Bates & Sarkar, 2006) in the R environment (R Development Core Team, 2006). We report regression coefficients (b), standard errors (SE) and p values (evaluated with the method suggested by Baayen, 2008, which estimates the degree of freedom by subtracting the number of fixed-effect parameters from the total number of data-points considered). Participants were introduced as random effects. The random effects included in our model significantly improved the explanatory value of the model as indicated by the likelihood ratio tests (all p <0.001)

4.3.1 Dual task paradigm

Reaction time. The RT analysis was performed only on correct responses. We log transformed the durational dependent measures to normalize the distribution and then we
removed observations 2.5 standard deviations greater or smaller than the mean. The effect of condition, single vs. dual task, was not significant (b = -0.18, SE = 0.01, p < 0.001) indicating that RTs in the dual task condition were slower than in the single task condition (Fig.4)

**Accuracy.** The dependent variable was dichotomous hence we applied a multiple regression model with a logistic link function and binomial variance (Jaeger, 2008). The effect of condition, single vs. dual task, was not significant (b = -0.02, SE = 0.12, p = 0.86) indicating participants in the dual task condition were as accurate as in the single condition.

4.3.2 Task switch

**Reaction time.** The RT analysis was performed only on correct responses. We log transformed the durational dependent measures to normalize the distribution and then we
removed observations 2.5 standard deviations greater or smaller than the mean. The effect of condition, repetition vs. switch, was significant \((b=-0.08, SE=0.01, p<0.001)\) indicating that RTs in the switch condition were slower than in the condition of repetition (Fig. 5).

**Accuracy.** The dependent variable was dichotomous hence we applied a multiple regression model with a logistic link function and binomial variance (Jaeger, 2008). The effect of the condition, repetition vs. switch, was not significant \((b=0.12, SE=0.11, p=0.27)\) indicating that there were no differences in the accuracy between the two conditions.

![Fig. 5 Task switch effect in the task switching paradigm](image-url)
4.3.3 Video Game

  I. Dual task effect

  Accuracy. The dependent variable was dichotomous hence we applied a multiple regression model with a logistic link function and binomial variance (Jaeger, 2008). The effect of condition, single vs. dual task, was significant (b= -2.08, SE= 0.08, p<0.001) indicating that in the dual task condition participants were less accurate than in the single task condition (Fig.6).

  **Fig. 6 Dual task effect in the videogame, accuracy measures (see 4.3.3)**

  Overall Time. The analysis of the time necessary to complete the trial was performed only on successful game trials. We log transformed the durational dependent measures to normalize the distribution and then we removed observations 2.5 standard deviations greater or smaller than the mean. The effect of condition, single vs. dual task, was significant (b= 0.76, SE= 0.03, p<0.001) indicating that the time to complete the trial in the dual task condition were longer than in the single task condition (Fig.7).
Fig. 7 Dual task effect in the videogame, time measures (see 4.3.3)

Timer D. The analysis of the time necessary to collect the first ‘diamond’ has performed only on successful game trial. We log transformed the durational dependent measures to normalize the distribution and then we removed observations 2.5 standard deviations greater or smaller than the mean. The effect of the dual condition, single vs. dual task, was significant (b = 0.04, SE = 0.01, p<0.001) indicating that the time to collect the first ‘diamond’ in the dual task condition was longer than in the single task condition (Fig.8).
Fig. 8 Dual task effect in the videogame, Timer D measure (see 4.3.3)

Space S. The analysis of the distance from the ‘snake’ after 3 sec. was performed only on successful game trials. We log transformed the dependent measures to normalize the distribution and then we removed observations 2.5 standard deviations greater or smaller than the mean. The effect of condition, single vs. dual task, was significant (b=0.26, SE=0.03, p<0.001) indicating that the distance from the ‘snake’ after 3 sec. in the dual task condition was longer than in the single task condition (Fig. 9).
II. Task switch effect

Accuracy. The dependent variable was dichotomous hence we applied a multiple regression model with a logistic link function and binomial variance (Jaeger, 2008). The effect of the switch condition, repetition vs. switch, was significant (b= 0.12, SE= 0.06, p<0.05) indicating that participants were less accurate when a trial followed a trial of a different task relative to when it followed a trial of the same task (Fig.10).
Overall Time. The analysis of the time necessary to complete the trial has performed only on successful game trials. We log transformed the durational dependent measures to normalize the distribution and then we removed observations 2.5 standard deviations greater or smaller than the mean. The effect of the switch condition, repetition vs. switch, was significant ($b = 0.05$, $SE = 0.02$, $p < 0.01$) indicating that participants were slower in completing the task when a trial followed a trial of the same task relative when it followed a trial of a different task (Fig. 11).
Timer D. The analysis of the time necessary to collect the first ‘diamond’ has performed only on successful game trials. We log transformed the durational dependent measures to normalize the distribution and then we removed observations 2.5 standard deviations greater or smaller than the mean. The effect of the switch condition, repetition vs. switch, was significant (b= 0.01, SE= 0.01, p<0.05) indicating that participants were slower to collect the first ‘diamond’ when one trial followed a trial of a different task relative to when it followed a trial of the same task (Fig.12).
Space S. The analysis of the distance from the ‘snake’ after 3 sec. was performed only on successful game trials. We log transformed the dependent measures to normalize the distribution and then we removed observations 2.5 standard deviations greater or smaller than the mean. The effect of the switch condition, repetition vs. switch, was not significant (b= 0.01, SE= 0.02, p= 0.995) indicating that there was no difference between the distance from the ‘snake’ after 3 sec. when one trial followed a trial of a different task relative to when it followed a trial of the same task.

4.3.4 Correlation

Videogame tasks, the switch between the ‘diamond’ task and the ‘snake’ task, and performing both the task simultaneously, showed switch cost and dual task cost, at least
for some dependent measures. The experimental tasks we chose as dual task and switch paradigms showed the expected cost effects in the RT measures. Then we evaluated if the performance in these very different tasks, supposedly measuring the same ability, correlated between each other. The dependent variables of the videogame were quite different from the classical RT measure: the overall accuracy (if the task was completed satisfactorily), the time to complete the trial and two measure thought to be more similar to the experimental measures. One is the time to collect the first diamond (Timer D) and the other is the distance from the snake after 3 sec from the onset of the trial (Space S).

We calculated the cost of each condition subtracting the performance in the easier level of the condition from the performance in the more difficult level. For example, the RT cost of the dual task was computed by subtracting the performance in the single task condition form the performance in the dual task condition. Then we computed Bravais-Pearson correlation between the cost in the RT of the two experimental paradigms and the cost in each of the different measures of the videogame.

**Dual task.** The cost in the RT of the ‘dual task’ paradigm was not correlated with the cost in the accuracy and in the time to perform the dual task condition of the videogame. The correlation between the cost of the dual task in the videogame variable ‘Space S’ and the cost in the RT of the dual task paradigm was $r=0.29$, but it was not significant. The correlation between the ‘Timer D’ variable and the RT of the dual task paradigm was significant, $r=0.41$, $p<0.05$. The correlation between the cost in the accuracy of the dual task paradigm and the cost for the ‘diamond’ task were significant, $r=0.37$, $p<0.05$ (Fig 13).
**Task switch.** Also in the case of the task switch there were no significant correlations between the costs in the accuracy and time to complete the trial and the RT cost measures in the task switch paradigm. Timer D was not correlated with RT cost but Space S was significantly correlated with the RT cost, $r = 0.41$, $p < 0.05$ (Fig. 14).
4.5 Discussion

The first aim of this study was to validate the game “Labyrinth”. Since the game was conceived to tap specific abilities, we tested the game to assess if the performance involves these abilities.

Playing a game with these characteristics is likely to involve many different cognitive skills, some more basic, and some of a higher level. For example, the achievement of the task requires selecting the relevant information and discarding the irrelevant one. Performing the task until the end of the session requires to sustain attention at an adequate level as long as the session length. The aim of the study was not to assess every kind of cognitive ability necessary to perform the game. We concentrated on some more higher level abilities that we think are peculiar of the game and we think they make the game particularly suitable for the rehabilitation of TBI patients. In
particular, we tried to assess if the performance of unimpaired participants showed the cost of the dual task and the cost of the switch task, confirming the involvement of divided and alternate attention.

The performance of the unimpaired participant in the session with the videogame showed the classic cost of dual task. We had four different score measures for the videogame: accuracy, time to perform the task and two special measures conceived to be more comparable with the RTs of classic experimental paradigms. Three of these measures confirmed that in the dual task condition the accomplishment of the task was more difficult than in the single task condition. The percentage of success, in terms of accuracy of the two tasks, was higher when the tasks were completed alone. The dual task effect was confirmed also in the time dependent variable, the time to complete the task, that was longer for the dual task condition compared to the single task condition. Likewise, the time to collect the first diamond in the ‘diamond’ task was longer when the gamer had to collect the diamond and to avoid the snake at the same time compared to when he/she had only to collect diamonds. The difference between the two conditions, single vs. dual task, did not differ for the other score, the distance from the snake after 3 sec. The finding that there was no dual task effect in Space S may be due to the possibility that sometimes the ‘snake task’ requires the use of complex strategies such as taking a longer route or wait for a while (see 3.3). This kind of strategies may act as a variable of confusion, adding noise that is not possible to control. Thus, assessing whether Space S is a valid measure or it is not, will require further investigation.

Altogether, the results confirm a robust dual task effect, thereby showing that completing the two tasks simultaneously requires to divide the attention between the two goals. The cognitive system has a limited capacity processing that acts as a bottleneck or severely constrains the performance of more than one task at the same time (see 1.2.3).
There is evidence that the limited capacity mechanism acts as a unified attentional bottleneck that does not allow to share attention between the two tasks (Tombu et al, 2011). In this case, the dual task condition implies the rolling over of one of the tasks with the consequence of lengthening the time to accomplish the goals or to deteriorate the performance.

The results of the analysis of the performance regarding the switch task are less clear. In this case we aimed to compare the performance between the condition of repetition, when one task followed a task of the same type, with the condition of non repetition, when one task followed a task of the other type. The distance from the snake after 3 sec. was not significantly different between the two conditions. Together with the previous finding, it argued against the validity of this measure, due to the high probability that it is affected by confusion variables. In contrast, the percentage of success in the condition of repetition was higher than in the switch condition. When the task followed the same task, it was less difficult to complete the task successfully compared to the condition when the task followed the task of the other type, in line with the findings using the classical switch task paradigm (Monsell, 2003). The other two measures, the time to complete the task and the time to collect the diamonds showed a switch cost in the opposite direction. It means that repeating the task led longer completion time than changing the task. The same happened for the time to collect the first diamond. Altogether, it is difficult to interpret the findings of the switch task. The effects on the accuracy measures and on time measures were in opposite directions. One possible hypothesis is that the effect of the switch is less robust than the dual task effect and that the time measures have been influenced by confounding variables. Indeed, the difference between the two conditions, repetition vs. switch, was very small compared to the time to complete the task. Therefore, the effect of the reconfiguration of the new task or of the
inhibition of the cognitive set of the prior task (see 1.2.4) may be covered by the relatively large amount of time that passed before finishing the trial. In contrast, the dual task effect was so robust that also the time measures showed the effect. In conclusion, accuracy measures appear to be a more reliable index of performance.

The study was carried out also to verify the external validity of the game. Indeed, in the same session, the participants carried out other two, experimental tasks, dual task paradigm and task switch paradigm. We hypothesised that if the videogame involves the same abilities tapped by the classic experimental paradigms, there should be correlation between the performance of the participants in the different tasks. A participant with a more efficient capacity to allocate the attention should have a better performance both in the videogame and in the two experimental paradigms. However, correlation between the different measures was modest. For the dual task condition, a positive correlation was found only between time to collect the first diamond and the RT in the dual task paradigm, and between the accuracies in the ‘diamond’ task and dual task paradigm. For the switch task, a positive correlation was found between the distance from the snake after 3 sec. and the RT of the switch paradigm.

On one side there is consistent evidence that, thought the existence of a unified attentional bottleneck limiting cognitive process also very different from each other (Tombu et al, 2011), there is also specific effects related to the particular task. Since the videogame and the experimental tasks used here differ for many aspects, it would be the case that the two performances do not correlate because they are influenced by the peculiarities of the specific tasks. Therefore, it is not possible to conclude that the two type of paradigms are tapping different abilities. The presence of both the cost in dual task condition and switch condition in the videogame scores proved it involves divided and alternate attention.
5. Study 2: Rehabilitation protocol with TBI patients

5.1 Introduction

Study 1 partially confirmed that playing the videogame “Labyrinth” involves at least some of the specific abilities it was conceived to enhance. To test the possibility to use the videogame as support to the rehabilitation of TBI patients, we carried out a pilot study with a rehabilitation protocol.

Neuropsychological rehabilitation is a process directed to help people who have sustained an insult to the brain to achieve their optimum well-being reducing the impact of their problems in everyday life. Rehabilitation needs to involve personally meaningful themes, activities, settings and interaction (Wilson, 2009). There are several ways to pursue this goal: helping patients use their residual skills, trying to compensate the impairment with the use of external aids etc. One of these is attempting to restore lost functioning and encouraging anatomical reorganization. Although there is debate about the evidence that this is an effective rehabilitation strategy (Wilson et al, 2009) we think that, together with other approaches, it has to be taken into account, especially considering the young age of most TBI patients.

There is evidence that neuroplasticity, that is the brain’s capacity to change and alter its structure and function, works in the adult brain as well in the young one. Learning and experience cause physical changes in the brain and the same mechanism that supports normal learning may be activated in individuals with brain damage (Kolb &Gibb, 1999). The plasticity is directly related to experience hence the training is useful to encourage the process of synaptic connectivity modification. Neuroplasticity may improve the
cognitive functions also supporting compensation in a neurological sense. Indeed, the reorganization of circuitry related to the lost function as well as compensatory reorganization of more remote neuronal circuits can provide a way to accomplish a given behaviour in a different manner (Xerri et al, 1998; Seitz et al, 1995). Moreover, Nudo et al, (1996) showed that exercise and training prevented the loss of representation in adjacent tissue in monkeys with lesion to the hand area.

Robertson and Murre (1999) have proposed the distinction between bottom-up and top-down process in rehabilitation. Bottom-up processes refer to the provision of perceptual, motor or similar inputs to the damaged network. Repetitive training of this type have consistently demonstrated to be effective in different domains such as motor recovery or speech (Butefish et al, 1995; Tallal et al, 1996). Top-down processes refer to the idea that frontal attentional circuits modulate the plastic changes in the brain (Meyer et al, 1991). Accordingly, it is possible to argue that recovery of function is related to the integrity of frontal attentional brain system (Sohlberg & Mateer, 2001). Therefore it is possible to conclude that efforts to improve attention function should be the most beneficial.

5.2 Method

5.2.1 Participants

Eight patients with diagnosis of severe TBI participated in the study. They were assigned to the two treatment groups in a way that allowed to match the groups for age, gender and education. All patients gave informed consent for participation.
Estimates of Post Traumatic Amnesia (PTA, mean=32 days). All of these cases were classified as very severe injuries according to Teasdale’s system (Teasdale, 1995)

**Inclusion criteria**

- Diagnosis of severe TBI;
- Attention and executive deficits diagnosed by neuropsychological assessment (see 2.3 and see Appendix A).

**Exclusion criteria**

- Presence of neurological and psychiatric impairment before the trauma;
- Presence of global intellectual impairment;
- Presence of alcohol or chemical addiction.

5.2.2 **Procedure**

Each participant was tested according to the following procedure:

I. **Assessment 1** included the battery of neuropsychological tests for the screening of attentional and executive functions and the Mini Mental State Examination (See 2.3);

II. **Two weeks of interval**;

III. **Assessment 2**: (See 2.3);

IV. **Treatments**: standard rehabilitation treatment and four weekly sessions, each lasting 30 min., for four weeks with a computer game:
   - Experimental group: videogame “Labyrinth”;
   - Control group: “Solitaire” Card Game.

V. **Assessment 3**: (See 2.3);
VI. Two months of interval:

VII. Assessment 4: (See 2.4).

5.2.3 Battery of tests for the neuropsychological assessment

The first assessment consisted of the battery of neuropsychological tests for the screening of attentional and executive functions and the Mini Mental State Examination Test (MMSE). MMSE was part only of the first assessment to exclude the presence of global intellectual impairments. Most of these tests are multifactorial requiring processing speed, visual scanning, in some case quick motor response, sustained attention, shifting or multitasking.

a) Mini Mental State Examination Test (MMSE): a cognitive screening instrument that enables the overall assessment of the patient’s mental state. It evaluates temporal orientation, spatial memory, attention, language and praxia (Folstein et al, 1975).

b) Attentive Matrices Test: a visual search test used as measure of selective attention. It requires also some degree of divided attention (Spinnler & Tognoni, 1987).

c) D2 Test: a concentration-endurance test involving simultaneous presentation of visually similar stimuli. It requires complex processing to differentiate targets and non targets and also to allow for detection of varying stimulus configurations of targets. It allow to analyze sustained, selective and divided attention (Brickenkamp & Zillmer, 1998; Bates & Lemay, 2004).

d) Wisconsin Sorting Card Test (WSCT): a test used in clinical practice to assess frontal lobe functions, in particular the ability of reasoning and of shifting cognitive strategies. It requires the ability to develop appropriate problem solving strategies and the ability to change them when negative rewarding occurs (Laiacona et al, 2000);
e) Stroop test: a test frequently used in clinical practice to assess selective attention, cognitive flexibility, sensitivity to interference and inhibitory control (Caffarra et al., 2002);

f) Tower of London Test: a test used to assess executive functions, in particular the ability to plan efficient solutions to solve a problem. The test requires the identification of a general plan, the identification of sub-goals and the organization of those sub-goals in a sequence (Shallice & McCarthy, 1982).

g) Trail Making Test (TMT): it consists of two different parts. Part A requires focused attention’ while part B requires set shifting and some degree of divided attention (Reitan & Wolfson, 1995, Mondini et al, 2008).

h) Phonemic and Semantic Fluency Test: these tasks measure the fluency component of the executive functions. They require retrieval from long-term memory, sustained attention and executive control to organize retrieval, monitoring responses to avoid repetitions, and inhibit responses that do not fit (Spinnler & Tognoni, 1987; Mondini et al., 2008).

i) Symbol Digit Modalities Test: it requires to match symbols with paired numbers. It is a test frequently used as measure of speed of processing, sustained attention and switching (Smith, 1973; Nocentini et al, 2006)

5.2.4 Treatment game of the control group

The control group used the “Solitaire Card Game” from the Windows package. This game is sometimes used as exercise for cognitive functions in rehabilitation centres. Since it is a more strategic game, it is likely that it involves numerous specific abilities such as planning and monitoring but it is not a fast pace game and does not require multitasking.
5.2.5 Experimental design

We used a mixed design with one factor as between-subjects variable (Treatment type, two levels: experimental vs. control) and one factor as within-subjects variable (Neuropsychological Assessment, four levels: two pre-treatments vs. two post treatments). Dependent variables are the scoring of the battery tests.

This design is particularly useful to control confounding variables such as learning effects and spontaneous improvements. When the same test is repeated several times it is likely there are a trend to have better performance but it is due to the repetition of the same. Test the first two assessments allow to have a baseline of the level of cognitive functioning, controlling potential effects due to repetition of the same tests. Indeed, a significant difference between the first two assessments can be attributed only to those kinds of effect. The treatment effect could be demonstrated only with a planned comparison between the first difference (assessment 1- assessment 2) and the second difference (assessment 2 - assessment 3), showing they are significantly different.

The comparison between the third and the fourth assessment is conceived to evaluate if positive effect of the treatment persists over time beyond the treatment period.

5.3 Results

5.3.1 Statistical analysis.
Since the number of patients is limited, we analyzed the data using every participant of the experimental group as ‘single case’ in comparison with the performance of the control group. For each patient we calculated the three difference score of interest:

- Difference 1: difference between the first and the second assessments, indicating learning or spontaneous improvement effects;
- Difference 2: difference between the second and the third assessments, indicating treatment effects;
- Difference 3: difference between the third and the fourth assessments, to evaluate if an improvement due to the treatment persists beyond the end of the treatment, at least for the subsequent two months.

We used the Test of Crawford for comparing an individual patient's score with a control sample (Crawford & Howell, 1998) for each difference to test if there is any difference between the performance of the experimental patients and the control patients. This test is more conservative compared to the one-sample t-test because it assigns the control group variance to the single subjects score rather than treating it as a constant with zero variance (see Mycroft at al. 2002).

5.3.2 Patient 1

The Difference 1 variable for the Fonemic Fluency test was significant $t(3)= 4.58$, $p<0.05$, indicating that the patient improved more than the control groups between the first and the second assessment. The Difference 1 variable for the Semantic Fluency test was significant $t(3)= 4.58$, $p<0.05$, indicating that the patient performance did not decrease compared with the control group performance between the first assessment and the second assessment. The Difference 1 variable for the TMT-B-A test was significant
t(3)= 4.58, p<0.05, indicating that the control group improved more than the patient between the first assessment and the second assessment. None of the Difference 2 variables showed a significant change in the patients with respect to the control group.

5.3.3 Patient 2

The Difference 1 variable for the Semantic Fluency test was significant t(3)= 5.5, p<0.05. The Difference 2 variable for the Tower of London test was significant t(3)= 5.62, p<0.01, indicating that the patient improved more than the control group between the assessment before the treatment and the assessment after the treatment (Fig 15).

![Tower of London - Patient 2](image)

*Fig. 15 Tower of London performance, patient 2.*

5.3.4 Patient 3
The Difference 2 variable for the Fonemic Fluency test was significant $t(3)= 3.39$, $p<0.05$ indicating that the patient improved more than the control group between the assessment before the treatment and the assessment after the treatment (Fig. 17). The Difference 1 variable for the Semantic Fluency test was significant $t(3)= -5$, $p<0.05$, indicating that the patient improved more than the control group between the first assessment and the second assessment. The Difference 2 variable for the Tower of London test was significant $t(3)= 5.61$, $p<0.05$ indicating that the patient improved more than the control group between the assessment before the treatment and the assessment after the treatment (Fig. 16).

The Difference 1 variable for the TMT B-A test was significant $t(3)= 19.63$, $p<0.05$, indicating that the control group performance declined compared with the patient performance between the first assessment and the second assessment.

The Difference 1 for the TMT B test approached significance $t(3)= -2.67$, $p=0.07$, indicating that there was a tendency for the patient to improve more than the control group between the first assessment and the second assessment. The Difference 2 for the TMT B test approached significance $t(3)= 2.62$, $p=0.07$, indicating that there was a tendency for the patient to improve more than the control group between the assessment before the treatment and the assessment after the treatment (Fig. 18).
Fig. 16 Patient 3, Tower of London test.

Fig. 17 Patient 3, Fonemic fluency test.
5.3.5 Patient 4

The Difference 1 variable for the TMT B-A test was significant \( t(3) = 18.47, p<0.05 \), indicating that the control group performance declined compared with the patient performance between the first assessment and the second assessment. The Difference 2 variable for the Tower of London test was significant \( t(3) = 7.67, p<0.01 \) indicating the patient improved more than the control group between the assessment before the treatment and the assessment after the treatment (Fig. 19).
5.4 Discussion

The aim of this pilot study was to examine the possibility to use the videogame ‘Labyrinth’ as a training tool to support the rehabilitation of specific functions in TBI patients. The study consisted in the administration of a rehabilitation protocol to eight patients that had sustained a TBI. The cognitive functions of the patients were assessed with a battery of neuropsychological tests particularly devoted to the evaluation of attention and executive disorders. Patients were divided in two groups, one that was treated with the videogame ‘Labyrinth’ and the other that was treated with a control game. The statistical analysis were designed to detect any difference between the two
groups in the improvement after the treatment. In particular, we expected the group that was treated with our videogame to improve more than the other group.

In Study 1 we demonstrated that the videogame require the involvement of divided attention and alternate attention. There is consistent evidence that action videogame play provides a marked increase in speed of information processing (see 2.2.10). Labyrinth involves abilities to plan, to inhibit the most automatic response, to chose complex strategies in addition to some more basic skills such as the selection of the stimulus to attend, the ability to maintain the attention on the task etc. Therefore we expected to find improvement in many different tests.

The battery of neuropsychological tests used for the assessment was broad and covered many aspects of attention functions (see 4.2.3). Moreover, each test is frequently used in the clinical assessment of cognitive functions. Two tests, Attentive Matrices and D2 are particularly indicated for the assessment of selective and divided attention. The Stroop test is used to assess selective attention and sensitivity to interference. TMT is particularly devoted to assess the ability to switch and to divide attention. WSCT and Tower of London are used to assess frontal lobe functions such as the ability to plan and to shift between different strategies. Fluency measures are indicative of the abilities to chose a good strategy and monitoring the results. Finally, Symbol digit is used to assess speed of processing. We chose those tests to assess the attention and executive functions we think are involved in playing the game.

Though patients were pathological in many of the administered tests (see Appendix A), each patient had a particular pattern of deficits. We analysed the difference in performance also in the test the patients was not particularly impaired with the idea that it is possible to find improvement also in a function that is not impaired.
Despite the broad range of cognitive functions covered by the battery of tests there was limited evidence of improvements between the assessment before the training and the assessment after the training. There were some significant differences between the first two assessment, which indicate that there were some effects of spontaneous improvement or more likely some learning effect between the first administration of the tests and the second administration. Therefore, those differences are not interesting because they simply control for the presence of those confounding effects.

Nevertheless, there was good evidence that at least for one test the improvement of the patients was significantly better than the improvement of the control group. Indeed, in the Tower of London test the difference in the performance between the assessment pre-treatment and the assessment post-treatment was significantly different, for three patients out of four of the experimental group compared with the control group. The Tower of London is a test originally developed by Shallice (1982), frequently used in the clinical practice to assess problem solving abilities, in particular the ability to plan. Shallice developed the test with specific reference to the notion of the supervisory attentional system (SAS, Norman & Shallice, 1986) arguing that solving the task requires the involvement of a general programming system, the SAS. This system is essential in non-routine tasks such as those that involve planning or the overcoming of dominant association. The idea fits well what with we hypothesised about some aspect of the videogame play, in particular for the ‘snake’ task (see 3.3). Indeed, we thought that the snake task in particular requires the involvement of complex strategies and the inhibition of more automatic behaviour (for example the tendency to choose the direct route toward the ’shelter’ house). We can conclude that the treatment with the game was successful in the enhancement of those abilities. This conclusion is supported also by the finding that one patient, patient 2, improved in the Fonemic Fluency test, that is another test requiring
involvement of executive function responsible for strategic search, monitoring and flexibility (Kavè et al, 2010).

Unfortunately the findings do not support the hypothesis that the experimental treatment was effective for the improvement of divided and alternate attention. The only exception was patient 3, showing improvement in the Fonemic Fluency test and a tendency for improvement in the Trail Making test, part B, that is especially devoted to the assessment of the abilities to switch.

Before concluding that the game is not useful for the treatment of deficits in those functions it is necessary to exclude two other possible explanations of the current findings.

One possibility is that the regimen of practice was not effective. Though it was spaced in time, the length of the daily session was quite short as compared with other training studies. The adequate training intensity is a fundamental aspect for obtaining a significant improvement (Sohlberg & Mateer, 2001).

Another factor that deserves further investigation is the choice of the tools for the assessment of the cognitive abilities before and after the treatment. We chose neuropsychological tests because they are in the middle of a continuum between the experimental paradigms to daily life activity observation. Experimental paradigms allow to study very specific functions but are far from the daily living. In contrast, it is difficult to quantify and identify the deficit only with observation of the daily activities. Neuropsychological tests often a good balance between two needs: on one side to have a standardized instrument sensitive to specific deficits and on the other side to assess the presence of impairment in behaviour controlled by higher functions, such as executive functions. However, Umiltà and Stablum (1998) clarified that studies reporting dual-task
costs for TBI no greater than controls have generally focused on errors in classical neuropsychological tests when administered in combination with simple interfering tasks. Instead, chronometric paradigms originating from the studies on executive functions in unimpaired individuals allowed to detect magnified dual task deficits in TBI patients. Moreover, experimental paradigms allow for a better control of experimental conditions and can contribute to elucidating the specific mechanisms and/or component processes underlying dysfunction in clinical population (eg, Holzman, 1994; MacDonald & Carter, 2002). Accordingly, chronometric tests would therefore provide a more effective tool to examine functions such as divided attention. The best solution may be the use of a mixed assessment with both experimental paradigms and neuropsychological tests.
6. Conclusion

Cognitive deficits following traumatic brain injury can profoundly affect daily living functioning. They often involve processes part of the executive and attentional functions that are fundamental to control and modulate other more basic abilities. In particular, patients have problems with the allocation of attention in an efficient way to select the relevant information, to manage with distractibility, to do more than one things simultaneously, to inhibit automatic responses and shift the cognitive resources between different sets to respond in a flexible way at the environment fast changes. Since there is evidence that brain plasticity mechanisms can help the recovery and compensation of lost skills, training that attempts to stimulate lost functioning should be an important aspect of the rehabilitation practice.

There is debate in multitasking literature about the question of whether cognitive resources are shared between two tasks or a bottleneck postpones some processes of the second task until the first is completed (Evans et al, 2011). There is also debate about the origins of the patient's problems in multitasking (eg. Mathias & Wheaton (2007). Do patients have a speed of processing deficit, less cognitive resources available or a specific impairment in the mechanism that controls the deployment of resources? If there is a specific mechanism for multitasking training could be useful to enhance the ability to use such mechanism. If the deficit of patients are due to the poor availability of resources they need training that promote fast processing. The current literature does not allow to disambiguate but there is evidence that dual task training is useful above all (Dux et al, 2009) because it promotes speed of processing in the bottleneck.
There is a growing body of evidence that videogame playing can enhance a variety of specific skills in addition to speed-up of information processing. Action videogames are characterized by fast motion and sudden appearance of stimuli, require simultaneous tracking of multiple targets and vigilant monitoring of visual field. They have proved to be an interesting tool to train at least visual attention skills (Achtmn et al, 2008). Other types of videogames showed to enhance strategic control. Since they promote transfer to more ecological settings and generalization to untrained skills, they seems to be a promising tool to stimulate brain plasticity.

We attempted to design a new videogame with specific features that induce the involvement of attention and executive functions. The playground is constituted by a maze changing at every trial, stimulating the gamer to plan the action to reach the goals, every time in a different way. In addition to requiring focusing and sustaining attention, the game requires to inhibit the most automatic strategy to chose a less easy solution. The two tasks of the videogame alternate between each other making the gamer switching between the two cognitive sets. Moreover, sometimes the gamer has to complete the two tasks simultaneously, dividing the resources between the two goals. The adaptive algorithm behind the game calibrates the level of difficulty under different dimensions to the gamer’s current performance allowing to manage the performance variability of the patients.

In the first study we attempted to validate the game to ensure the involvement of the functions it was supposed to train. Unimpaired participants performed the game and two experimental paradigms in the same session. The cost of the dual task condition of the game was confirmed by three of the four score measures of the game. Performing the collection of diamonds and avoiding the snake simultaneously appeared to be quite difficult compared with the performance of the two task
separately. In agreement with the literature on the dual task, it is possible to conclude that performing the dual task condition of the game requires to divide attention between the two goals.

The effect of alternating the two tasks between was less clear. The percentage of success in completing the tasks showed a classic cost of switching between different cognitive sets. The two tasks are quite different both from a perceptual point of view and as regards the set of rules. In particular, avoiding the snake requires a strategy that may be opposite to that used for collecting the diamonds. Then, it is possible to expect both an effect of the reconfiguration of the new task and a proactive interference of the prior task. Since the accuracy measure confirmed the cost of the switch but the different time measures did not, we have to take into account two possible explanation. First, it is possible that the switch cost is due predominately to the proactive interference of the prior task. If the set of the prior task is still active it may lead to using a wrong strategy which in turn is likely to conduct to fail the. Second, the time to complete the task is extremely long compared with the time scale of classic switch paradigm, so intervening factors could act as a confound and make the time measures not reliable.

We were also interested in evaluating the external validity of the game. The presence of a unified bottleneck limiting cognitive processing leads to the prediction that individuals with a more efficient mechanism for dividing resources between competing tasks should be better in every task that involves that mechanism. Performances of the same individual in different dual tasks, such as the dual task condition of the videogame and the experimental dual task, should therefore correlate between each other. In the same way, if there is a common mechanism underlying the different forms of switching, individuals who efficiently shift between different
cognitive sets should be better in every type of switching. A positive correlation would
have assured that videogame is tapping the same abilities of the experimental
paradigms. Unfortunately, performance in the game and in the experimental paradigms
showed limited correlation. However, the literature about both multitasking and task
switching reveals that there may be effects linked to the specific task. Thus, it cannot
be concluded that the videogame and the experimental paradigms do not involve the
same mechanisms.

The aim of the second study was to test the videogame in a pilot study with TBI
patients. Despite the presence of dual task effects and partially of task switching effect,
shown in the in the first study, we were unable to induce an enhancement of divided
attention and alternate attention skills. Several factors could explained this finding. On
one side, it is possible that the regimen of practice, in particular the daily session length,
was not sufficient to ensure a valuable improvement. On the other side, neuropsychological tests could be not sensitive enough to assess the improvement. Nevertheless, in agreement with our hypothesis that the game requires planning and using complex strategies, enhancement of those abilities emerged clearly from the performance in the Tower of London test.

In conclusion, the present finding suggests the our videogame may be useful for
the remediation of some cognitive impairments. Further investigation is necessary to
better understand if some limit in the rehabilitation protocol concealed potential
improvement on the expected functions or if we should change the game to obtain the
desired effects.
7. Appendix A
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Notes:Totals of the mean (2), correct items (2), and errors (2) are not specified in the table.
6. References


