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Networked virtual environments with increased communication and self-expression tool

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Abstract (for dissemination)	This document provides SoA review on the previous developments within the area of Brain Computer Interface (BCI) based systems used with Virtual Reality (VR)
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1 Introduction

WP4 addresses one of the main objectives of BrainAble project. It will create a user-centric virtual environment and tools for home and urban automation control, self-expression and social networking and training. This document reviews current SoA in the Virtual Reality (VR), and VR projects that have been using Brain Computer Interface (BCI) technologies.

Virtual reality (VR) was originally conceived as a digitally created space that humans could access by donning sophisticated computer equipment (e.g., Lanier, 1992). One of the major goals driving the design and development of virtual reality was to create a space for people to interact without the constraints of the physical world (Lanier, 1992). As Biocca and Delaney (Biocca & Delaney, 1995) noted, “VR is a medium for the extension of body and mind”.

The virtual environments allow creation of user experiences that are only limited by the imagination of VE designers. The goal of virtual environments is to replace the stimuli and signals of the real world environment with digital representations of them. Therefore, virtual environments can evoke the same emotions and behavioural responses in users as their experiences in real life (e.g. imagine, for example, the fire alarm simulation). However, VE experiences are safe, since the user is now located in a protected and controlled environment.

1.1 VR hardware setups

Driven by the gaming industry, Virtual Reality technologies become more and more mature and there are different hardware platforms that can be used for rendering virtual environments. Slater and colleagues (Slater, Linakis, Usoh, & Kooper, 1996) propose the classification that is based on the level of technology that the different virtual reality systems use. Slater defines the term “immersion”[1] to refer to what is, in principle, a quantifiable description of a technology. Immersion can be then defined as the extent to which the computer displays are extensive, surrounding, inclusive, vivid and matching. In other words, one can also talk about sensory depths and breadth of such displays (Steuer, Biocca, & Levy, 1995, págs. 33-56).

Following the classification of VR technologies based on immersion criterion, several levels can be highlighted (Figure 1 show the examples of each technology):

- Rudimentary VEs (desktop)
- Head-mounted display (HMD)
- Huge immersive virtual environment (HIVE)
- Computer-assisted virtual environment (CAVE®)

[1] Note that here immersion is not related to user subjective experiences (see section 4.1 describing use responses in VR, in particular, the presence research)

Figure 1: ***Different types of Virtual Reality[2].***

All these systems can use two- or three-dimensional representation of visual VE. In the similar way, different levels of sound delivery (via stereo setups or via more immersive, loudspeaker arrays) are another factor of immersion. [3]

The immersion has a strong impact on subjective experiences to the user (see section 4.1 for more details). For example, Lécuyer et al. (Lécuyer et al., 2008) compared feedback obtained using 2D displays and 3D technology in BCI applications. The study showed that more immersive displays increased accuracy in BCI experiments and decreased training time for the user. More focused research is needed to determine the exact perceptual and cognitive mechanisms that might be involved in such improvement. The benefits could be due to both increased motivation and increased sensory depth of the display.

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[2] Desktop applications, Rehabilitation Gaming System at SPECS, desktop view (left upper panel). HMD example, http://www.stereoscopy.com (upper right panel). Large scale multi-user mixed reality room, SPECS (bottom left panel). BCI experiments using CAVE environment performed by g.tec and TUG in Presenccia project (bottom right panel).

[3] See (Larsson, Väljamäe, Västfjäll, Tajadura-Jiménez, & Kleiner, 2009) for a recent review.

1.2 Workflow of creating Virtual Environments

On the software side, the creation of real-time 3D VR applications relies on a so called 3D engine or game engine. The workflow of using a commercial 3D engine like Unity for creating VE is summarized on Figure 2 below (see section 3.3 for comparison of different game engines). First, the application assets (e.g., 3D objects, animations, sounds videos, textures) have to be generated by using the appropriate software tools. They also can be loaded from existing libraries.

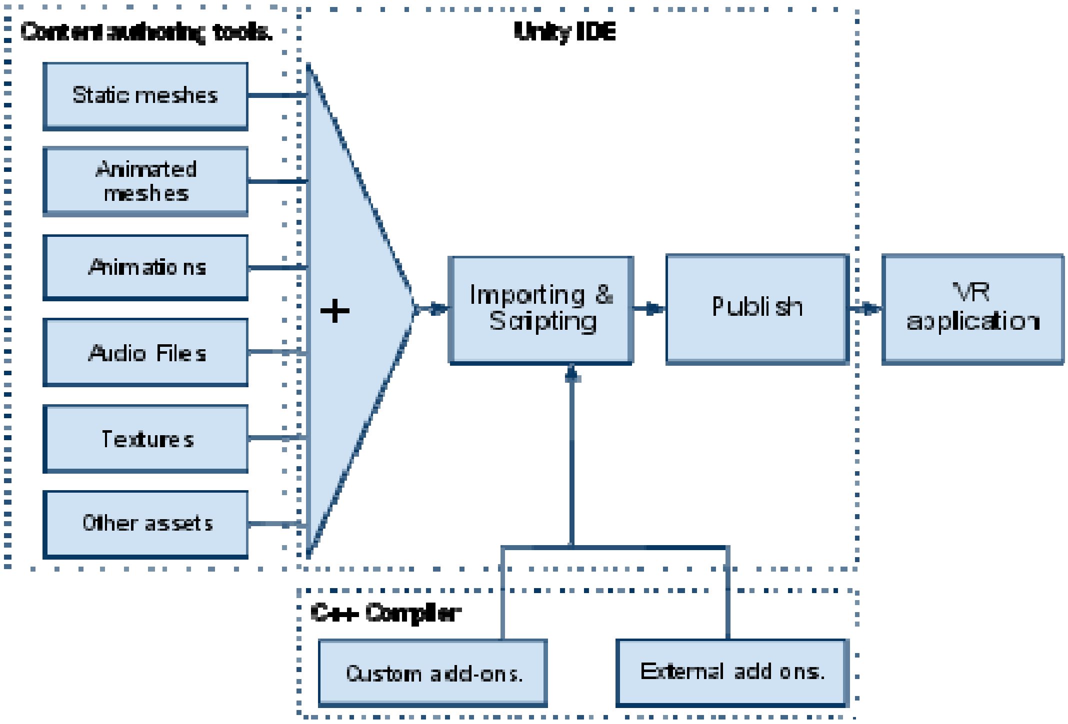

Figure 2: ***The workflow when creating a VE*** [4]

In Unity, the Integrated Development Environment (IDE) makes straightforward the asset importing and the scene creation (see Figure 3). The IDE also allows the scripting, avatar or object animation editions and provides profiling statistics, project management and final application publishing for different platforms (e.g., exporting the VE for using with web browser). If third party tools are needed (for example, avatar lips synchronization between visual and sound streams), they can be compiled and added to the engine. It is also possible to extend the engine features with custom add-ons.

[4] See Figure 3 for individual steps. From the VE developer viewpoint, the workflow should have as few intermediate steps (e.g. switching between different software apps) as possible. The developing environment should have tools both for high-level operations, and for scripting access to core, low-level code to allow customization.

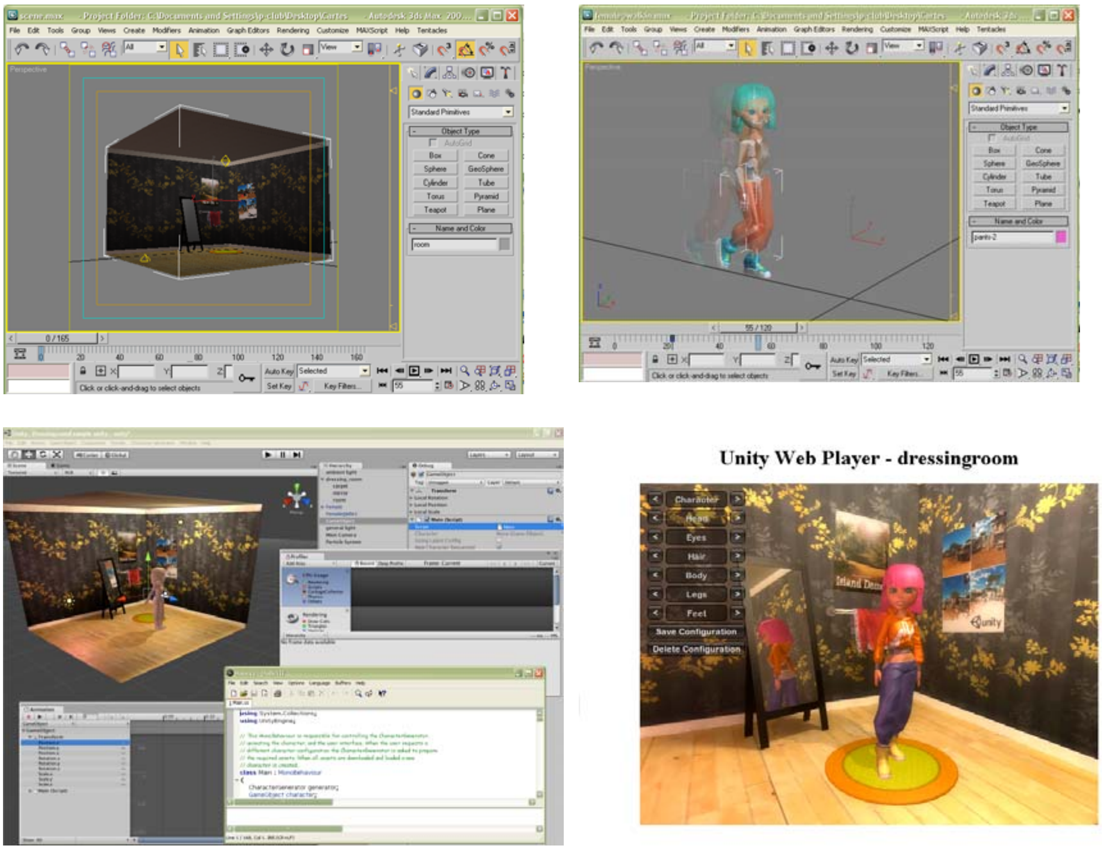

Figure 3: ***The workflow steps when creating a VR application[5].***

1.3 Comparison of 3D game engines

Currently, a large number of 3D engines is available on the market (e.g. Game and Graphics Engines Database, www.devmaster.net/engines). The choice between them can be determined by the trade-off between the source code accessibility and the effectiveness of the workflow with the engine. Therefore, it is important to define the requirements of the specific application(s) before selecting a proper engine. On one hand, there are 3D engines that are simple abstractions of low-level graphic APIs. They allow for a total control over all aspects of the given application, but also imply that the functionalities are based on the custom code which might require substantial programming efforts and also external dependences, if the source code is not available. On the other hand, some game engines are intended provide an easy game development platform using some high level editors, but do not give access to the core features of the engine. There is also a range of intermediate choices that exist between these two extremes.

There are several other important features of 3D engines that help in the selection process. For example, some engines provide ***tools for generating characters animation, their emotion***

[5] First, a static 3D object is created in a 3D modelling application (upper left panel). Second, a rigged 3D object has been created (upper right panel). Note that the avatar has a skeleton which makes it possible to animate it. Third, components are imported and scripted using the Unity IDE (bottom left panel). Finally, the application is exported for the use with a browser plug-in player (bottom right panel). The applications can be also compiled for distribution as a standalone executable. This example can be viewed at http://unity3d.com/gallery/hosted-demos/dressingroom.html.

modelling and behaviour. However, for that these engines integrate custom software components that usually differ from engine to engine. The other important criterion is VE rendering quality (photorealism, number of polygons that can be used, lighting/shading and texture quality). These parameters influence the overall look and subjective impression from the generated scenes. The ***accessibility to the source code*** of the engines is another important criterion when comparing 3D engines. In addition, commercialization of content and applications created by the selected 3D engine may depend on the ***licensing and exploitation terms***.

Table 1 shows first list of commercial technologies that are already used by a significant number of communities and proved in a range of final releases. The list of candidates is: Torque Game Engine, Torque 3D, Unity, UDK and Crytek. All these engines provide standard architectures for 3D technology, giving the opportunity to the programmer to deal with core rendering, optimization and synchronization tasks using scripting tools. Also, all these programs allow direct management of objects and their interaction control, both at high and low levels of implementation.

Most of the commercial engines do not give access to their source code, or only provide it under limited conditions. An exception is GarageGames products (Torque Game Engine and Torque 3D) that provide complete source code access. The usual practice is that VE creators can implement custom components and features written in other programming languages and use them via DLLs or SOAP - Simple Object Access Protocol (http://www.w3.org/TR/soap). The custom component integration usually works as a plug-in or as a totally independent process that communicates with the 3D engine core acting as a presentation layer.

For BrainAble project, the licensing and exploitation terms of the 3D engines may become very important criteria. The only engines of the list that have royalty free distribution are Torque Game Engine, Torque 3D and Unity. On the other hand, UDK establish a 25% royalty on revenue above $5,000 (US). For professional versions of UDK no information about pricing and royalties is available, like Crytek, which does not provide licensing information.

Considering the factors listed in Table 1, Unity seems to be the best candidate for BrainAble project needs. This engine allows high level scripting in standard C# and Javascript programming languages and custom component integration. Also, an Integrated Development Environment (IDE) is provided with a collection of high-level editor components and features like physics, inverse kinematics, browser plug-in and internet based asset delivery. The rendering quality meets the current standards of photorealistic rendering. In addition, the new version release of Unity has been that will be specifically focused on the rendering quality and performance. Furthermore, the free version release in November of 2009 aimed to boost the Unity developer community, which already has more than 14500 forum registered members. Finally, the absence of royalties can make it attractive for third parties to develop and commercialize new products and services using the BrainAble platform.

Regarding the rest of the 3D engines listed in Table 1, the main drawback of Torque Game Engine and Torque 3D is the poor productivity in their workflow, as the lack of a dedicated IDE. In Torque, the coding has to be done in the external editors without the convenient link between content and coding. Crytek represents an excellent program for rendering, and is free for educational institutions, but there is not enough information available about custom code integration and licensing. Finally, UDK could be a comparable alternative to Unity with a better rendering quality and an audio based facial animation, but its disadvantages are licensing politics and the lack of support for internet content delivery.

Table 1: Comparison of 3D game engines currently available on the market (see the section 1.3 and 1.4 for the details)

Name	Torque game Engine	Torque 3D	Unity	Crytek	UDK
Web url	www.torquepowered.com	www.torquepowered.com	www.unity3d.com	www.crytek.com	www.udk.com
Platform	PC, Mac, Linux	PC, Mac	PC, Mac	PC (DirectX)	PC
Art WorkFlow	Very poor. 3D assets have to be tested in external tools. Unstable exporters	Poor. Some built in tools. Improve previous versions with support for the 3D content (standard Collada)	Good set of high level tools. Integrated Development Environment (IDE)	Very good. Lots of high level editors. IDE.	Good set of high level tools. IDE
Rendering Quality	Very poor.	Medium	Good	Superb. Almost photorealistic	Very good.
Scripting	Propietary (Torque Script). Access to engine exposed objects.	Propietary (Torque Script). Access to engine exposed objects.	Javascript and C#. Access to rendering context.	Proprietary visual scripting system.	Proprietary visual scripting system (Krismet) and text (UnrealScript) Java based Script. Built in debugger.
Code access	Access to C++ source code.	Access to C++ source code.	Custom component creation in C++	Info not available	DLL Binding
Animation import	Own format, Collada	Own format, Collada	Collada	Info not available	Own format
Characters	Nothing specific	Nothing specific	Character locomotion system.	Character specific tools, subsurface scattering for realistic skin rendering	Built in facial animation
Price /Licencing	Discontinued. SPECS owns the license	$1000	Professional $1200 (50% for academia)	Free for academic institutions	Free
Other notes			Web browser plug-in	Best at rendering but computationally heavy	

1.4 Avatar movements control in 3D engines

In BrainAble, very important aspect of 3D engines is the functionalities for creation and control of avatar animations. An Avatar is a digital version of a user. The user's real movements (or control signals) can be linked to the avatar animations. 3D engines can import mesh, skeletal and animation data of avatars in two ways: using proprietary file formats or using industry standards like Collada. Technically, there are not special advantages between either of these options (e.g., Maya, 3DMax, Blender). However, a standard format exporter is usually included in 3D authoring tools, the proprietary file formats create problems, since exporting software has to be updated each time the new version of 3D authoring tool.

Another feature of 3D engines is the availability of high level editors that allow user to edit and blend avatar animations. Some engines have procedural animation systems that adapt the current animation to the environment (for instance a walking cycle can be adapted to a stairway), trigger expressions or synchronize lip movement with speech sound files. On one hand, Torque game engine and Torque 3D do not have any specific high-level editors for avatar control. On the other hand, Crytek incorporates natively all functionalities listed above. Both Unity and UDK represent intermediate solutions integrating animation editors and procedural animations. In the case of UDK, a lip synchronization add-on is available (http://www.facefx.com/) that can be purchased separately for any other engine.

Character workflow possibilities have been tested for Torque and Unity. Compared to Torque solutions, Unity allows more straightforward import of animations and its modular approach allows stacking together different animation behaviours. For example, a walking cycle animation and a terrain adaptation can be added to a character. This means that the walk cycle can be changed or even blended with another movement animation while maintaining the terrain adaptation. A significant advantage of the architecture used in Unity is that the components can be reutilized over any character that shares the same skeleton.

2 Virtual environments as psychological mediators

Apart from being a strong driver for technological innovation, Virtual Reality can be seen as a versatile psychological mediator. The possibility of changing in real-time the surrounding environment of the user have attracted researchers from social sciences. For instance, VE can be used to study social interactions patterns and various social phobias, like fear of public speaking. This is possible because people react to VE as they would react to real stimulus. For example, research has indicated that people often react to virtual humans similarly to how they react to real people (Donath, 2007; Garau, Slater, Pertaub, & Razzaque, 2005).

2.1 Measuring human responses to Virtual Environments

Virtual Reality can evoke the same emotions, thoughts and behavioural responses as the ones experienced in a real-world situation (Hodges et al., 1994). We can classify the research on user responses to VE into several categories:

- **Presence responses** (also referred to as telepresence). Presence is the user's feeling that his reactions respond to actions on the virtual world. The user feels the virtual environment like a real one. This subjective experience impacts the effectiveness of virtual treatments. Lee (2004) identified three different aspects of presence, including physical, spatial, or environmental presence (the feeling that you are in a particular virtual space; (K. M. Lee, 2004), social presence (the feeling that another person is sharing the virtual space with you; (Biocca, Harms, & Burgoon, 2003)), and personal or self-presence (the experience of a virtual self-representation as an extension of the self; (Ratan, Santa Cruz, & Vorderer, 2008). An extensive review of various types of presence measures has been given in deliverable from OminPress project: "Measuring Presence: A Guide to Current Measurement Approaches" (Van Baren & IJsselsteijn, 2004)

- **Emotional responses.** VE can be used to induce emotional states like anger, fear, and joy, and hence influence subjective, behavioural and psychophysiological responses related to these. Psychophysiological responses that have been measured by various research groups in VR settings include pupil dilation, EEG, heart rate, blood pressure, electrodermal activity, respiration, or skin temperature. With advances of real-time fMRI (functional Magnetic Resonance Imaging), VR has been also used to meditate complex adaptive stimuli (Caria et al., 2007).

- **Physiological side effects.** Exposure to virtual devices can create cybersickness in some users. However, a recent study (Bailenson, Yee, Merget, & Schroeder, 2006), has proven that a negative reaction to VE (cybersickness) tends to decrease as users gain experience with VR.

2.2 Assistive and therapy applications of Virtual Reality

A common application of VEs is via virtual reality exposure therapy (VRET). VRET has been used to treat various disorders, including:

- Acrophobia (the fear of heights; Coelho(Coelho, Santos, Silvério, & Silva, 2006)
- Agoraphobia (fear of open spaces; (Botella et al., 2007)
- Arachnophobia (fear of spiders; (Côté & Bouchard, 2005)
- Aviophobia (fear of flying; (Rothbaum, Hodges, S. Smith, J. H. Lee, & Price, 2000)
- Public speaking anxiety (Harris, Kemmerling, & North, 2002)
- Panic disorder (Botella et al., 2007)
- Social phobia (Roy et al., 2003)
- Posttraumatic stress disorder.
- Alcohol cravings or nicotine cravings in cigarette smokers in cognitive behavioural therapy.
- Physical rehabilitation (gaming scenarios).
- Pain patients. Used like an effective distraction method

Aside from these applications, VE has been used as interactive tools for teaching for medical applications, flight simulators, develop cross-cultural communication skills or training employers, among others. For the BrainAble, VE use as a **communication tool** is especially important**.** It is possible to link user's emotional state with a virtual expression in media, like a virtual world, that would increase the communication possibilities of the motion impaired user.

Virtual reality can be also seen as a unique technique for transformed social interaction (TSI), as noted in (Bailenson & Beall, 2006; Bailenson, Beall, Loomis, Blascovich, & Turk, 2004). As Bailenson and colleagues note, TSI presents advantages over traditional forms of communication in three distinct ways. First, TSI presents users enhance their normal perceptual abilities (e.g. perspective taking). Second, VEs also enable manipulations of the content, so that the same scenes can be replayed (or, re-experienced). Third, users can now control their self-representation, which may alter the usual ways they communicate in real life. For example, (Yee & Bailenson, 2007) showed that when participants embodied attractive avatars, they disclosed more personal information and approach other avatars more closely. Or, when participants embodied taller avatars, they were more confident in a negotiation task.

3 VR applications and their use with BCI technology

This section will provide a review of BCI papers published between 2005-2010 in the area of BCI and VR applications (Table 2). During this review, we paid specific attention to the types of applications (type of interaction), the BCI technology used, and number of commands available.

Since BCI has very low communication bandwidth, the number of commands (NoC) in one of the most crucial features of these applications. The number of commands defines the control commands available for the user in the VE. For example, in a navigation task where the EEG patterns are linked to the commands “turn left”, “turn right” and “move forward”, there are three commands available.

Another way to define BCI control is to talk about the “degrees of freedom” (Edlinger, Holzner, Groenegress, Guger, & Slater, 2009). This metric defines the different brain states or patterns that can be differentiated between each other or the background activity of the brain. Different techniques (P300, Motor Imagery, Steady State Evoked Potentials…) have different degrees of freedom. For example, steady state evoked potential BCIs have more degrees than BCIs based on motor imagery because a wider range of EEG frequencies can be used. The “degrees of freedom” are especially useful when discussing hybrid BCIs, in which several techniques can be combined (Allison et al., 2010; Brunner et al., 2010; Pfurtscheller et al., 2010). When discussing the applications, the degrees of freedom create a basis for a numbers of commands to be used.

Table 2: Selected papers published in the period 2003-2010 (BCI and VR applications)

Type of interaction	Synchronous/ self-paced (asynchrony.)	BCI paradigm	NoC	Application details	Reference
Manipulating Virtual Objects (VO)	Synchronous	P300	2	Control of virtual apartment (on/off switch)	(Bayliss, 2003)
	Synchronous	P300	2	Control of an object movement using a graphical interface	(Piccione et al., 2006)
	Synchronous	SSVEP	2	Control of a virtual character	(Lalor et al., 2005a)
	Synchronous	MI	2	Control of a virtual body by thought in CAVE	(Friedman, Leeb, Dikovsky, et al., 2007)
	self-paced	MI	1	Lifting up a virtual character (“Use the force!” game)	(Lotte, Lécuyer, & Arnaldi, 2009)
	Synchronous	MI	2	Control a virtual hand	(Neuper, Scherer, Wriessnegger, & Pfurtscheller, 2009)

Navigation in Virtual Environments (VE)	Synchronous	P300	2	Virtual driving environment with traffic lights as control	(Bayliss & Ballard, 2000)
	Synchronous	MI	2	Motion along a straight path on a virtual street	(Friedman et al., 2004)
	Synchronous	MI	2	Control of a virtual car	(Ron-Angevin, Estrella, & Reyes-Lecuona, 2005)
	Synchronous	MI	2	Motion along a virtual street	(Pfurtscheller et al., 2006)
	Synchronous	MI	2	Navigation through a virtual apartment	(Leeb et al., 2007)
	self-paced	MI	1	move the wheelchair from one position in a virtual street to another other	(Leeb, Friedman, Slater, & Pfurtscheller, 2007)
	self-paced	MI	1	moving through a virtual model of the Austrian National Library	(Leeb, Settgast, Fellner, & Pfurtscheller, 2007)
	Synchronous	ERP	2	Virtual driving game	(Lin et al., 2007)
	Synchronous	Lateralized Readiness Potential (LRP)	2	Navigation in the labyrinth ("Brain Pacman" game)	(Krepki, Blankertz, Curio, & M\üller, 2007)
	Self-paced	MI	3	Navigation in a VE and picking up items	(Scherer et al., 2008)
	Synchronous	MI	2	Control of a virtual car	(Ron-Angevin & Díaz-Estrella, 2009)
	Synchronous	P300	2	Control of character's motion along the z-axis	(Finke, Lenhardt, & Ritter, 2009)
	Synchronous	P300	42	Moving around a virtual apartment and controlling objects	(Edlinger et al., 2009)
	Synchronous	P300	22	Moving around a virtual apartment and controlling objects	(Guger, Holzner, Grónegress, Edlinger, & Slater, s.d.)
	Self-paced	MI	4	Drive a car in 3D virtual reality environment	(Zhao, Zhang, & Cichocki, 2009)
	Synchronous	Lateralized Readiness Potential (LRP)	2	"Ping Pong" video game	(Lotte et al., 2009)
	Synchronous	MI	4	Two-Dimensional Cursor Control	(Huang, 2009)
	Asynchronous	SW SSVEP	3	SSVEP Avatar navigation in virtual reality scenarios	(Faller, Müller-Putz, Schmalstieg, & Pfurtscheller, 2010)
Moving a Virtual Camera (VC)	Self-paced	μ rhythm	2	Navigation in a three-dimensional (3-D) first-person shooter video game	(Pineda, Silverman, Vankov, & Hestenes, 2003)
	Synchronous	MI	2	Rotation in a virtual bar	(Friedman, Leeb, Guger, et al., 2007)
	Synchronous	MI	2	Exploration of a virtual conference room	(Leeb, Scherer, F. Lee, Bischof, & Pfurtscheller, 2004)
	Self-paced	SSVEP	2	Exploration of a virtual environment	(Touyama, Aotsuka, & Hirose, 2008)

From this research literature review, we can see some tendencies for using specific BCI techniques for specific VR applications. When VR applications need a small number of commands, like in navigation task, SSVEP or MI is often used. For virtual object manipulation, avatar control and smart home control, the P300 technique seems to be more appropriate. SSVEP and MI BCIs are best for graded control, and P300 BCIs are better for direct selection. Further research should explore different BCI types with different applications, including hybrid BCIs.

3.1 VR features that may influence BCI performance

The specifics of VR technology have to be taken into account when designing the application for BCI. The following parameters can be important when designing a successful interface:

- Physical interference between VR and BCI technologies. For example, Head Mounted Displays can have an impact on the recorded signals (Sharples, Cobb, Moody, & Wilson, 2007).

- Immersion level. Spatial sound, 3D vs 2D.

- Real life situations. Mixed reality challenges – cognitive load, distractors.

- Ergonomics. BCI paradigms require different level of user adaptation. Different types of BCIs may be better suited to different types of VR environments ((Nijholt, Reuderink, & Oude Bos, 2009); see also section 6.1). Bayliss and Ballard (Bayliss & Ballard, 2000) first validated a P300 BCI in a virtual environment, in which P300 based control was embedded into the virtual environment scenario by using traffic lights. Other work has validated ERD (Leeb et al., 2007; Pineda et al., 2003) and SSVEP (Faller, M\üller-Putz, Schmalstieg, & Pfurtscheller, 2010; Lalor et al., 2005b) BCIs in virtual environments for virtual navigation.,.

Given the requirements of BrainAble, where users need to control VE with BCI for a long time, the level of comfort of different BCI paradigms is a very important factor (P. J. McCullagh, M.P. Ware, & G. Lightbody, s.d.; Paul McCullagh et al., s.d.). Wolpaw (Wolpaw, Birbaumer, McFarland, Pfurtscheller, & Vaughan, 2002) is the most heavily cited BCI article in the literature, and divides BCIs into five categories, which are slightly updated here: Steady Evoked Potentials (SSEP), slow cortical potentials (SCP), P300 evoked potentials, mu and beta rhythms (corresponding to ERD BCIs, and cortical neuronal action potentials. One change since then is that the SCP approach has not as heavily used anymore in BCI research, since SCP BCIs require the most training and are slower than other BCIs. The group that most actively pursued the SCP BCI approach, the Birbaumer group in Tübingen, has focused on other BCI approaches of late. Brain, TOBI, Better, and most active projects do not involve SCP BCIs. Therefore, BrainAble does not involve SCP BCIs.

Table 3. Comparison of BCI paradigms in terms of user ergonomics (Paul McCullagh et al., s.d.)

BCI paradigm	Description	Disadvantages
Visually Evoked Potentials (VEP/SSVEP), but also Auditory or Tactile evoked potentials can be used	Small changes in the ongoing EEG (more prominent in the occipital cortex) generated in response to visual stimuli (e.g. flashing lights). If a visual stimulus is presented repetitively at a rate > 5 Hz, a continuous oscillatory response is elicited in the visual pathways.	- Needs concentration by the user. - Can be tiring - Habituation to the stimulus can appear.

Slow Cortical Potentials (SCP)	Slow, non-movement potential changes on the brain activity generated by the subject. They reflect changes in cortical polarization of the EEG lasting from 300 ms up to several seconds.	- It requires extensive training. - Subjects can not control their brain potentials quickly enough for biofeedback (Kotchoubey, Schleichert, Lutzenberger, & Birbaumer, 1997)
P300 evoked potentials	Infrequent or particularly significant auditory, visual, or somatosensory stimuli, when interspersed with frequent or routine stimuli, typically evoke in the EEG a positive peak that begins about 300 milliseconds after such stimulus presentation (over the parietal cortex). This peak is called the P300.	- It requires concentration by the user. - After familiarization to P300 stimulus, the response becomes lower. - User has to be focused on the correct symbol.
Motor real and imagery activity mu and beta rhythms (8-12 Hz & 13-30 Hz)	Originate in the sensorimotor cortex. These rhythms are more prominent when a person is not processing sensorimotor inputs or in producing motor outputs. A voluntary movement results in a circumscribed desynchronization in the mu and lower beta bands. This desynchronization, called event related desynchronization (ERD), begins in the contralateral rolandic region ~2 s prior to the onset of a movement and becomes bilateral before execution of movement. After the movement, the power in the brain rhythm increases (event related synchronization, ERS). Motor imagery elicits similar patterns of activity.	- It requires training. - It requires concentration by the user. - It is less reliable than other interface techniques.

3.2 Related Projects on VR and BCI

AsTeRICS (EU, http://www.asterics.eu/)
AsTeRICS provide a flexible and affordable construction set for realizing user driven AT by combining emerging sensor techniques like Brain-Computer Interfaces and computer vision with basic actuators. People with reduced motor capabilities get a flexible and adaptable technology at hand which enables them to access Human-Machine-Interfaces (HMI) at the standard desktop and even in embedded systems like mobile phones or smart home devices.

BACS (EU, http://www.bacs.ethz.ch/index)
Bayesian Approach to Cognitive Systems is an Integrated Project conducted under the Thematic Priority: Information Society Technologies - Sub-topic: Cognitive Systems - of the 6th Framework Program of the European Commission. By taking up inspiration from the brains of mammals, including humans, the BACS project investigate and apply Bayesian models and approaches in order to develop artificial cognitive systems that can carry out complex tasks in real-world environments.

BEAMING (http://www.beaming-eu.org)
Beaming, a four year collaborative project to develop science and technology to give people a real sense of physically being in a remote location with other people without actually physically travelling. The project coordinator – the R+D company Starlab.

Brain (EU, http://www.brain-project.org/)
This research project pushes Brain Computer Interfaces (BCI) into practical assistive and ICT tools to enhance inclusion for a range of different mobility impaired users, by allowing them to interact with loved ones, home appliances and assistive devices, or personal computer

and internet technologies. Improvement of reliability, flexibility, usability, and accessibility entail upgrades to all four components of a BCI system - signal acquisition, operating protocol, signal translation, and application. Lightweight, inexpensive, non-invasive / easy to use sensors are developed. Automated signal processing improves signal translation. An intuitive universal interface enables control of existing applications, including home assistive technologies.

BrainGain (EU, http://www.nici.ru.nl/cgi-brain/index.cgi?page=index;lang=nl)
BrainGain is a Dutch research consortium consisting of researchers, industry and potential users of Brain-Computer and Computer-Brain interfaces. BrainGain is researching possibilities of applications for both mobility impaired and non-impaired users, and aims to eventually manufacture off-the-shelf products making use of their research results.

BrainGate (USA, http://www.braingate2.org)
Focused on developing technologies to restore communication, mobility, and independence of people with neurologic disease, injury, or limb loss. This project creates and tests the devices that are ushering in a new era of transformative neurotechnologies. Using a baby aspirin-sized array of electrodes implanted into the brain the intent to move a limb can be "decoded" by a computer in real-time and used to operate external devices. This investigational system, called BrainGate has allowed people with spinal cord injury, brainstem stroke, and ALS to control a computer cursor simply by thinking about the movement of their own paralyzed hand.

Presenccia (EU, http://www.presenccia.org)
An Integrated Project funded under the European Sixth Framework Program, Future and Emerging Technologies (FET), which is tackling the operational approach to the concept of presence from a number of different angles. It concentrated on measuring the similarity of response with what they might observe or predict if the sensory data—the situation, place, or events—were real, rather than virtual. The PRESENCCIA project is highly interdisciplinary, combining neuroscience, computer science, psychiatry, psychology, psychophysics, mechanical engineering, philosophy and drama.

SM4ALL (EU, http://www.sm4all-project.eu)
The SM4ALL project investigates an innovative middleware platform for inter-working of smart embedded services in immersive and person-centric environments, through the use of composability and semantic techniques for dynamic service reconfiguration. By leveraging on P2P technologies, the platform is inherently scalable and able to resist to devices' exploitation and failures, while preserving the privacy of its human users as well as the security of the whole environment. This is applied to the challenging scenario of private houses and home-care assistance in presence of users with different abilities and needs. Various scenarios will be investigated in which invisible embedded systems need to continuously interact with human users, in order to provide continuous sensed information and to react to service requests from the users themselves.

TOBI (EU, http://www.tobi-project.org)
TOBI focuses on development of practical technology for non-invasive brain-computer interaction (BCI) prototypes combined with other assistive technologies (ATs), to augment their adaptive capabilities, in order to improve the quality of life of people with motor disabilities. The project aims to create impact in four application areas, in terms of pre-

clinical validation: Communication and Control, Motor Substitution, Entertainment, and Motor Recovery.

Tremor (EU, http://www.iai.csic.es/tremor/)
This research project validates, technically, functionally and clinically, the concept of mechanically reducing the tremor through selective Functional Electrical Stimulation of muscles. The Brain Computer Interaction (BCI) detection of involuntary motor activity combines CNS (Electroencephalography) and PNS (Electromyography) data with biomechanical data (Inertial Measurement Units, IMUs). The system model and track tremor and voluntary motion.

3.3 VR areas important for BrainAble project

The area of VR technology and its applications spans from computer games, industrial simulators to cybertherapy. The particular needs of BrainAble users will drive the research topics that are central for the creation of a successful system prototype. We foresee the following topics:

VR as an interface between real word and mobility impaired users, like in the case of smart home environment. Here the realization of this interface can be approached using realistic, one to one mapping of real environment into a virtual one. However, VR also offers new options to view and navigate in a virtual home (e.g. bird's eye view).

Avatar – a virtual representation of a user in VR. VR research shows the importance of body-centred feedback when navigating in virtual environments (e.g. hearing one's footsteps, see your virtual hands etc.). While avatars can be manipulated by users via a BCI device, the work on the autonomous and semi-autonomous virtual characters can facilitate the avatar-based communication. In such scenarios, the avatars can learn the "behaviour" of the user (via BCI commands patterns and associated implicit physiological cues).

Multiuser VR environments. Since 1990s 3D virtual worlds have changed dramatically in terms of features, usability and graphical appearance and gave rise to 3D virtual communities like Second Life (http://www.secondlife.com) or Massive Multiplayer Online Role Playing Games (MMORPG) like World of Warcraft (www.worldofwarcraft.com). Taking one step further, such communities can host both real and synthetic characters and also operate in the mixed reality mode.

Cognitive stimulation and mastering BCI control. While typical applications for cognitive stimulation are using 2D environments (e.g. puzzle solving), spatial navigation tasks in VR environments might be more efficient for prevention of cognitive decline. In addition, several BCI studies show that 3D feedback leads to better performance (training time and accuracy) compared to classical 2D displays (Friedman, Leeb, Guger, et al., 2007; Leeb et al., 2007; Ron-Angevin & Díaz-Estrella, 2009)

4 Conclusions and the outline of WP4 work

The reviews presented in this deliverable show that Virtual Environments have been used with BCI technologies in numerous past projects. The important difference between BrainAble and these projects is that virtual reality applications that BrainAble will create are oriented for every-day use by mobility impaired users. Hence, the user-centered design will be a key component when designing and refining these applications. In this respect, D2.1 will provide the descriptions of user groups and level of their functional disability.

Based on the literature and technologies reviewed above, several aspects have to be highlighted for upcoming WP4 work.

First, it is important to concentrate on VR features that will influence users' acceptability of BCI techniques. Hence, by making VR interface more interesting (in terms of novelty and changing details), more presence inducing, or by applying to it emotional design principles we can increase the acceptability and usability of BrainAble prototypes. In addition, these seemingly subjective features can have a qualitative impact on BCI performance and reduce fatigue and boredom from long usage of the interface. These aspects will be addressed in the following design tasks T4.1 (forthcoming Deliverable D4.2, M12) and T4.4 (forthcoming Deliverable D4.2, M24), and validated by user tests in WP6.

Second, hybrid BCIs are just starting to be used in various applications. On one hand, it is important to explore the new options for controlling VE that now will be given by combining explicit (BCI control signals) and implicit cues (monitoring of EEG and non-EEG activity). For example, monitoring the level of user attention and alertness can be incorporated into some VE features. Such feedback can be provided both to the user and his/her assisting personnel to define the best times for BCI operation. In addition, implicit cues can be used to augment virtual characters behaviour in social scenarios. On the other hand, it is important to study and optimize VE that will allow combination of different BCI paradigms (e.g. SSVEP and P300 hybrids for navigation and selection of items, respectively). These aspects will be addressed in collaboration with WP3, tasks T4.1 (forthcoming Deliverable D4.2, M12) and T4.4 (forthcoming Deliverable D4.2, M24), and user tests in WP6.

Third, a networked virtual community is an important communication tool for BrainAble. Given a low bandwidth of BCI technology, non-verbal communication via avatars or other VE features can provide alternative methods for reconnecting with relatives and friends. Work with user groups and partners of BrainAble that represent them should give further insight into the design of use case scenarios defined in D2.1. The BrainAble Virtual Community work will be addressed in design task T4.3 (forthcoming Deliverable D4.3, M24) and will be tested with users in WP6.

Last but not least, the selection of the tools (3D engine, characters animations) should be discussed within the consortium in the view of possible commercialization and spin-offs (WP7).

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List of Key Words/Abbreviations

AT: Assistive Technologies
BCI: Brain Computer Interfaces
CAVE: Cave Automatic Virtual Environment
CNS: Central Nervous System
EEG: Electroencephalography
EMG: Electromyography
EP: Evoked Potentials
ERD: Event related desynchronization
ERS: Event related synchronization
ERP: Event-Related Potential
EU: European Union
FET: Future and Emerging Technologies
fMRI: functional Magnetic Resonance Imaging
HCI: Human Computer Interfaces
HMI: Human-Machine-Interfaces
ICT: Information and Communication Technology
IDE: Integrated Development Environment
IMUs: Inertial Measurement Units
LRP: Lateralized Readiness Potential
MI: Motor Imagery
MMORPG: Massive Multiplayer Online Role Playing Games
NoC: Number of Commands
P2P: Peer-to-Peer
PNS: Peripheral Nervous System
RGS: Rehabilitation Gaming System
SoA: Service Oriented Architecture
SOAP: Simple Object Access Protocol
SSVEP: Steady State Visual Evoked Potentials
USA: United States of America
VE: Virtual Environment
VO: Virtual Object
VR: Virtual Reality