sensors

Article

Characteristics and Usability of a System Combining Cognitive and Physical Therapy in a Virtual Environment: Positive Bike.

Elisa Pedroli [1]*, Luca Greci[2], Desirèe Colombo[3], Silvia Serino[1,4], Pietro Cipresso[1,4], Sara Arlati[2,5], Marta Mondellini[2], Lorenzo Boilini[6], Valentina Giussani[6], Karine Goulene[6], Monica Agostoni[7], Marco Sacco[2], Marco Stramba-Badiale[6], Giuseppe Riva[1,4], and Andrea Gaggioli[1,4]

[1] Applied Technology for Neuro-Psychology Lab, I.R.C.C.S. Istituto Auxologico Italiano, Milano, Italy; e.pedroli@auxologico.it
[2] Industrial Technologies and Automation, Consiglio Nazionale delle Ricerche, Milano, Italy; {luca.greci,sara.arlati,marta.mondellini,marco.sacco}@itia.cnr.it
[3] Department of Basic Psychology, Clinic and Psychobiology, Universitat Jaume I, Av. Sos Baynat, s/n, 12071, Castellón, Spain; dcolombo@uji.es colombo.dsr@gmail.com
[4] Department of Psychology, Università Cattolica del Sacro Cuore, Milano, Italy; {silvia.serino,pietro.cipresso,giuseppe.riva,andrea.gaggioli}@unicatt.it
[5] Department of Electronics, Information and Bioengineering, Politecnico di Milano, Milano, Italy
[6] Department of Geriatrics and Cardiovascular Medicine, I.R.C.C.S. Istituto Auxologico Italiano, Milano, Italy; lo.boilini@gmail.com; {v.giussani,goulene,stramba_badiale}@auxologico.it
[7] Nursing Home Monsignor Bicchierai, (I.R.C.C.S.) Istituto Auxologico Italiano, Milano, Italy; m.agostoni@auxologico.it
* Correspondence: e.pedroli@auxologico.it; Tel.: +39 02 61911 2892

Received: date; Accepted: date; Published: date

Abstract: We present the architecture and usability evaluation of virtual reality system – "Positive Bike" - designed for improving cognitive and motor conditions in frail elderly patients. The system consists of a cycle-ergometer integrated in an immersive virtual reality system (CAVE) which allows combining motor and cognitive exercises according to a "dual-task" paradigm. We tested the usability and user's experience of the prototype in a pilot evaluation study that involved five elderly patients. The prototype was tested in one-session training to understand the limitations and areas for improvement of our system. The evaluation consisted in (i) usability assessment using the System Usability Scale; (ii) evaluation of user's engagement using the Flow State Scale, and (iii) expert evaluation involving interviews with domain experts. Results showed a good usability, both for System Usability Scale and the semi-structured interview. The level of flow (i.e., enjoyment with the task at hand) measured using the Short Flow State Scale, was also high. Analysis of semi-structured interview carried out with domain experts provided further indications improving the system. In overall, these findings show that, despite some limitations, the system is usable and provide an enjoyable user's experience.

Keywords: Virtual reality, rehabilitation, ageing, frailty, usability, UX.

1. Introduction

1.1. The problem of frailty

Aging is a physiological process involving both cognitive and motor domains and affecting therefore many aspects of everyday life. According to the World Health Organization, the proportion of people older than 60 year-old is increasing rapidly and faster than all the other age groups [1]. Within this part of the population, in the last decade there has been a lot of interest in "frail" patients, constituting the 6.9% of adults older than 65-year-old [2]. Specifically, frailty is a clinical condition and a state of vulnerability associated with increasing age and affecting multiple domains like gait, mobility, balance and cognition [3]. According to the standardized definition of Fried and colleagues, three or more of the following criteria should be met: unintentional weight loss (10 lbs in past year), self-reported exhaustion, weakness (grip strength), slow walking speed, and low physical activity [2]. This condition has been directly associated with higher risks for adverse health outcomes, such as mortality, disability and, especially, high risk of falls [2, 4-6].

Even though cognitive and motor impairments have been always considered and treated independently, literature is showing evidence for a strong relation between them, both in healthy and pathological conditions. An example of this relationship is the risk of falls. Among old adults and frail patients, falls are one of the most critical public health problems, as well as the major cause of injuries: one in three old people, indeed, falls at least once in a year [7], with subsequent consequences in terms of loss of independence and adverse psychosocial problems [8, 9]. The increased fall rate among older adults has been interpreted in light of the Cognitive Motor Interference (CMI) theory [10, 11].

CMI, a specific type of Dual Task interference (DTi), refers to the simultaneous execution of a cognitive and a motor task, that requires a great amount of cognitive control in terms of executive functions and attentional abilities [12]. The concurrent performance of a cognitive task can cause a decline either in the motor or in the cognitive execution, or even in both, depending on the cognitive demand [1, 12, 13]. To the current literature, the mechanisms supporting DT are still unclear. As a matter of fact, a specific brain structure devoted to the control of DT has not been yet identified: rather than being a simple addictive effect, DT could be the result of a complex coordination and interplay between different specialized information-processing systems [14]. Concerning the cognitive mechanisms, instead, two different attentional theories have been proposed. Along with the Wickens' theory of shared attentional resources [15], the concurrent execution of two activities would require to divide and re-allocate attention, thus decreasing the attentional resources assigned to each single task [16]. On the other hand, the bottleneck hypothesis argues that the main cause of interference would be the competition for information-processing in neural pathways [16]: tasks that are supported by a similar neural network could not be carried out in parallel, but only in sequence.

Interestingly, successful locomotion requires the ability of performing simultaneously a cognitive task that can cause an interference in gait performance, especially in older adults. Several works showed the efficacy of this paradigm [17-20]. The age-related decrease in attentional and executive functioning would impair the ability of managing the concurrent execution of different motor and cognitive activities, normally occurring in everyday life [21, 22]. Notably, frailty has been described as a reversible dynamic process, characterized by recurrent transitions between states over time [23]. As a consequence, a growing number of studies focused on the possibility of creating specific interventions, either to improve or prevent frailty and, specifically, to reduce the risk of fall [24]. For instance, regular physical exercise and motor interventions, either in their aerobic or strength form [25], were proved to bring many benefits for reducing the fall risk [26-29] and improving the general cognitive functioning [30]. Accordingly, a recent systematic review showed the main role played by muscular strength and postural balance for the prevention of falls [28].

Recently, DT has been suggested as a more efficient approach for the improvement of cognitive and motor performances [21, 31-33]. Specifically, the important contribution of high-order cognitive systems in gait control would make DT an effective training for the reduction of fall risk [21].

1.2. The potential of virtual reality to counteract frailty

Thanks to the development of new technologies and to the great diffusion of Virtual Reality (VR) in the clinical field, it is now possible to develop and implement interactive cognitive-motor trainings. VR offers indeed the opportunity to create ecological and realistic environments in which to reproduce daily-life situations, leading to higher acceptance and adherence rates among patients [34].

The adoption of VR trainings, mainly involving balance and functional mobility, has already shown promising outcomes in the clinical field, thus suggesting VR as an appropriate complementary approach in the field of rehabilitation [35].

Several studies already adopted a VR cycling training for the motor rehabilitation of old adults or stroke patients [36-40], but no one ever implemented it into a DT protocol, thus requiring the execution of some interactive cognitive tasks during the physical performance of the virtual ride. In the following, we describe the rationale, the design and the usability testing of "Positive Bike", a fully-immersive VR biking experience for the implementation of an interactive DT training. To our knowledge, most of the studies on balance rehabilitation have focused on exercises in standing posture; conversely, less research has been conducted on sitting posture trainings [39]. Stationary cycle exercises, instead, can improve balance, weight shifts and gait, as well as lower body extremity functioning, thus translating into a significant reduction of the fall risk [41, 42]. The pattern of cycling is indeed very close to walking, as they are both cyclical, they both involve the reciprocal flexing and extension movements from the hip, the knee and the ankle, and they both activate alternatively agonist and antagonist muscles [43-45]. Moreover, the use of a stationary bike results in providing the user with a controllable workload and a safer equipment; indeed, with respect to the treadmill (the other equipment allowing an easy modification of the workload), The employment of a cycle-ergometer is associated with a lower risk of injury, especially in case of elderly and frail users [46]. Another key requirement was to create a task which provided participants with positive and engaging experience. According to Riva and colleagues [47, 48] a key asset of VR for rehabilitation is that this technology allows creating artificial environments that promote optimal experience through surprising psychological resources and increase in the involvement. Accordingly, VR is a powerful tool that can be used to improve the engagement of the participants, thanks to the creation of challenging tasks designed accordingly to the user's personal skills and resources. This approach, also called "transformation of flow" has shown promising results in the field of rehabilitation, both cognitive and physical [49, 50]

1.2.1. System architecture

The system is constituted by a cycle-ergometer (Ergosana Eurobike 320), a pushing button anchored on the cycle-ergometer handlebars, an Arduino2 board connecting the button to the computer and an Xbox controller mounting reflective markers. All these components are placed inside a Cave Automatic Virtual Environment (CAVE), which allows the 3D visualization of the Virtual Environments (VEs) thanks to the combination of four stereoscopic projectors (Full HD 3D UXGA DLP, coupled with stereoscopic glasses), three rear projection screens and one direct projection screen having a projectable area of 266 cm x 200 cm. CAVE is also equipped with a position tracking system, which allows a correct reading of the simulated spaces and distances with a 1: 1 scale ratio, thus enhancing the feeling of being immersed in the virtual scene.

A Vicon motion tracking system, with four infrared cameras with 1-megapixel resolution, allows the tracking of specific reflective markers positioned on target objects. A cluster system composed of two HPZ620 Graphics Workstations, mounting Nvidia Quadro K6000 GPU with dedicated Quadro Sync cards, is responsible for the rendering of the four projection surfaces, user tracking and functional logic.

Interactions with the VE occurs via the Xbox controller, whose reflective markers are recognized by the tracking system integrated in the CAVE. It can be used like the 3D equivalent of the PC mouse: the markers indicate (as a wand) the pointing direction, whereas the click action is performed with the "A" button. The cycling velocity, as well as the workload, can be read and set thanks to an ad-hoc communication protocol developed exploiting the cycle-ergometer Software Development Kit (SDK) provided by the manufacturer; the bike is connected to the computer via a serial cable, as well as the Arduino board.

The VE has been designed and implemented using Unity3D and displayed in the CAVE using MiddleVR for Unity (http://www.middlevr.com/middlevr-for-unity/). This Unity plug-in provides driver mappings for a variety of existing input devices and accessories - such as Vicon trackers -

and delivers abstractions to split functional and graphical logic into a clustered stereoscopic multi display setup allowing for multi-screens / multi-computers synchronization for higher-resolution VR systems. A schematic representation of the hardware setup is shown in Figure 1.

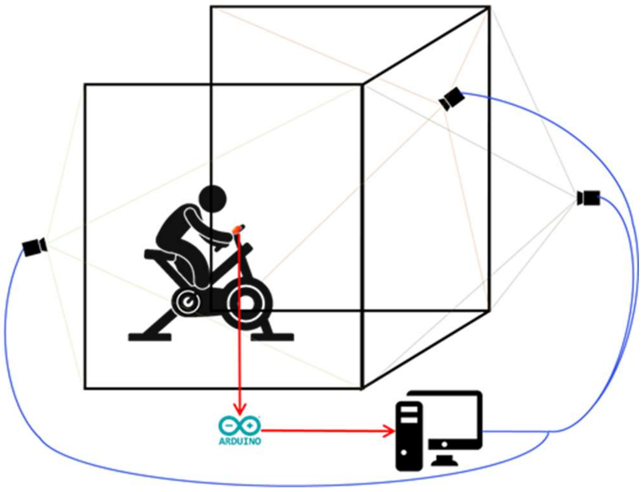

Figure 1. A schematic representation of the hardware setup.

1.2.1. Virtual Environments

Positive-Bike VE is composed of three subsequent scenes: (1) login and settings, (2) exercise and (3) attention test. The login and settings scene is populated with a 3D graphical user interface (GUI) allowing the therapist either to create a new user or to load the information of an already-existing user. Moreover, it permits the setting of the parameters defining the exercise, which are:

- *Game type*: the operator can set the target typology – and thus the exercise type – by choosing between animals or objects (street furniture).
- *Characteristic of the target to select*: for animals, the first letter of the animal's names (C/G/T/S); for objects, distinct colors are available (orange/blue /yellow/violet).
- *Level*: two levels of difficulty are available; in level 1, targets appear on the route each 15 second, in level 2, each 10 second.
- *Cycle-ergometer workload*: the operator can set the bike workload selecting among 20/30/40/50 W.
- *Time*: The duration of the exercise, the operator can select 15 or 20 minutes.

The selection of the user and of the training parameters are ~~is~~ carried out with the wand.

After the definition of the parameters, the therapist can start the exercise. The exercise scene contains a trail in the park (see Fig. 2) that flows according to the pedals velocity (measured by the cycle-ergometer in round-per-minute, RPM). The path is created thanks to the placements of subsequent nodes on the route, whose interpolation occurs in real-time using quaternion spherical linear interpolation (slerp). The user cannot brake or turn intentionally; only slight bends are present to avoid the occurrence of cyber-sickness due to the expectation of lateral accelerations [51].

All participants are instructed to keep their cycling velocity between 55 and 65 rpm: the exercise intensity, in fact, is adjusted according to the subjects' capabilities by choosing different workloads. Two different audio warnings are used to provide the users with feedback when the velocity is too high or too low. In particular, an acute sound indicates that the user is cycling too fast, whereas a grave one signals a too low velocity. Both feedbacks are given in the form of earcons [52]: this type of auditory display, defined as "abstract and synthetic tones", were preferred to visual indications because they provide an immediate feedback without distracting the patient from the accomplishment his/her dual task [53]. During the whole exercise, a rustle simulating the cycling on an untarmacked road is reproduced.

During the cycling, the targets appear randomly, on either the left or right side of the street at a distance of 20 meters from the user position, so that the participant has the time to clearly distinguish its appearance and features. Targets' orientation is random, too. The time elapsing between two subsequent apparitions is driven by the difficulty level selected.

To select a target the user has to push the button, positioned on the cycle ergometer handlebar, before the target gets out of his/her visual field (i.e. it is not displayed anymore on the CAVE lateral wall). A visual feedback is given to the user both for wrong (target becomes red) or right answer (target becomes green). No feedbacks are given when the user does not press the button, either if the choice is correct (the displayed animal/object is a distractor) or if the target has been missed.

At the end of the exercise, in scene (3), the user is administered an attention question: the application asks the player – via written text – how many targets he/she encountered during the exercise. The user tells the therapist how many targets he/she remembers. The result of this query inserted in the system by the operator, together with session data (date, time and duration), exercise parameters and user's performance (# selected/missed targets) are stored in the user's folder in the form of an XML file.

Figure 2. A screenshot of the exercise scene. A dog appeared on the route.

2. Usability study

Usability can be defined as the degree to which a specific subject is able to use a given system to achieve specific goals effectively, efficiently and satisfactorily within a well-defined context of use [54]. According to this definition, usability is composed by three main factors, all related to the characteristics and the goals of the users and the context of use:

- Effectiveness: the possibility for the users to achieve goals,
- Efficiency: the effort made by the user to reach the goal
- Satisfaction: what users think about the interaction with the system.

Formative evaluation is a process for the assessment of the usability in order to understand what the usability problems are and suggest solutions able to address the developer's work based on expert perspective. In the present study, a formative evaluation was carried out using three validated instruments: The System Usability Scale (SUS) The System Usability Scale (SUS) [55], an Italian adaptation of the Short Flow State Scale [56] and a formative evaluation carried out through a semi-structured interview:

- SUS is a "quick and easy to use" questionnaire composed by ten items and created by Brooke in the 1996 [55]. The final score can range from 0, lack of usability, to 100, best usability (for an interpretation of SUS scores, see [57]).

- The Short Flow State Scale [56] assesses nine key flow dimensions: challenge-skill balance, action-awareness merging, clear goals, unambiguous feedback, concentration on the task at hand, sense of control, loss of self-consciousness, time transformation, and autotelic experience. These characteristics were constructed using the conceptual flow model [58, 59].

The aim of the " formative evaluations" is to collect information about the usability and interaction from the point of view of the final users. The interview focused on four primary areas: (1) Usability; (2) Sense of Presence; (3) Cyber Sickness and; (4) Expectations. For the first two of these topics minor themes were identified:

1. Usability:
    - Utilization,
    - Learning,
    - Pleasantness.
2. Sense of Presence:
    - Spatial Presence,
    - Engagement,
    - Realism.

In the Table 1 some exemplificative questions are reported.

The outcome is a description of the main difficulties emerged during the user of application, the impact of the problem on the usability and the practical solutions. The results of the analysis could be used to refine the interaction design.

Table 1. Questions of Semi-Structured Interview.

TOPIC	SUB-TOPIC	QUESTIONS
USABILITY	Utilization	What difficulties did you encounter in carrying out the task? Was it difficult to use the instrument? There were technical issues during the session?
	Learning	Did you have to ask for help to understand how to use the system? Did it take a long time to figure out how the instrument works? Was exercise complicated?
	Pleasantness	Did you like the virtual environment? Some parts of the system were uncomfortable? Did you have any trouble riding a stationary bike with 3D glasses?
SENSE OF PRESENCE	Spatial Presence	Did you feel part of the environment? Do you feel you have control over the environment?
	Engagement	Were you happy that the exercise was over? What do you think about the duration of the experience? Did you easily get distracted during exercise?
	Realism	How did you find the environment, realistic or too artificial?
CYBER SICKNESS	Physical side-effects	Did you feel bad during exercise? Did you have nausea, dizziness or other physical symptoms during exercise?
EXPECTATIONS		Would you like to use this system to do exercise? Do you think this system can be useful for other types of patients?

2.1. Sample

For the usability assessment 5 elderly subjects were recruited, 3 females and 2 males. The mean age was 70 (SD 11,70) and the mean years of education (y.o.e.) were 11 (SD 5,61). All the demographic data are reported in the Table 2.

Table 2. Demographic data.

	age	y.o.e.	gender	MMSE
Sbj 1	87	5	M	27
Sbj 2	65	16	F	25,2
Sbj 3	77	5	M	20,9
Sbj 4	59	16	F	25,2
Sbj 5	62	13	F	30
Mean	70,00	11,70		25,66
SD	11,70	5,61		3,31

Before the session all participant was given written information about the study and were asked to give written consent to be included. The study received ethical approval from the Ethical Committee of the Istituto Auxologico Italiano.

Subject with physical problems that prevent riding or with dementia were excluded from the study, no other exclusion criteria was considered.

2.2. Task

Each subject had to perform the same exercise inside the CAVE. The task requires to ride the cycle-ergometer for 15 consecutive minutes inside the virtual environment. The cycle-ergometer workload was set at the minimum level (20W) for all the subjects. The eyeglasses that commanded the visual feedback were hanged on the neck of the patients, who had to wear spectacle goggles; this was done to prevent subjects from experiencing cybersickness, such as nausea or dizziness, as while pedalling their head could swing excessively and cause abrupt movements in the virtual environment. Subjects had to keep constant speed during the task. They received an audio feedback if the speed comes out of the parameters (§2.1). Everyone used animals beginning with letter "C" as target (camel, dog, kangaroo, horse and deer, respectively cammello, cane, canguro, cavallo and cervo in Italian) and the lowest difficult level (Level 1).

3. Results

The mean values of the usability, calculated with the SUS, are 76,88 (SD=17,00) as showed in figure 3.

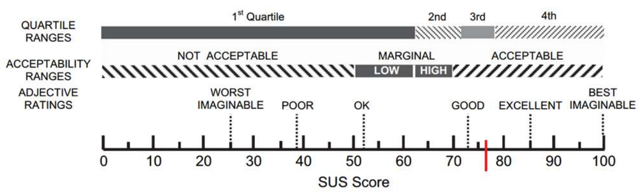

Figure 3. A graphic representation of the SUS' score.

A global score of flow was obtained calculating the mean of each score of the nine items of the Short Flow State Scale. The mean score of our participants were 4,33 (SD=0,84). A single dimension mean score was presented in Table 3.

Table 3. Short Flow State Scale single dimension mean score.

	Dimension	mean	SD
Q1	Challenge-skill	4,6	0,49
Q2	Action-awareness	4	1,26
Q3	Clear goals	4,4	0,80
Q4	Unambiguous feedback	4,2	0,98
Q5	Concentration	4,4	0,80
Q6	Sense of control	4,4	0,80
Q7	Loss of self-consciousness	5	0,00
Q8	Transformation of time	3,8	1,60
Q9	Autoletic experience	4,2	1,60
Q10	Total	4,33	0,75

The outcome of formative evaluation was divided into two table for clarity. In the table 4 the positive feedbacks of the subjects were reported; the negative ones were presented in table 5. Direct comments of the subjects are reported in quotation marks, unlike the researchers' observations.

Table 4. Positive Feedbacks from Formative Evaluation.

TOPIC	SUB-TOPIC	POSITIVE FEEDBACK
USABILITY	Utilization	"Both the motor and cognitive tasks were easy"
	Learning	"There was no problem in learning the use of the system"
	Pleasantness	"The 3D glass was not uncomfortable." "The environment was beautiful." "The cycle-ergometer was manageable."
SENSE OF PRESENCE	Spatial Presence	"The feeling was to be in the real park." "I had the feeling of being suspended" "The environment was relaxing"
	Engagement	"I was focused on the task" "I think I've been pedaling for 5 minutes" "I forget you (the examiners) were here too"
	Realism	"The environment was realistic"
CYBER SICKNESS	Physical side-effects	None present side effect like cyber-sickness or nausea
EXPECTATIONS		"This system could be useful for several types of patients" "I think it's easier to train with this tool"

Table 5. Negative Feedbacks from Formative Evaluation.

TOPIC	SUB-TOPIC	NEGATIVE FEEDBACK
USABILITY	Utilization	"It's difficult to recognize small animals." "It's not easy to identify animals placed backward." "Some similar animals were confused (zebra-horse and turkey – swan)."

	Learning	The sound of the bike might be confused with the sound that give a feedback about speed. "When frequency increases the exercise becomes more difficult."
	Pleasantness	"Animals are repetitive."
SENSE OF PRESENCE	Spatial Presence	"I had the feeling that animals bumped me".
	Engagement	"I felt passive and not active in the environment".
	Realism	"The environment was nice but did not look very real." "Some animals are "out of context"."
CYBER SICKNESS	Physical side-effects	One patient was tired before the end of the task.
EXPECTATIONS		There is no difference between this type of treatment and another.

4. Discussion

The results reported below above were very encouraging and show that the system had good usability.

The SUS' score [48] was 76,88 (SD=17,00) and indicated a satisfactory level of usability: indeed, the score can be included in the third quartile, as showed in the figure 4. According to this test, no adaptation of our system would be necessary.

However, several issues that could be improved emerged during the formative evaluation. As showed in table 3, subjects highlighted some features that, in their opinions, could be modified to improve the quality and the usability of the system.

Most patients reported problems in recognizing animals. In some cases, the problem was related to the dimension of the target. The more the animal was smaller, the more patients had trouble recognizing it. To solve this problem, the size of smaller animals could be increased, even if this would involve a less realistic choice. Alternatively, other animals, that have not been inserted in this test because they were difficult to recognize or easily confused with others (for example, pricket, goat, stork; in italian: cerbiatto, capra, cicogna), could be inserted after a special training with patients to make them familiarize with the animals' appearance. In other cases, the difficulty was related to the way the animals were presented. If the animal was presented backward some subject had some problem to recognize it correctly. A simple way to fix this problem is to constrain the rotation of all the animals along the path and make them always face the subject.

Two subjects confused some similar animals, i.e. they called "horse", the zebra and "swan", the turkey. A training preceding the exercise with the purpose of familiarizing with animals can be of help in this case too. In addition to this, a general improvement of the quality of the 3D animal models could enhance their recognizability and, thus, the usability of the virtual environment.

A problem related to the discrimination of the audio feedback used for the regulation of the riding speed emerged during the sessions. As said before, an acute tone indicated a too-high speed; conversely, a grave tone indicated a too-low speed. These two earcons overlapped the realistic sound of the bike riding that was provided with the aim of improving the realism, the sense of control and the agency in the environment. One subject has difficulty in differentiating the sounds, especially at the beginning of the exercise. Adding a training phase before the exercise, during which subjects could listen to the different sounds and learn to discriminate them, could be an easy-to-use solution to avoid this problem.

In several occasions, a problem with the button showed up: patients pushed it, but the system did not respond. This technical difficulty could be accommodated by adjusting or replacing the button.

The analysis of flow resulted in a very high score: 4,33/5 (SD=0,84). This indicated that subjects were very involved in the environment and in the task. Csikszentmihalyi described flow as a sensation that people feel when they act with total involvement. Flow could be also strongly related to wellbeing, because it emerges when good balance between challenge and personal skills is present, that is a situation characterized by high sense of control. As reported in Table 2, a subject referred that during the task, she forgot the presence of the examiners. Another subject has even perceived that the frequency of appearance of animals had increased, when in reality it was always the same (table 2).

Analysing the single dimensions of the scale, it is possible to identify the dimension with the major and minor score. The lowest score was related to the item "The way time passed seemed to be different from normal". The totality of subjects responded with the maximum rate (5) at the item "I was not worried about what others may have been thinking of me". This specific sentence is related to the "Loss of self-consciousness" dimension. The subjects forgot the context in which they were during this exercise: they forgot to be in a hospital for a rehabilitation program. This aspect could be a strength of the developed system because it may encourage the patients to be part of the rehabilitation sessions and increase their adherence to the program.

5. Conclusions and Future Works

VR represents a promising technology that, in the near future, can be easily become part of different rehabilitation treatments, as demonstrated by the great number of studies reported in literature. However, before its introduction in the clinical practice, it is necessary to consider both the pathology-related complications that potential users may have and the usability aspect of the designed system.

In this work, an innovative system for motor rehabilitation was presented together with an ad-hoc VE developed for the provision of a dual-task exercise to frail patients. The first usability study – conducted on five elderly subjects – with the aim of assessing the system usability and the end users' satisfaction resulted in a good level of usability.

A strength of our system was the high level of flow showed by the participants associated with high immersion and fun during the experience. This indicate that the system is able to engage the subjects more than a classical training programs. This is an important factor to consider when designing interactive systems in the medical and rehabilitative field, as greater involvement leads the patient to achieve better results [60].

However, different issues related both to software and hardware have been highlighted both by patients and by operators observing the training sessions. These issues will be corrected before the next trial and a training phase, during which the patient is instructed about the tasks and the types of feedback, will be arranged. Moreover, since a great limitation of this work is the restricted number of participants involved in the experiment, after the aforementioned adjustments, a new usability assessment will be performed including a larger number of participants; for the reasons already explained, an investigation of the sense of presence and of subjects' flow should also be included. It would also be interesting to compare the performance and the involvement of patients with this system and with another device, particularly with a Head Mounted Display. A HMD in fact could enhance the navigational experience in the VEs and increase the sense of presence, thought it may have the drawback of inducing cyber-sickness [57]. Future works include also the integration of sensors to monitor the patient physiological status during the training. A heart rate monitor or a breath rate monitor could be easily integrated in the setup to ensure patients' safety throughout the training sessions and to measure their potential progress during the program.

Acknowledgments: This work was supported by the Italian funded project "High-end and Low-End Virtual Reality Systems for the Rehabilitation of Frailty in the Elderly" (PE-2013-02355948).

Author Contributions: "E.P., A.G., S.S. and P.C. conceived and designed the experiments; E.P., M.M., L.B., V.G. performed the experiments; L.G. and S.A. participated in the design, developed the environment and integrated the cycle-ergometer functionalities; E.P., D.C., L.G., wrote the first draft, all the authors revised the final version of manuscript, M.A., M.S., M.S.B., G.R., and A.G. supervised the study"

Conflicts of Interest: "The authors declare no conflict of interest."

References

1. Woollacott, M.; Shumway-Cook, A. Attention and the control of posture and gait: a review of an emerging area of research. *Gait Posture* **2002**, *16(1)*, 1-14, DOI: https://doi.org/10.1016/S0966-6362(01)00156-4.
2. Fried, L.P., et al. Frailty in older adults: evidence for a phenotype. *J Gerontol A-Biol* **2001**, *56(3)*, M146-56, DOI: https://doi.org/10.1093/gerona/56.3.M146.
3. Gobbens, R.J., et al. Toward a conceptual definition of frail community dwelling older people. *Nurs Outlook* **2010**, *58(2)*, 76-86, DOI: https://doi.org/10.1016/j.outlook.2009.09.005.
4. Speechley, M.; Tinetti, M. Falls and injuries in frail and vigorous community elderly persons. *J Am Geriatr Soc* **1991**, *39(1)*, 46-52, DOI: https://doi.org/10.1111/j.1532-5415.1991.tb05905.x.
5. Fried, L.P., et al. Untangling the concepts of disability, frailty, and comorbidity: implications for improved targeting and care. *J Gerontol A-Biol* **2004**, *59(3)*, 255-63, DOI: https://doi.org/10.1093/gerona/59.3.M255.
6. Rockwood, K. What would make a definition of frailty successful? *Age Ageing* **2005**, *34(5)*, 432-4, DOI: https://doi.org/10.1093/ageing/afi146.
7. Blake, A.J., et al. Falls by elderly people at home: prevalence and associated factors. *Age Ageing* **1988**, *17(6)*, 365-72, DOI: https://doi.org/10.1093/ageing/17.6.365.
8. Donald, I.P.; Bulpitt, C.J. The prognosis of falls in elderly people living at home. *Age Ageing* **1999**, *28(2)*,121-5, DOI: https://doi.org/10.1093/ageing/28.2.121.
9. Zijlstra, G.A., et al. Prevalence and correlates of fear of falling, and associated avoidance of activity in the general population of community-living older people. *Age Ageing* **2007**, *36(3)*, 304-9, DOI: https://doi.org/10.1093/ageing/afm021.
10. Lundin-Olsson, L.; Nyberg, L.; Gustafson, Y. "Stops walking when talking" as a predictor of falls in elderly people. *Lancet* **1997**, *349(9052)*, 617, DOI: https://doi.org/10.1016/S0140-6736(05)61565-6.
11. Montero-Odasso, M., et al. Gait and cognition: a complementary approach to understanding brain function and the risk of falling. *J Am Geriatr Soc* **2012**, *60(11)*, 2127-36, DOI: https://doi.org/10.1111/j.1532-5415.2012.04209.x.
12. Yogev-Seligmann, G.; Hausdorff, J.M.; Giladi, N. The role of executive function and attention in gait. *Movement Disord* **2008**, *23(3)*, 329-42, DOI: https://doi.org/10.1002/mds.21720.
13. Plummer, P., et al. Cognitive-motor interference during functional mobility after stroke: state of the science and implications for future research. *Arch Phys Med Rehab* **2013**, *94(12)*, 2565-2574, DOI: https://doi.org/10.1016/j.apmr.2013.08.002.
14. Leone, C., et al. Cognitive-motor dual-task interference: A systematic review of neural correlates. *Neurosci Biobehav R* **2017**, *75*, 348-360, DOI: https://doi.org/10.1016/j.neubiorev.2017.01.010.
15. Wickens, C.D. The structure of attentional resources. *Attention Perform* **1980**, *8*, 239-257.
16. Pashler, H. Dual-task interference in simple tasks: data and theory. *Pol Psychol Bull* **1994**, *116(2)*, 220-44, DOI: http://dx.doi.org/10.1037/0033-2909.116.2.220.
17. Al-Yahya, E., et al. Cognitive motor interference while walking: a systematic review and meta-analysis. *Neurosci Biobehav R* **2011**, *35(3)*, 715-28, DOI: https://doi.org/10.1016/j.neubiorev.2010.08.008.
18. Ranky, R., et al. VRACK—virtual reality augmented cycling kit: Design and validation. Proceedings of Virtual Reality Conference (VR), Waltham, Massachusetts, USA, 20-24 March 2010; IEEE.
19. Killane, I., et al. Dual motor-cognitive virtual reality training impacts dual-task performance in freezing of gait. *IEEE J Biomed Health* **2015**, *19(6)*,1855-1861, DOI: 10.1109/JBHI.2015.2479625.

20. Dunsky, A.; Fishbein, P.; Hutzler, Y. Dual-task training using virtual reality: Influence on walking and balance in three post stroke survivors. *Int J Therap Rehabil Res* **2013,** *2(2)*, 22-34, DOI: 10.5455/ijtrr.00000021.
21. Wang, X., et al. Cognitive motor interference for preventing falls in older adults: a systematic review and meta-analysis of randomised controlled trials. *Age Ageing* **2015**, *44(2)*, 205-12, DOI: https://doi.org/10.1093/ageing/afu175.
22. Hsu, C.L., et al. Examining the relationship between specific cognitive processes and falls risk in older adults: a systematic review. *Osteoporosis Int* **2012**, *23(10)*, 2409-24, DOI: 10.1007/s00198-012-1992-z.
23. Gill, T.M., et al. Transitions between frailty states among community-living older persons. *Arch Intern Med* **2006**, *166(4)*, 418-23, DOI: 10.1001/archinte.166.4.418.
24. de Labra, C., et al. Effects of physical exercise interventions in frail older adults: a systematic review of randomized controlled trials. *BMC Geriatr* **2015**, *15*, 154, DOI: https://doi.org/10.1186/s12877-015-0155-4.
25. Aguirre, L.E.; Villareal, D.T. Physical Exercise as Therapy for Frailty. *Nes Nutr I Work Se* **2015**, *83*, 83-92, DOI: https://doi.org/10.1159/000382065.
26. Cadore, E.L., et al. Multicomponent exercises including muscle power training enhance muscle mass, power output, and functional outcomes in institutionalized frail nonagenarians. *Age* **2014**, *36(2)*, 773-85, DOI: 10.1007/s11357-013-9586-z.
27. Inokuchi, S., et al. Feasibility and effectiveness of a nurse-led community exercise programme for prevention of falls among frail elderly people: a multi-centre controlled trial. *J Rehabil Med* **2007**, *39(6)*, 479-85, DOI: 10.2340/16501977-0080.
28. Gillespie, L.D., et al. Interventions for preventing falls in older people living in the community. *Cochrane Db Syst Rev* **2009**, *2(2)*, DOI: 10.1002/14651858.CD007146.pub2.
29. Sherrington, C., et al. Effective exercise for the prevention of falls: a systematic review and meta-analysis. *J Am Geriatr Soc* **2008**, *56(12)*, 2234-43, DOI: https://doi.org/10.1111/j.1532-5415.2008.02014.x.
30. Kramer, A.F., et al. Fitness, aging and neurocognitive function. *Neurobiol Aging* **2005**, *26(1)*, 124-7, DOI: https://doi.org/10.1016/j.neurobiolaging.2005.09.009.
31. Silsupadol, P., et al. Effects of single-task versus dual-task training on balance performance in older adults: a double-blind, randomized controlled trial. *Arch Phys Med Rehab* **2009**, *90(3)*, 381-7, DOI: https://doi.org/10.1016/j.apmr.2008.09.559.
32. Lauenroth, A.; Ioannidis, A.E.; Teichmann, B. Influence of combined physical and cognitive training on cognition: a systematic review. *BMC Geriatr* **2016**, *16*, 141, DOI: https://doi.org/10.1186/s12877-016-0315-1.
33. Schoene, D., et al. The effect of interactive cognitive-motor training in reducing fall risk in older people: a systematic review. *BMC Geriatr* **2014**, *14*, 107, DOI: https://doi.org/10.1186/1471-2318-14-107.
34. Wajda, D.A., et al. Intervention modalities for targeting cognitive-motor interference in individuals with neurodegenerative disease: a systematic review. *Expert Rev Neurother* **2017,** *17(3)*, 251-261, DOI: https://doi.org/10.1080/14737175.2016.1227704.
35. Donath, L.; Rossler, R.; Faude, O. Effects of Virtual Reality Training (Exergaming) Compared to Alternative Exercise Training and Passive Control on Standing Balance and Functional Mobility in Healthy Community-Dwelling Seniors: A Meta-Analytical Review. *Sports Med* **2016**, *46(9)*, 1293-309, DOI: 10.1007/s40279-016-0485-1.

36. Yin, C., et al. A Virtual Reality-Cycling Training System for Lower Limb Balance Improvement. *Biomed Res Int* **2016**, *2016*, 9276508, DOI: http://dx.doi.org/10.1155/2016/9276508.
37. Anderson-Hanley, C.; Arciero, P.J.; Brickman, A.M.; Nimon, J.P.; Okuma, N.; Westen, S.C.; Merz, M.E.; Pence, B.D.; Woods, J.A.; Kramer, A.F.; Zimmerman, E.A. Exergaming and older adult cognition: a cluster randomized clinical tria. *Am J Prev Med* **2012**, *42(2)*, 109-119, DOI: 10.1016/j.amepre.2011.10.016.
38. Deutsch, J.E., et al. Feasibility of virtual reality augmented cycling for health promotion of people poststroke. *J Neurol Phys Ther* **2013**, *37(3)*, 118-24, DOI: 10.1097/NPT.0b013e3182a0a078.
39. Kim, N.G.; Kim, Y. Y.; Kwon, T. K. Development of a virtual reality bicycle simulator for rehabilitation training of postural balance. In *Computational Science and Its Applications - ICCSA 2006*; Gavrilova M., et al., Eds.; Springer: Berlin, Heidelberg, 2006; Volume 3980, pp. 241-250, ISBN: 978-3-540-34070-6.
40. Song, C.G.; Kim, J.Y.; Kim, N.G. A new postural balance control system for rehabilitation training based on virtual cycling. *IEEE Trans Inf Technol Biomed* **2004**, *8(2)*, 200-7, DOI: 10.1109/TITB.2004.828887.
41. Lee, C.W.; Cho, G.H. Effect of stationary cycle exercise on gait and balance of elderly women. *J Phys Ther Sci* **2014**, *26(3)*, 431-3, DOI: https://doi.org/10.1589/jpts.26.431.
42. Brown, D.A.; Kautz, S.A. Increased workload enhances force output during pedaling exercise in persons with poststroke hemiplegia. *Stroke* **1998**, *29(3)*, 598-606, DOI: https://doi.org/10.1161/01.STR.29.3.598.
43. Raasch, C.C.; Zajac, F.E. Locomotor strategy for pedaling: muscle groups and biomechanical functions. *J Neurophysiol* **1999**, *82(2)*, 515-25, DOI: https://doi.org/10.1152/jn.1999.82.2.515.
44. Mazzocchio, R., et al. Cycling, a tool for locomotor recovery after motor lesions? *NeuroRehabilitation* **2008**, *23(1)*, 67-80.
45. Fujiwara, T.; Liu, M.; Tanuma, A.; Hase, K.; Tsuji, T. Pedaling exercise for neuromuscular re-education: a review. *Crit Rev Phys Rehabil Med* **2005**, *17(3)*, 163-178, DOI: 10.1615/CritRevPhysRehabilMed.v17.i3.10.
46. Astrand, P. Measurement of maximal aerobic capacity. *Can Med Assoc J* **1967**, *96(12)*, 732.
47. Riva, G.; Mantovani, F.; Gaggioli, A. Presence and rehabilitation: toward second-generation virtual reality applications in neuropsychology. *J Neuroeng Rehabil* **2004**, *1(1)*, 9, DOI: https://doi.org/10.1186/1743-0003-1-9.
48. Riva, G.; Castelnuovo, G.; Mantovani, F. Transformation of flow in rehabilitation: the role of advanced communication technologies. *Behav Res Methods* **2006,** *38(2)*, 237-244, DOI: 10.3758/BF03192775.
49. Robinson, J., et al. The effects of exergaming on balance, gait, technology acceptance and flow experience in people with multiple sclerosis: a randomized controlled trial. *BMC Sports Sci Med Rehabil* **2015**, *7(1)*, 8, DOI: https://doi.org/10.1186/s13102-015-0001-1.
50. Pedroli, E., et al. Assessment and rehabilitation of neglect using virtual reality: a systematic review. *Front Behav Neurosci* **2015**, *9*, DOI: https://doi.org/10.3389/fnbeh.2015.00226.
51. Nichols, S.; Patel, H. Health and safety implications of virtual reality: a review of empirical evidence. *Appl Ergon* **2002**, *33(3)*, 251-271, DOI: https://doi.org/10.1016/S0003-6870(02)00020-0.
52. Blattner, M.M.; Sumikawa, D.A.; Greenberg, R.M. Earcons and icons: Their structure and common design principles. *Int J Hum-Comput Int* **1989**, *4(1)*, 11-44, DOI: 10.1207/s15327051hci0401_1.
53. Rosati, G., et al. On the role of auditory feedback in robot-assisted movement training after stroke: review of the literature. *Comput Intel Neurosc* **2013**, *2013*, 11, DOI: 10.1155/2013/586138.
54. 9241, I.I., Ergonomic requirements for office work with visual display terminals (VDTs)
55. Brooke, J. SUS-A quick and dirty usability scale. *Usability Evaluation Industry* **1996**, *189(194)*, 4-7.

56. Jackson, S.A.; Marsh, H.W. Development and validation of a scale to measure optimal experience: The Flow State Scale. *J Sport Exercise Psy* **1996**, *18(1)*, 17-35, DOI: https://doi.org/10.1123/jsep.18.1.17.
57. Bangor, A.; Kortum, P.; Miller, J. Determining what individual SUS scores mean: Adding an adjective rating scale. *J Usability Stud* **2009**, *4(3)*, 114-123, DOI: 10.1.1.177.1240.
58. Jackson, S.A.; Martin, A.J.; Eklund, R.C. Long and short measures of flow: The construct validity of the FSS-2, DFS-2, and new brief counterparts. *J Sport Exercise Psy* **2008**, *30(5)*, 561-587, DOI: https://doi.org/10.1123/jsep.30.5.561.
59. Csikszentmihalyi, M. *Flow. The Psychology of Optimal Experience*, 1st ed.; Harper Perennial Modern Classics: New York, 2008; ISBN: 978-0061339202.
60. Zimmerli, L., et al. Increasing patient engagement during virtual reality-based motor rehabilitation. *Archives of physical medicine and rehabilitation* **2013**, *94(9)*, 1737-1746, DOI: https://doi.org/10.1016/j.apmr.2013.01.029.