

DEVELOPMENTS OF COLLABORATIVE RESEARCH ON VR APPLICATIONS FOR MENTAL HEALTH. FOCUS ON CYBERSICKNESS AND MEMORY TESTING.

L Pugnetti, L Mendozzi, E Barbieri, D Alpini
Gnocchi Foundation, Milan, ITALY

EA Attree, BM Brooks, and FD Rose
University of East London, UK

A Motta
Policlinico di Monza, ITALY

ABSTRACT

The collaboration between our two scientific institutions is significant contributing to VR research into several fields of clinical application. Concerning the important issue of side-effects, future studies will clarify whether the encouraging results obtained in the recent past, that demonstrate few side-effects, in patients with neurological diseases can be confirmed, and whether specific recommendations for the use of immersive VR in selected clinical populations can be made. Recent collaborative studies on the application of non-immersive VR to improve clinical testing of spatial memory provided evidence of good replicability of results in both healthy and neurologically affected groups. The development of retraining applications for spatial memory impairments and future studies aimed at assessing the impact of ambulatory disability on spatial cognitive abilities will be based on these findings. Finally, a newly approved transnational project will lead our groups into the field of the assistive technology to improve working skills and opportunities for employment of people with mental disabilities who seek employment.

1. Introduction

Though it has been promoted as a revolutionary tool, VR has not yet entered clinical practice and changed the methods of cognitive testing and rehabilitation. In the last few years, our two groups in Milan (FDG) and London (UEL) have been developing the rationale to propose VR as a clinical tool (Rose et al., 1996), together with software programmes and testing protocols to assess whether this technology can be safely used to produce meaningful results in both research and clinical contexts. This report deals with some the most recent developments of our collaborative projects.

An immersive VR analog of the Wisconsin Card Sorting test (WCST) paradigm has been originally developed by the FDG group on a proprietary platform as a research workbench for testing so-called "strategy application disorders" (Pugnetti et al., 1995). An improved version is now being developed in collaboration with UEL. It has an open configuration and runs on a standard fast PC workstation in both immersive and non-immersive modes. The psychometric characteristics of the preceding immersive system have been recently published (Pugnetti et al., 1998). It has also proved useful as a means to expand our investigations into aspects of VR-induced exploratory behavior and their psychophysiological correlates (Alpini et al., 1996; Pugnetti et al., 1996b).

The results of studies with the new versions are not yet available, thus, the discussion focuses upon unpublished findings concerning side-effects reported by participants interacting with a previous version of the immersive system which was described in a previous publication (Pugnetti et al., 1995). The main objectives of this study were to assess the impact of immersive VR on participants who may be considered to have an increased risk for side-effects because of neurological diseases involving the central nervous system and brainstem, and to compare the results with studies that used similar measures and procedures.

A group of 36 outpatients, (mean age 36.3 years, sd 11.4, range 18-65) of both sexes with neurological impairments as a result of multiple sclerosis (MS; n.25, cerebrovascular disease (n.4), traumatic brain injuries (n. 5) and normal-pressure hydrocephalus (n.2), and 32 healthy participants matched for age and level of education gave informed consent to participate in VR test sessions of 45 minutes maximum duration. Patients were recruited among those with stable neurological conditions, good bilateral visual acuity, preserved dominant hand dexterity, no history of epilepsy, psychiatric, and vestibular disorders, and an overall moderate-to-severe cognitive impairment. Before any test session all participants were given a carefully explanation of the aims of the research, the potential risks of immersive VR and the way in which they would interact with the virtual environment (VE). They were asked to navigate a VE structured as a series of 32 decagonal rooms connected by corridors. The task was to choose among four exit doors the one leading to the next room, taking the clue from the entrance door [[slide 1]]. As on the WCST, participants needed to match a response card with one of four reference cards according to one attribute, in the VR condition the entrance and exit doors needed to be matched by either color, shape or number of pinholes. Whereas any of the exit doors would open and lead to a corridor, only after a correct match would the door at the end of a corridor open to let the participant into a new room. A wrong choice would force the participant back to the "preceeding" room which, in fact, was never the same.

Participants were interviewed about previous experiences with immersive VR, their susceptibility to common kinetosis and were given the opportunity to wear the headset (HMD) and practice with another VE for up to

15 minutes while instructions were repeated to assure full comprehension. All practice and test sessions were carried out with the participants seated comfortably on a chair which could revolve; this was necessary to equate controls' posture to that of some of the patients who could not stand easily because of their illness. Cables connecting the headset to the VR server were hanging from the ceiling above participants' head. Two experimenters were always present during the VR sessions, but participants were always tested individually. They were instructed to rotate smoothly and slowly, and to avoid the combination of forward movements in the VE and real head rotations that produces a visuo-vestibular sensorial conflict. Participants who reported any side-effects during or after the practice trial were reassured about the benign nature of the symptoms and allowed to re-examine their decision to participate. They were not encouraged to continue the session in spite of symptoms and could withdraw at any time. Both training and test sessions were carried out in a small but quiet facility in the hospital. Test sessions were run usually the day after practice.

The recording of side-effects was carried out according to the methodology reported by Regan and Price (1993, 1994). The Motion Sickness History Questionnaire (MSHQ) was used to rate each individual's susceptibility to common kinetoses. A Malaise Questionnaire (MQ) was used at 5 minute intervals to assess the presence of any physical discomfort of a cybersickness nature. A Simulator Sickness Questionnaire (SSQ, 26 items version) was compiled by the participants prior to and immediately after the VR session to rate the presence and severity of symptoms other than malaise. In addition, structured interviews based on the Equipment and Display Questionnaire (E&DQ) and a 6 items Immersion Questionnaire (IQ) were carried out at the end of each test session to investigate ergonomic factors and participative feelings. The reader is referred to the original papers by Regan and Price (1993, 1994) for details on the rating instruments.

In addition to self report measures, objective measurements of static balance control were taken on a sub-sample of participants by means of a clinical computerized stabilometric platform. The time to complete the VR session and a performance index computed as the ratio of correct to incorrect selections were used to correlate with side effects ratings.

Rating Scales

- a) A pre-immersion Motion Sickness History Questionnaire (MSHQ) adapted from the Pensacola MSHQ (an estimation of sensitivity to kinetoses)
- b) Rating on the Malaise Scale at each of the following time periods (to monitor target symptoms)
 - pre immersion
 - at 5 minutes intervals up to 45 minutes
 - at 5 and 10 minutes post immersion
- c) a pre-immersion symptom checklist (SSQ)
- d) a post immersion SSQ (to profile aftereffects)

- e) an equipment and display questionnaire (EDQ) (judgement of system performance)
- f) an Immersion Questionnaire (IMQ) (measurement of subjective experience)

Objective measures

- a) Computerized stabilometry (subgroup)

Performance Measures

- a) Time to complete the VR session
- b) Actions - exploration and transfer
- c) Decisions (right-wrong)
- e) Summary index

Table 1. Summary of measurements taken for the side effects studies

VR Server: Compaq Prosigma, processor Pentium 60 Mhz, 16 Mb RAM
HMD: Virtual Research EyeGen 3, CRT with color shutters and adjustable optics and IPD, 40° diagonal FOV; weight: 600 gr.
Tracking: 2 Polhemus Fastrack - 120 meas./sec., 4 msec. latency, 10 ft. range
Additional: 486 DX 33 workstation with 2 video boards for simultaneous image acquisition during the sessions from the VE and a VHS camera.

Table 2. Specifications of the VR system used for the Immersion Side Effects studies

3. Results

3.1 VR SESSIONS COMPLETION

No instance of severe malaise was observed during the practice sessions. Of the 73 participants, 1 patient withdrew from the session because of inability to follow instructions; the performance data of 2 participants were missing because of technical faults; two of the patients did not complete the test within the maximum allotted time of 45 minutes. Five participants (7%) - 3 healthy controls and 2 MS patients - asked to discontinue the test because of severe nausea which always occurred between 10 and 20 minutes from the start. Their condition did not require any treatment besides removal of the HMD and a brief rest. Their data were not included in the other statistics. Three patients and 2 controls reported symptoms at the pre-immersion Malaise Scale, but all were able to complete the VR session. In two (one patient and 1 control) symptom ratings actually improved during VR, while in the remaining three participants they remained stable throughout. As some of the questions in the questionnaires have been occasionally misinterpreted, total valid responses for patients and controls are reported along with group means and standard deviations [[slide 2]].

3.2 GROUP DIFFERENCES

The time course of the malaise ratings on the Malaise Scale (any symptom) followed the pattern already described by Regan and Price; it increased to reach a maximum of 40% of the participants reporting at least one symptom after 25 minutes of exposure, decreasing thereafter to return at baseline levels 10 minutes after the end of the session (Fig. 1) [[slide 3]]. The mean prevalence of VR-induced symptoms across a 30 minutes session was 16% in the total sample. Again, patients did not report more symptomatology than healthy controls, and females (n.27) did not differ significantly from males (n.36) on the total Malaise Scale score.

The prevalence of VR-induced side-effects of any type was measured by the pre- vs post-VR change on the total sickness score of the SSQ, and was around 7.5 points for both patients and healthy controls who completed 30 minutes of testing. This figure was neither related to the severity of neurological condition (in the patients), measured on a 7 point disability scale similar to the EDSS (Kurtzke et al., 1983) [[slide 4]], nor to an unspecific sensitivity to kinetoses (for both groups); patients and controls did not differ in terms of general susceptibility to motion sickness as rated on the MSHQ [[slide 5]]. On the SSQ, the maximum change was observed on Kennedy's (Kennedy et al., 1992) disorientation factor (mean of 12 points), followed by the oculomotion and nausea factors (< 6 points each) (Fig. 2)[[slide 6]]. Patients showed lower SSQ changes than controls (total scale score - controls: mean 9.37 [sd 12.05] n.32, patients: mean 4.6 [sd 12.47] n. 32); the difference approached significance on the disorientation scale (controls: mean 14.79 [sd 20.29] n. 32, patients: mean 6.2 [sd 21.5] n. 32; Mann-Whitney U test $p=.06$). This occurred partly because patients scored higher than controls on the disorientation scale on pre-immersion SSQ (controls: mean 1.3 [sd 4.12] n.32, patients: mean 4.78 [sd 10.96] n.32) [[slides 7 and 8]] though the difference did not reach statistical significance (Mann-Whitney U test $p=.09$). On average, 38% percent of the total sample (n.63) reported some negative rating concerning ergonomic factors of the HMD (8 items on the EDQ), over 60% rated it as uncomfortable for a prolonged use, while 48% found it too heavy [[slide 9]]. On average, the efficiency of the display was rated somewhat negatively by 25% of the participants, mainly due to the difficulty to adjust the focus and the interpupillary distance or to keep regulations steady, so that the images were felt to be unstable. The response of the tracker was also criticized by 25% of the users; they felt it too slow or imprecise for an optimal interaction with the VE. Forty-five percent of the users were not satisfied with the pointer we have adopted (a hand-made light-weight wooden key incorporating the tracker). Only 21%, however, reported that the above ergonomic factors may have interfered with their performance. Interestingly, patients tended to complain less than healthy controls on the EDQ. Patients, however, rated the visual efficiency of the HMD more negatively than controls (patients: mean 1.64 [sd 1.32] n. 25, controls: mean 1.03 [sd 1.32] n. 29; Mann-Whitney U Test $p=.05$); no other group differences were noted. To analyse this finding the patients' group was split according to the presence/absence of a history of optic neuritis (ON). Patients with a past history of ON scored significantly higher on the HMD efficiency scale (ON group: mean 2.71 [sd 1.38] n.7, no-ON group: mean 1.22 [sd 1.06] n.18; Mann-Whitney U test $p=.017$) [[slide 10]].

From the analysis of the Immersion Questionnaire (IMQ) it emerged that 34% of the participants did not feel "immersed" in the virtual environment during the session, whereas 43% did, in the remaining 22% the effect was modest [[slide 11]]. Only 14% felt that the virtual experience had changed their affective state toward excitation, 58% reported no change, whereas 27% reported only slight changes. Patients and controls did not differ on any of the

IMQ items nor on the total scale score (patients: mean 12.08 [sd 3.05] n. 25, controls: mean 13.06 [sd 2.01] n. 29). The total "immersive effect" was modest-to-moderate, given that the maximum score attainable was 30.

No clinically significant after-effects were noticed on standard clinical balancing tests carried out on healthy participants after the session. Since it was felt that clinical measurements could not pick up subtle changes, a pilot study using a computerized stabilometric platform was carried out on a subsample of 8 healthy participants and 6 MS patients who underwent VR testing and were matched to 10 controls and 7 MS patients who did not; detailed results have been already published elsewhere (Pugnetti et al., 1996). Computerized stabilometry with eyes open and eyes closed standing conditions was performed before and after VR sessions. Results showed that immersive VR did not worsen static balance of either healthy controls or neurological patients, though the latter showed significant absolute impairments due to their illness.

Patients took significantly more time than controls to complete the VR test (patients: mean total time (seconds) 1982.7 [sd 531.7] n. 33, controls: mean 1753.0 [sd 348.7] n. 35; Mann-Whitney U test $p=.05$), but performed the same number of actions in the Ves [[slide 12]]. Patients also scored significantly worse than controls on the performance index (controls mean 1.71; sd 0.87 n. 35; patients mean 1.33; sd 0.70 n. 35; Mann-Whitney U test $p=.017$). A more detailed analysis of performance data can be found in another recent report (Pugnetti et al., 1998).

3.3 CORRELATIONS

Age was significantly correlated with total immersion time on the total sample (n. 70, $r = .43$, $p=.01$), but not on separate groups. The correlation between total Malaise Scale ratings and total time in VR was steeper and more significant for controls (n. 29, $r = 0.50$, $p=.005$) than for patients (n. 32, $r = 0.2547$, $p = 0.16$) [[slide 13]]. The correlation between total time and the variation (post-pre) in the nausea score of the SSQ was significant in the total sample (n. 61, $r = .60$, $p = .000$). The total score on the MSHQ was weakly - albeit significantly - correlated with post-immersion SSQ nausea scale score (n. 60, $r = 0.29$, $p = 0.02$), but not with the total malaise scale score [[slide 14]]. None of the demographic, questionnaire measures and temporal measures were significantly correlated with the performance Index.

Figure 1. Percent of participants reporting at least one symptom on the MS as a function of time

4. Discussion

These findings are consistent with those reporting that immersive VR causes symptoms incompatible with the continuation of the experience in 5 to 30% of users (Stanney et al., 1998). Since hardware factors are important determinants of the type and prevalence of VR-induced side-effects, our data should be compared only to those obtained with comparable systems and methodologies. Regan and Price's data (1993) seem to fit that criterion. They reported higher overall ratings of nausea both on the MQ and on the SSQ which were administered to a larger sample (n.150) of healthy volunteers. Eight (5%) of their participants withdrew from the experiment because of

severe side-effects. The differences may be explained by a number of concurrent factors such as the weight and technical characteristics of the HMDs, but perhaps the most notable differences were that our participants, unlike those in Regan's study, were seated on a chair, that could revolve, during the experiment and that they were instructed to avoid movements that could exacerbate symptoms. In a further experiment comparing 44 participants who sat while using VR with 24 participants who stood, the same authors did not find significant differences in malaise ratings (results reported by Kolasinsky, 1995). Further studies are needed to clarify this issue.

The time-course of malaise ratings was also different; in Regan's study symptoms were reported to last longer after reaching their maximum at the end of the VR period (20 minutes) [[slide 3]]. In our study, symptom reports tended to decrease after 25 minutes, when participants were still interacting with the VE, and returned to baseline levels at the 10 minute post-VR rating point. Therefore, our findings do not totally support the conclusion that malaise ratings increase steadily as a function of immersion time. The occurrence of a within-session adaptation may also be considered. Our hypothesis is that adaptation may be associated to the changing pattern of interaction that we have shown to occur with our VR task; i.e. the time spent in each successive virtual room decreased as participants routinized their strategy and reduced exploratory movements (head and body rotations) in the second half of the session (Pugnetti et al., paper presented at MMVR7, San Diego, California, January 21, 1998).

Perhaps the most relevant finding of our study is that neurological patients - who may be considered at greater risk to develop side-effects from immersive VR - are, in fact, no more susceptible than matched healthy participants. Instead, patients tended to report less symptoms and less discomfort than healthy controls. One possibility is that patients with chronic neurological diseases, such as multiple sclerosis, may have developed psychological or physical tolerance to relatively minor symptoms such as those produced by immersive VR. Alternatively, they might have misinterpreted VR-related symptoms as disease-related and, therefore, not worth reporting. On the MS and SSQ, in fact, patients rated themselves as already sicker than controls before the VR session. Hence, a problem with the specificity of the rating instruments may exist - e.g. as they were not developed for patients' use they may not be able to pick up qualitatively different changes in patients' condition. Ceiling effects are unlikely to have occurred as none of the participants reported extreme ratings at baseline. Another possibility is that neurological diseases - and the associated cognitive impairments - may have reduced the patients' ability to be able to accurately report relatively subtle changes in their physical and psychological condition. It should be noticed, therefore, that the above conclusion is based mostly on subjective reports, they do not necessarily imply that immersive VR can be already safely introduced in a clinical setting. Motion sickness history questionnaire did not seem to be a useful predictor of symptoms. Aside

from cybersickness, self reports concerning ergonomic factors suggest that patients with visual residual impairments may show increased problems adapting to HMDs.

Our findings on the maintenance of static balance after VR exposure confirm Regan and Price's results (1993, 1994), but appear at variance with other studies (Di Zio and Lackner, 1997) reporting significant - albeit transient - impairments of static balance after immersive VR. Admittedly, our data need confirmation on larger patient samples. It seems, however, that comparisons across studies employing diverse hardware, software, time of exposure, postures during exposure, measurement devices and criteria must be considered very cautiously. Replication studies are needed in this important area of VR research. The development of the new immersive and non-immersive versions of this paradigm in collaboration with the UEL group will allow the planning of studies aimed at revisiting the main questions raised by our previous studies: whether immersive VR can really be safely proposed for clinical use, and whether immersive and non-immersive versions differ in terms of psychometric value.

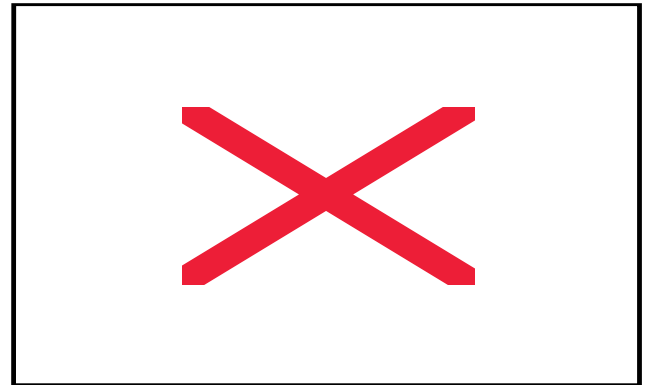


Figure 2. Pre-immersion, post-immersion and change profiles on the SSQ for all participants

4.1 MAIN CONCLUSIONS

1) Compared to previous studies (Regan & Price, 1993) using the same rating instruments, our results suggest a reduced impact of immersive VR on subjective ratings of side-effects though the average time spent in VR was increased. This finding may be related to improved equipment.

2) Patients with mild to moderate neurological impairments are not at increased risk of side effects; indeed, they seem to be less affected than healthy controls. Possible explanations include:

- a degree of psychological or physical tolerance to symptoms similar to those experienced during the acute phases of their diseases;
- questionnaires used for healthy participants are not adequate for patients.

3) MS patients with a history of optic neuritis feel more uneasy wearing a HMD than healthy controls and patients

with no history of optic neuritis. This issue needs to be more specifically addressed in future studies.

4) Patients' cognitive performance was worse, which was not explained by adverse effects or slowness in interaction with the VE.

Further studies will directly compare immersive and non-immersive versions of the same VR test.

5. Review Of VR Studies For Memory Research

The demonstration that VR is an efficient tool for diagnosing memory deficits and their retraining is also being actively pursued by our groups. Most, if not all, of the evidence concerning visuospatial memory deficits in neurological patients has been collected using two-dimensional, non-interactive stimuli (e.g. pictures) in typical "paper-and-pencil" tests. These studies have generally found impairments on tests of egocentric spatial orientation and tests of anterograde memory for visuospatial (topographical) information, all of which exclude locomotion and/or extensive exploration of large-scale spaces. This is unfortunate, because the integration of sensorimotor information has been shown to be important in the development of cognitive representations of space and, specifically, of the external environment (Kirasic, 1991). The most essential use of spatial knowledge is that of assisting the interaction between an individual and his/her surrounding space. For example, memory for a layout should facilitate route finding whereas memory for objects should serve other purposes. In fact, there is growing neurobiological evidence that cortical areas and pathways involved in processing spatial coordinates (where?) are rather distinct from those processing shapes or patterns that mediate objects recognition (what?) (Epstein and Kanwisher, 1998). VR lends itself to devise experiments employing true 3D visual stimulation and exploration of large-scale spaces while assessing the differential effect of being an active or passive participant on different memory systems. Such studies have been pioneered by the UEL group in London, where initial research was carried out with 'non-impaired' adult volunteers (Attree et al., 1996; Brooks et al., 1999). It was found that active participation enhanced memory for the spatial layout, whereas passive observation enhanced object memory. No differences were found for object location memory. Similar results were found with patients with vascular brain injury (Rose, et al., in press), and with patients with traumatic brain injury. These findings have recently been replicated - for the first time - in Milan using the original yoked-control methodology described by Andrews et al. (1995) and Attree et al. (1996) in a non-immersive VE. The replication study investigated whether exploration of computer-generated environments can selectively enhance spatial memory in patients with MS (Pugnetti et al., 1998b). The hypothesis was that active participants would show better recall of the spatial layout of

the environments they explored, whereas passive participants would show better recall of the contents of the VEs. Consistent with the hypothesis and results of the previous studies, 15 patients and 15 healthy participants, who controlled their movements in a virtual house using a joystick, recalled the spatial layout [[slide 15 and 16]] of the environments better than 15 patients and 15 controls who merely watched the active participants' progress (Fig. 3) [[slide 17]]. Among passive participants, only healthy controls did significantly better than active participants in the recall of virtual objects. There were no significant differences between active and passive participants' recall of correct object locations in the virtual environments. MS patients' recall of the spatial layout and of the virtual objects was significantly worse than that of healthy participants, but patients' data did not correlate with traditional neuropsychological measures of spatial memory on which MS patients have been shown to be impaired (Beatty et al., 1988). We concluded that VR can be used to test aspects of spatial memory that are not measured by traditional tests. We have also reported an enhanced effect of being an observer in a second experiment in which a different group of 26 MS patients were asked to recognize pictures of the objects they had incidentally memorized while exploring the same VE (Pugnetti et al., 1998). In that study we found the time dedicated to VE exploration to be directly related to recognition memory in patients but not in healthy controls, whereas the ability to handle the joystick to navigate the VE was slightly impaired in some of the patients and may have selectively influenced their ability to freely recall the objects they have seen. These results have implications also for the design of future clinical VR applications based on standard PC platforms.

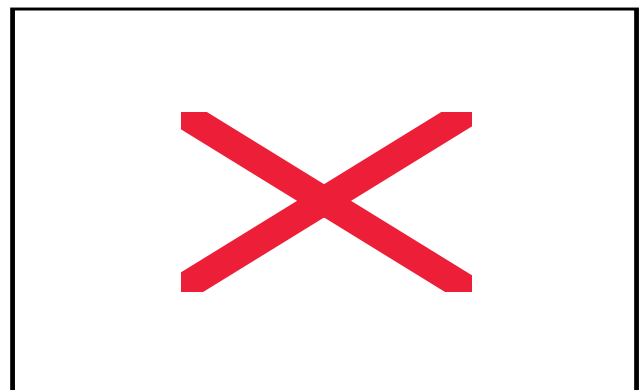


Figure 3. Mean probability for recall of spatial Layout in MS patients and healthy controls.

Though the precise reasons why an enhanced spatial memory occurs after active exploration are uncertain (see Brooks et al., 1999, Pugnetti et al., 1998b for discussions on this issue), it appears that the use of VR-based simulations can help at least the identification of the conditions and factors - other than known disease-related variables - that favor or mitigate the expression of memory deficits in neurological disorders such as MS and stroke, as recently

reported by Rose et al. (1997). This appears to be a genuine instance of added value of a VR application to a clinical diagnostic problem. We have shown that a form of spatial memory, which has not been tested so far in MS patients because of the lack of adequate means, is defective, but can be modulated by direct interaction with the environments, whereas object memory does not seem to benefit by not being involved in an active exploration. Future research could investigate whether there is any transfer to the real world of spatial knowledge trained with VR in selected MS patients, and whether memory for objects would be improved by active interaction with them. VR applications could also contribute to the understanding of whether severe motor disability per se can be a factor in the development of visuospatial deficits due to the restriction imposed on self-controlled exploratory activity.

6. Future Plans

In the winter of 1997 a project, aimed at the development of a training tool based on VR, to assist people with mental disabilities who are seeking employment, was approved by the Italian Ministry of Labour and Social Affairs. The project, named VIRT (Virtual Reality Training), is led by CIRAH, a non-profit association based in Milan that supports initiatives for the disabled who are eligible for employment [[slide 18]]. Our two institutes - Fondazione Don Gnocchi and the University of East London - participate in the VIRT consortium as partners along with national cooperatives (IL MELOGRANO and CSLS) and national associations from Spain (FEPROAMI) and France (UNAPEI and QUARTZ) that promote education, training, social and work integration of people with disabilities. The project is supported by the Horizon - Employment Initiative European funding program and has links with other projects, such as TIME, that also offer training opportunities to people with disabilities using new forms of information technology.

The main aim of the VIRT project is to assess whether low-cost VR technology is suitable to develop models that will supplement and improve current training procedures for people whose mental impairments do not totally preclude their integration in a productive activity. The project will enable educators, trainers and enlightened employers to be aware of the potential of VR and will also make them responsible for a number of critical choices concerning the development and use of the new training tool. A flexible tool to simulate a wider range of working tasks than those available at the actual place will have a precise role in the training curriculum of people with disabilities. In general, it will serve to broaden their working experience, to foster their decisional autonomy, and to increase awareness of their skills.

7. Acknowledgements

This work has been partly supported by the Italian Ministry of Health, Contract ICS49.6/RF93.25 to the Scientific Institute "S.Maria Nascente". The authors wish also to thank the "Gruppo Volontari per l' incremento della Ricerca sulla Sclerosi Multipla" for their continuous support. Gratitude is also expressed to Prof. Carlo L. Cazzullo and to all the patients who participated and who gave important suggestions for future improvements. Aaron Brancotti and Tony Leadbetter are also gratefully acknowledged for their technical expertise.

REFERENCES

- D Alpini, L Pugnetti, A Cesarani, L Mendozzi and E Barbieri (1996), Evaluation of vestibular strategies in human exploration of the environment by means of immersive virtual reality, In *Giddiness and Vestibulo-Spinal Investigations* (CF Claussen, MV Kirtane, L Constantinescu & D Schneider, Eds), Elsevier Science, Amsterdam, pp. 315-323
- TK Andrews, FD Rose, AG Leadbetter, EA Attree and J Painter (1995), The use of virtual reality in the assessment of cognitive ability, In *The European Context for Assistive Technology: Proceedings of the 2nd TIDE Congress*, IOS Press, Amsterdam, pp. 276-279
- EA Attree, BM Brooks, FD Rose and AG Leadbetter (1996), Memory processes and virtual environments: I can't remember what was there, but I can remember how I got there. Implications for people with disabilities. In *Proceedings of the 1st European Conference on Disability, Virtual Reality and Associated Technologies* (PM Sharkey, Ed.), Maidenhead, UK, pp. 117-122.
- WW Beatty, DE Goodkin and N Monson (1988), Anterograde and retrograde amnesia in patients with chronic progressive multiple sclerosis, *Arch.Neurol.*, **45**, pp. 611-619
- BM Brooks, EA Attree, FD Rose and AG Leadbetter (1999), The specificity of memory enhancement during interaction with a virtual environment, *Memory*, **7**, pp. 65-78..
- P DiZio and JR Lackner (1997), Circumventing side effects of immersive virtual environments, In *Design of Computing Systems: Social and Ergonomic Considerations*, (M Smith, G Salvendy & R Koubek, Eds.), Elsevier Science, Amsterdam, pp. 893-896
- R Epstein and N Kanwisher (1998), A cortical representation of the local visual environment, *Nature*, **392**, pp. 598-601
- RS Kennedy, NE Lane, MG Lilienthal, KS Berbaum and LJ Hettiger (1992), Profile analysis of simulator sickness symptoms: application to virtual environment systems, *Presence*, **1**, 3, pp. 295-301
- KC Kirasic (1991), Spatial cognition and behavior in young and elderly adults: implications for learning new environments, *Psychol. Aging*, **6**, 1, pp. 10-18.

- EM Kolasinski, SL Goldberg and JJ Hiller (1995), Simulator sickness in virtual environments, Technical Report 1027, U.S. Army Research Institute for Behavioral and Social Sciences, Alexandria, VA.
- JF Kurtzke (1983), Rating neurological impairment in multiple sclerosis: an expanded disability status scale (EDSS). *Neurology*, **33**, pp. 1444-1452
- L Mendozzi, A Motta, E Barbieri, D Alpini and L Pugnetti (1998), The application of virtual reality to document coping deficits after a stroke: report of a case. *Cyberpsychol.Behav.* **1**, *1*, pp. 79-91.
- L Pugnetti, L Mendozzi, A Motta, A Cattaneo, E Barbieri and A Brancotti (1995), The evaluation and retraining of adults' cognitive impairments: which role for virtual reality technology? *Comp.Biol.Med.*, **25**, *11*, pp. 213-228
- L Pugnetti, D Alpini, A Cattaneo, E Barbieri and L Mendozzi (1996), Computerized stabilometry in the assessment of some physiological after-effects of immersive virtual reality: a pilot study, In *Giddiness and Vestibulo-Spinal Investigations* (CF Claussen, MV Kirtane, L Constantinescu & D Schneider, Eds), Elsevier Science, Amsterdam, pp. 47-52
- L Pugnetti, L Mendozzi, E Barbieri, FD Rose and EA Attree (1996b), Nervous system correlates of virtual reality experience, In *Proceedings of the 1st European Conference on Disability, Virtual Reality and Associated Technologies* (PM Sharkey, Ed.), Maidenhead, UK, pp. 239-246.
- L Pugnetti, L Mendozzi, EA Attree, E Barbieri, BM Brooks, CL Cazzullo, A Motta and DF Rose (1998), Probing memory and executive functions with virtual reality: past and present studies, *Cyberpsychol.Behav.* **1**, *2*, pp. 151-161.
- L Pugnetti, L Mendozzi, BM Brooks, EA Attree, E Barbieri, D Alpini, A Motta and DF Rose (1998b), Active versus passive exploration of virtual environments modulates spatial memory in MS patients: a yoked control study, *It.J.Neurol.Sci.*, **19**, pp. S424-S430
- EC Regan and KR Price (1993), Some side-effects of immersion virtual reality, Report 93RO10, Army Personnel Research Establishment, Farnborough, Hampshire, UK.
- EC Regan and KR Price (1994), The frequency of occurrence and severity of side-effects of immersion virtual reality, *Aviat.Space Environ.Med* , **65**, pp. 527-530
- FD Rose, EA Attree and DA Johnson (1996), Virtual reality: an assistive technology in neurological rehabilitation. *Curr.Op.Neurol.* **9**, pp. 461-467
- FD Rose, EA Attree and BM Brooks (1997), Virtual environments in neuropsychological assessment and rehabilitation, In *Virtual Reality in Neuro-Psychophysiology*, (G Riva, Ed.), IOS Press, Amsterdam, pp. 147-156
- K Stanney, G Salvendy, J Deisinger et al. (1998), Aftereffects and sense of presence in virtual

environments: development of an R&D agenda, *Int.J.Hum.Comp.Interact.*, **10**, *2*, pp. 135-187

BIOGRAPHIES

Luigi Pugnetti, M.D., is a psychiatrist and neurophysiologist, leading the neurophysiology laboratory at the Scientific Institute S. Maria Nascente, Fondazione Don Gnocchi of Milan. He has been actively involved in research for VR applications for mental health since the early nineties and has contributed to the promotion of VR as an educational tool for the disabled both in Italy and abroad. He has also strong interests into brain-behavior relationships and neurophysiological correlates of complex behavior.

Contact information:

Luigi Pugnetti
Scientific Institute S. Maria Nascente
Don Gnocchi Foundation
via Capecelatro 66, 20148 Milan, ITALY
Email: lpugnett@dongnocchi.it