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Towards a Virtual Reality Cognitive Training System for Mild Cognitive Impairment and Alzheimer's Disease Patients

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***Abstract*—The rapid growth of the aged population has stimulated research directed at designing interventions to support the associated social, economic and health challenges in an elderly population. Environmental interventions, like cognitive rehabilitation, stimulation and training can significantly improve cognitive functioning, so mitigating the cognitive decline. In this area, the adoption of state-of-the-art virtual reality technologies can provide a cost-effective, flexible and comprehensive solution for realizing complex cognitive training environments. With the aim of preserving mnestic and logical-praxic functions of patients with MCI or Alzheimer's disease at the early stages, in this paper we describe our ongoing work in designing a novel, fully-equipped virtual reality cognitive training system. The system is characterized by a high degree of realism and interactivity, to provide the patient with an adequate sense of presence within the virtual environment. Moreover, it is able to monitor the patient's biomedical signals and collect quantitative data on the training sessions, so allowing the therapist to analyze and tailor the training strategies to the patient.**

I. Introduction

As in other countries, the aged population in Italy is growing as a percentage of the total, rising from 20.8% in 2012 to 22.3% in 2017, the population's mean age increasing from 43.8 in 2012 to 44.9 in 2017 [1]. This rapid growth has stimulated research directed at designing interventions to support the associated social, economic and health challenges in an elderly population. A decline in various cognitive abilities, particularly executive control functions, has been observed in older adults [2]. For the majority of older people the extent of any cognitive decline is relatively small, but some individuals experience more extensive difficulties and are at greater risk of developing a form of dementia.

Cognitive function is a specific target area and relates to the reduced independence, impaired well-being and increased need for care associated with cognitive decline [3]. Literature on this topic has demonstrated that environmental interventions can significantly improve cognitive functioning [4], [5].

In the literature, multiple terms have been used for such interventions, including cognitive rehabilitation, cognitive stimulation and cognitive training. Cognitive rehabilitation, and cognitive stimulation are the most popular approaches, referring to an involvement in activities designed to increase cognitive and social function [6].

Cognitive training (CT) involves standardized training in tasks designed to optimize cognitive function [7]. The rationale for CT intervention is found in the concept of "plasticity", which encompasses the latent cognitive potential of individuals and the capacity of the brain for reactive changes in cognitive flexibility [8]. Plasticity has been measured by using observable behavioral indicators [9] or through neuroimaging [10]. Research into plasticity undertaken with older people has challenged the assumption that cognition remains fixed or declines and has demonstrated the potential for interventions to stimulate cognition [11].

A recent review of the literature on cognitive decline has shown that CT has improved cognition in different studies by up to 5 years [11], and has thereby delayed cognitive and functional decline [12]. The growth in CT for healthy older populations has corresponded with an increase in scientific research into the efficacy of CT for individuals including also those living with Mild Cognitive Impairment (MCI) and dementia [13].

Systematic reviews and meta analyses [14], [12], [15], [16], [17], [18] have demonstrated that individuals living with MCI have shown improvements in cognitive domains following CT. However, in studies where an active control condition was included, these improvements were no longer significant. These mixed results, small effect sizes and the

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unspecified influence of an active vs no contact control in these populations [19] means a majority of studies call for further research.

Traditionally, CT has been administered in groups by a psychologist or therapist. Technological innovations have resulted in computerized cognitive training (CCT) and virtual reality cognitive training (VRCT), which provide more cost effective, accessible, flexible and comprehensive interventions.

In this paper, the design of a novel VRCT system is detailed. The goal is to provide a complete cognitive training solution for patients with MCI or Alzheimer's disease (AD) at the early stages, with the aim of preserving their mnesic and logical-praxic faculties for as long as possible through exercise and cognitive stimulation. The system comprises two cognitive training environments, together with customization, monitoring and analysis tools. Moreover, the proposed VRCT system is characterized by a high degree of realism and interactivity, to provide the patient with an adequate sense of presence within the virtual environment.

The rest of the paper is structured as follows. In Section II, related work on the use of VR in cognitive training is briefly introduced. In Section III, the VRCT system is detailed in terms features and components, whereas in section IV the design of the user study is discussed. Finally, Section V, concludes the paper.

II. Related Work

In the last few years, several VR systems for CT have been designed and evaluated. The first type of system targets navigation skills, making the patient perform a navigation task within a virtual environment. In [20], a training system, where people at the early stages of AD had to navigate within a virtual building to measure and to improve their spatial navigation abilities, is presented; the proposed VR configuration includes a head-mounted display (HMD) and a custom wheelchair used to navigate within the virtual environment. In [21], a real-world navigation test used with subjects with recognized or incipient AD was compared with a virtual reality simulation of the same environment, the study providing evidence of a correlation between the two approaches. Similar VR systems focusing on navigation skills are described in [22], [23].

A second type of VR system is aimed at impeding cognitive decline and improving memory functions. In [24], the authors show that the VR system can, after a six month memory training, improve memory function by enhancing focused attention. Man et al. investigated in [25] the effectiveness of a VR-based memory training for older adults with questionable dementia, demonstrating a generally positive training effect and a specific improvement in objective memory performance if compared with a non-VR group. Studies on the relation between VR and age-related differences and the effect of AD on executive functioning and episodic memory are presented in [26], [27]. In [28] a diagnosis and assessment system that uses an HMD, gaming and low-cost sensors to generate an interactive and panoramic scenario for the assessment of executive functions and memory is presented; a pilot study also shows a general acceptance of the technology by the user. In [29], patients with MCI and dementia were involved in an attentional task, the goal of which was to evaluate acceptability, interest and usability problems.

A different type of system simulates activities of daily living (ADL) with the aim of improving a person's ability to live independently. To achieve this objective, Foloppe et al. explore in [30] whether it is possible to increase autonomy in AD patients during cooking activities using interventions based on error-less learning, vanishing-cue, and techniques; the data collected show that the recruited patients could relearn some cooking activities using VR techniques, and transfer them into real life. In [31] and [32], the cognitive and psychomotor problems associated with functional impairments of AD patients in activities of daily living are also investigated. In [33], in order to assess and train the cognitive abilities of brain-injured patients, a virtual supermarket is presented; the study highlights the difficulties in using the joystick because of its weight and its instability but also due to physical problems, suggesting the use of more comfortable interfaces for this kind of user.

III. The Virtual Reality Cognitive Training System

This section presents an overview of the system architecture, also highlighting requirements and activities of the main actors.

A. Overview

The system has been realized as a VR based environment applied to the CT of MCI and AD patients, which has been conceived to be used at the same time by therapists and patients. The VR domain has allowed us to combine in a single system the different needs of therapists and patients. In fact, while therapists need more support during the training sessions, including the possibility of monitoring the patient's actions and vital signs in real time, the patient requires a personalized training environment, able to facilitate the training process while keeping her/him engaged.

In the proposed system, the patient is immersed in a synthetic environment having the possibility of enjoying different scenarios and consequently different experiences without moving from a safe area. At the same time, the therapist is able to observe the behavior of the patient in that environment and to intervene when necessary. The training sessions proposed

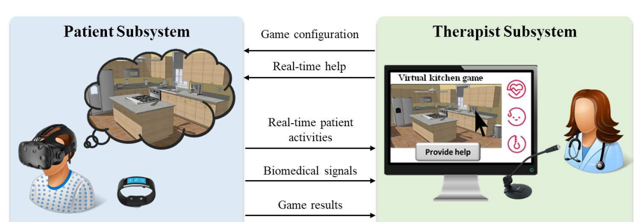

Fig. 1. Conceptual design of the system.

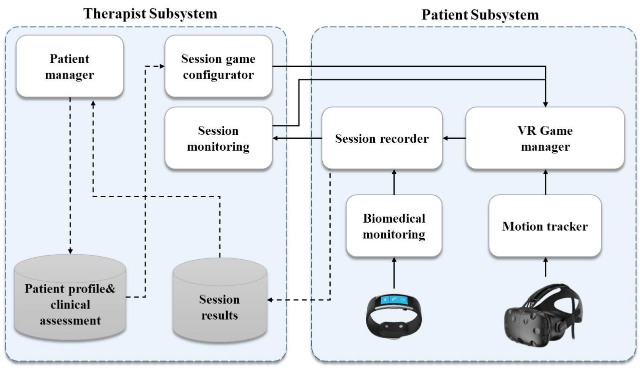

Fig. 2. The high-level system architecture.

to the patient have been designed in the form of a serious game that involves two players, the patient and therapist, characterized by different points of view, abilities and goals.

As depicted in fig. 1, the system comprises two subsystems, which expose two different interfaces: one is used by the patient to complete an assigned task; the other by the therapist to control the training session and monitor the patient's behavior. In more detail, the patient subsystem allows her/him to perform the training session while being immersed in a virtual environment that requires the carrying out of everyday tasks. The aim is to enhance the patient's engagement through gaming, so encouraging her/him to perform the tasks with minimal assistance.

The system provides several serious games for the CT of patients in the very earliest stages of dementia, which can be tailored to a specific patient by setting the level of difficulty, where different levels corresponding to different cognitive loads. Some of them simulate ADL (e.g., a cooking activity, see figure 3), others are focused on memory training (e.g, autobiographical memory [34], which is often impaired in early stages of AD [35], see figure 4). All the elements inside the virtual environments are interactable, using interaction metaphors similar to those used in real life. To enhance the degree of realism, specific physical features have been designed for each virtual element (e.g., a plate breaks if it falls to the ground). Furthermore, directional audio is used to attract the patient's attention. All the exercises have a difficulty level that can be configured through parameters set by the therapist before starting the exercise.

The therapist subsystem provides the therapist with a support tool, which enables her/him able to monitor the patient's exercises. The subsystem also provides the therapist with a complete and detailed report, so improving her/his knowledge on the patient's training progress. The therapist subsystem has been realized as a stand-alone application that provides instruments for profiling the patients and customizes the selected exercises based on training goals and performances achieved during the previous sessions. The therapist subsystem is connected with that of the patient to start the execution of a session or to interrupt it in the case of a dangerous situation, considering the patient's behavior in the virtual environment [36] or her/his vital parameters. The therapist can check all the patient's actions during the game execution, monitoring in real time her/his vital signs, and, if necessary, providing more explicit instructions, supporting the patient in the achievement of the goal. Finally, this subsystem collects all the session measures, making them available to the therapist.

The technical equipment comprises an HTC Vive HMD, which allows a full immersion in a virtual environment involving both sight and hearing and a multimodality interaction with the virtual world and its 3D entities performed through the tracking of the user's head and hand movements in a room-scale environment. Moreover, the equipment includes a Microsoft Band v2 bracelet, which tracks the patient's biomedical signals. Finally, for the development of the VR-based serious games, Unity 3D, a game-creation platform, is used.

B. Software components

As shown in fig. 2, the system is organized in different components, which communicate with each other, sharing common repositories.

The *Patient Manager* is the primary point of access for the therapist, where she/he can profile each patient, collect an initial assessment, monitor her/his training and collect the follow-up assessment. In the *Patient Profile & Clinical Assessment* repository, further information is collected in relation to, for example, drugs taken, support treatments, sight problems, head pains, physical activity, diet followed, and the presence of a caregiver. For assuring data privacy, techniques for the formal verification of the requirements [37] are used. The Patient Manager component is also used by the therapist to control the patient's performances, which are stored in the *Session Results* repository.

The *Session Game Configurator* component is used by the therapist to define the daily training sessions. The therapist chooses the type of game to propose to the patient together with the difficulty level. Next, this configuration is used to initialize the virtual environment managed by the *VR Game Manager*. The latter is the component in charge of executing the immersive game, in which the patient's movements are

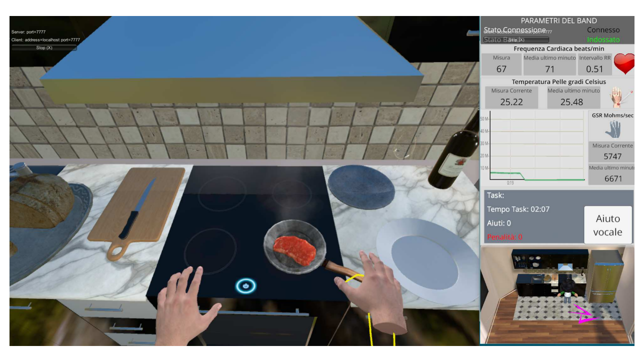

Fig. 3. A virtual environment for cooking activities.

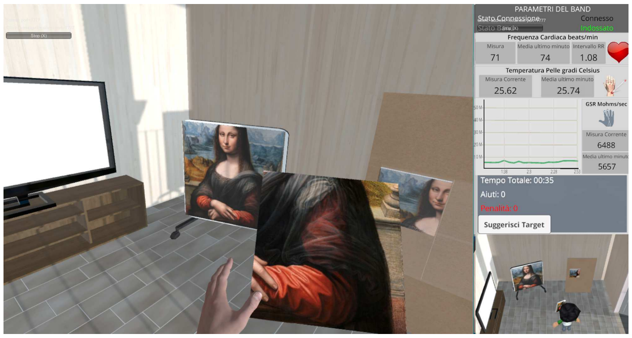

Fig. 4. A virtual environment for memory training.

transformed into interactions with the synthetic elements of the scene. All the interactions, involving multiple degrees of freedom [38] and target selection techniques [39], are evaluated in relation to the game logic and the training goals.

The VR Game Manager component receives its input from the *Motion Tracker* component, which tracks the patient's movement by using the embedded sensors of the devices employed. Moreover, during the therapy session, the patient's vital signals are collected by the *Biomedical Monitoring* component.

All the session data produced by both the VR Game Manager and the Biomedical Monitoring are handled by the *Session Recorder*. This component is in charge of elaborating the data to send a real-time summary of everything to the Session Monitoring component. This component shows the therapist the data elaborated by the Session Recorder including the patient's point-of-view in the scene; the action that she/he is performing; the distance traveled within the scene while executing an action; and the biomedical signals, the latest measurements acquired and the averages computed to the last minute. Thus, the therapist can check the patient's activities to identify any possible uncomfortable or stressful situations.

Furthermore, the therapist can actively intervene in the training session of the patient to guide her/him to accomplish the task assigned and prevent her/him from feeling too isolated when immersed in the virtual environment. To achieve this aim, the component features some special functions to manipulate the objects in the scene or to launch a directional vocal message.

IV. Study design

In the following, we briefly introduce the design of the controlled trial that will be carried out in order to evaluate the outcome deriving from the use of the proposed solution.

The VR cognitive training will be implemented as a randomized controlled trial, with a cross-over design, two groups comparison (intervention group vs control group). Inclusion criteria will comprehend subjects aged between 18 and 70, with MCI or dementia diagnosis. Exclusion criteria will comprehend subjects with epilepsy, diabetes, addictions, physical disabilities. Each participant will be randomly assigned to a VR treatment or to a standard of care treatment. Participant will be recruited by their doctors and informed about possibility of virtual reality treatment and/or standard of care treatment. The administration of the cognitive intervention will last totally 60 mins, with one session of treatment per week, for a total of four months of treatments.

A set of cognitive tests will be used in order to verify the efficacy of the treatments in terms of decline, no decline, improving in different cognitive domains, with three timing of administration: pre-test, post-test and follow up 2 months later. Neuro-phisiological measures, taken during the treatment, will be considered, too.

- Attention and memory: prose memory test, digit symbol, digit span forward and backword, delay recall of Rey figure, selecting reminding test [40], [41];
- Executive functions: Trail making test A B; Tower of London, Stroop test [42], [43];
- Verbal fluency: verbal letter fluency and verbal semantic fluency, Boston naming test [44];
- Global cognition: Mini Mental, ADAS-cog [45], [46];

V. Conclusion

In this paper, the first steps in the design of a novel VR system for the CT of patients with MCI or AD in the first stages are presented. The aim has been to design and implement a highly realistic and interactive system in which to stimulate patients to learn and practice some real-life activities.

In relation to other state-of-the-art VR systems for CT, the proposed solution differs due mainly to its high degree of realism. It is based on a totally wireless VR solution, so making it possible for the patient to move without considering physical obstacles. Additionally, thanks to the realistic rendering, illumination, and audio, the sense of the presence of the patient while performing the training exercises can be increased. Moreover, rather than employing joysticks or other interaction devices that could be difficult to use, the system makes it possible to interact with digital objects by using movements and actions similar to those used in real life.

Our future work will focus on designing a testing protocol with clinicians, carrying out a pilot study, in which cognitive progress or decline can be monitored over an adequate time interval, and the motivation and engagement of the patients using the system can be estimated and compared with that achieved by adopting traditional training methods.

References

[1] "Statistiche istat," 2017. [Online]. Available: http://dati.istat.it/Index.aspx
[2] C. Basak, W. R. Boot, M. W. Voss, and A. F. Kramer, "Can training in a real-time strategy video game attenuate cognitive decline in older adults?" *Psychology and aging*, vol. 23, no. 4, p. 765, 2008.
[3] R. Logsdon and S. Albert, "Quality of life in alzheimers disease: Longitudinal research and implications for care," *Gerontologist*, vol. 39, p. 163, 1999.
[4] J. Nithianantharajah and A. J. Hannan, "Enriched environments, experience-dependent plasticity and disorders of the nervous system," *Nature Reviews Neuroscience*, vol. 7, no. 9, p. 697, 2006.
[5] A. Herring, O. Ambrée, M. Tomm, H. Habermann, N. Sachser, W. Paulus, and K. Keyvani, "Environmental enrichment enhances cellular plasticity in transgenic mice with alzheimer-like pathology," *Experimental neurology*, vol. 216, no. 1, pp. 184–192, 2009.

[6] S. Tardif and M. Simard, “Cognitive stimulation programs in healthy elderly: a review,” *International journal of Alzheimers disease*, vol. 2011, 2011.

[7] M. Martin, L. Clare, A. M. Altgassen, M. H. Cameron, and F. Zehnder, “Cognition-based interventions for healthy older people and people with mild cognitive impairment.” *Cochrane database of systematic reviews (Online)*, vol. 1, 2011.

[8] M. Lövdén, L. Bäckman, U. Lindenberger, S. Schaefer, and F. Schmiedek, “A theoretical framework for the study of adult cognitive plasticity.” *Psychological bulletin*, vol. 136, no. 4, p. 659, 2010.

[9] S. L. Willis, “Cognitive plasticity: findings from cognitive training studies,” *Annual Report of Meiso University*, vol. 28, pp. 37–49, 2010.

[10] B. Draganski, C. Gaser, V. Busch, G. Schuierer, U. Bogdahn, and A. May, “Neuroplasticity: changes in grey matter induced by training,” *Nature*, vol. 427, no. 6972, p. 311, 2004.

[11] H. Coyle, V. Traynor, and N. Solowij, “Computerized and virtual reality cognitive training for individuals at high risk of cognitive decline: systematic review of the literature,” *The American Journal of Geriatric Psychiatry*, vol. 23, no. 4, pp. 335–359, 2015.

[12] A. L. Gross, J. M. Parisi, A. P. Spira, A. M. Kueider, J. Y. Ko, J. S. Saczynski, Q. M. Samus, and G. W. Rebok, “Memory training interventions for older adults: a meta-analysis,” *Aging & mental health*, vol. 16, no. 6, pp. 722–734, 2012.

[13] A. Minutolo, M. Esposito, and G. De Pietro, “A mobile reasoning system for supporting the monitoring of chronic diseases,” in *International Conference on Wireless Mobile Communication and Healthcare*. Springer, 2011, pp. 225–232.

[14] N. Gates and M. Valenzuela, “Cognitive exercise and its role in cognitive function in older adults,” *Current psychiatry reports*, vol. 12, no. 1, pp. 20–27, 2010.

[15] J. Reijnders, C. van Heugten, and M. van Boxtel, “Cognitive interventions in healthy older adults and people with mild cognitive impairment: a systematic review,” *Ageing research reviews*, vol. 12, no. 1, pp. 263–275, 2013.

[16] F. Zehnder, M. Martin, M. Altgassen, and L. Clare, “Memory training effects in old age as markers of plasticity: a meta-analysis,” *Restorative Neurology and Neuroscience*, vol. 27, no. 5, pp. 507–520, 2009.

[17] L. Jean, M.-È. Bergeron, S. Thivierge, and M. Simard, “Cognitive intervention programs for individuals with mild cognitive impairment: systematic review of the literature,” *The American Journal of Geriatric Psychiatry*, vol. 18, no. 4, pp. 281–296, 2010.

[18] V. Faucounau, Y.-H. Wu, M. Boulay, J. De Rotrou, and A.-S. Rigaud, “Cognitive intervention programmes on patients affected by mild cognitive impairment: A promising intervention tool for mci?” *The journal of nutrition, health & aging*, vol. 14, no. 1, pp. 31–35, 2010.

[19] H. Li, J. Li, N. Li, B. Li, P. Wang, and T. Zhou, “Cognitive intervention for persons with mild cognitive impairment: A meta-analysis,” *Ageing Research Reviews*, vol. 10, no. 2, pp. 285–296, 2011.

[20] P. J. White and Z. Moussavi, “Neurocognitive treatment for a patient with alzheimer’s disease using a virtual reality navigational environment,” *Journal of experimental neuroscience*, vol. 10, pp. JEN–S40 827, 2016.

[21] L. A. Cushman, K. Stein, and C. J. Duffy, “Detecting navigational deficits in cognitive aging and alzheimer disease using virtual reality,” *Neurology*, vol. 71, no. 12, pp. 888–895, 2008.

[22] O. Ranjbar Pouya, A. Byagowi, D. M. Kelly, and Z. Moussavi, “Introducing a new age-and-cognition-sensitive measurement for assessing spatial orientation using a landmark-less virtual reality navigational task,” *Quarterly Journal of Experimental Psychology*, vol. 70, no. 7, pp. 1406–1419, 2017.

[23] I. Tarnanas, A. Tsolakis, and M. Tsolaki, “Assessing virtual reality environments as cognitive stimulation method for patients with mci,” in *Technologies of Inclusive Well-Being*. Springer, 2014, pp. 39–74.

[24] G. Optale, C. Urgesi, V. Busato, S. Marin, L. Piron, K. Priftis, L. Gamberini, S. Capodieci, and A. Bordin, “Controlling memory impairment in elderly adults using virtual reality memory training: a randomized controlled pilot study,” *Neurorehabilitation and neural repair*, vol. 24, no. 4, pp. 348–357, 2010.

[25] D. W. Man, J. C. Chung, and G. Y. Lee, “Evaluation of a virtual reality-based memory training programme for hong kong chinese older adults with questionable dementia: a pilot study,” *International journal of geriatric psychiatry*, vol. 27, no. 5, pp. 513–520, 2012.

[26] N. Jebara, E. Orriols, M. Zaoui, A. Berthoz, and P. Piolino, “Effects of enactment in episodic memory: a pilot virtual reality study with young and elderly adults,” *Frontiers in aging neuroscience*, vol. 6, p. 338, 2014.

[27] H. Sauzéon, B. N’kaoua, P. A. Pala, M. Taillade, S. Auriacombe, and P. Guitton, “Everyday-like memory for objects in ageing and alzheimer’s disease assessed in a visually complex environment: The role of executive functioning and episodic memory,” *Journal of neuropsychology*, vol. 10, no. 1, pp. 33–58, 2016.

[28] S.-C. Yeh, Y.-C. Chen, C.-F. Tsai, and A. Rizzo, “An innovative virtual reality system for mild cognitive impairment: diagnosis and evaluation,” in *Biomedical Engineering and Sciences (IECBES), 2012 IEEE EMBS Conference on*. IEEE, 2012, pp. 23–27.

[29] V. Manera, E. Chapoulie, J. Bourgeois, R. Guerchouche, R. David, J. Ondrej, G. Drettakis, and P. Robert, “A feasibility study with image-based rendered virtual reality in patients with mild cognitive impairment and dementia,” *PloS one*, vol. 11, no. 3, p. e0151487, 2016.

[30] D. A. Foloppe, P. Richard, T. Yamaguchi, F. Etcharry-Bouyx, and P. Allain, “The potential of virtual reality-based training to enhance the functional autonomy of alzheimer’s disease patients in cooking activities: A single case study,” *Neuropsychological rehabilitation*, pp. 1–25, 2015.

[31] I. Tarnanas, C. Mouzakidis, and W. Schlee, “Functional impairment in virtual-reality-daily-living-activities as a defining feature of amnestic mci: Cognitive and psychomotor correlates,” in *Virtual Rehabilitation (ICVR), 2013 International Conference on*. IEEE, 2013, pp. 27–34.

[32] M. F. Gago, D. Yelshyna, E. Bicho, H. D. Silva, L. Rocha, M. L. Rodrigues, and N. Sousa, “Compensatory postural adjustments in an oculus virtual reality environment and the risk of falling in alzheimer’s disease,” *Dementia and geriatric cognitive disorders extra*, vol. 6, no. 2, pp. 252–267, 2016.

[33] J. H. Lee, J. Ku, W. Cho, W. Y. Hahn, I. Y. Kim, S.-M. Lee, Y. Kang, D. Y. Kim, T. Yu, B. K. Wiederhold *et al.*, “A virtual reality system for the assessment and rehabilitation of the activities of daily living,” *CyberPsychology & Behavior*, vol. 6, no. 4, pp. 383–388, 2003.

[34] M. Benoit, R. Guerchouche, P.-D. Petit, E. Chapoulie, V. Manera, G. Chaurasia, G. Drettakis, and P. Robert, “Is it possible to use highly realistic virtual reality in the elderly? a feasibility study with image-based rendering,” *Neuropsychiatric disease and treatment*, vol. 11, p. 557, 2015.

[35] U. Seidl, U. Lueken, P. A. Thomann, J. Geider, and J. Schröder, “Autobiographical memory deficits in alzheimer’s disease,” *Journal of Alzheimer’s disease*, vol. 27, no. 3, pp. 567–574, 2011.

[36] A. Coronato and G. De Pietro, “Situation awareness in applications of ambient assisted living for cognitive impaired people,” *Mobile Networks and Applications*, vol. 18, no. 3, pp. 444–453, 2013.

[37] F. Amato and F. Moscato, “A model driven approach to data privacy verification in e-health systems,” *Transactions on Data Privacy*, vol. 8, no. 3, pp. 273–296, 2015.

[38] L. Gallo, “A study on the degrees of freedom in touchless interaction,” in *SIGGRAPH Asia 2013 Technical Briefs*. ACM, 2013, p. 28.

[39] N. Brancati, G. Caggianese, M. Frucci, L. Gallo, and P. Neroni, “Touchless target selection techniques for wearable augmented reality systems,” in *Intelligent Interactive Multimedia Systems and Services*. Springer, 2015, pp. 1–9.

[40] H. Spinnler, “Standardizzazione e taratura italiana di test neuropsicologici,” *Ital J Neurol Sci*, vol. 6, pp. 21–120, 1987.

[41] H. Buschke and P. A. Fuld, “Evaluating storage, retention, and retrieval in disordered memory and learning,” *Neurology*, vol. 24, no. 11, pp. 1019–1019, 1974.

[42] R. M. Reitan, “Validity of the trail making test as an indicator of organic brain damage,” *Perceptual and motor skills*, vol. 8, no. 3, pp. 271–276, 1958.

[43] J. Stroop, “Stroop color word test,” *Journal of Experimental Physiology*, vol. 18, pp. 643–662, 1935.

[44] N. Butters, E. Granholm, D. P. Salmon, I. Grant, and J. Wolfe, “Episodic and semantic memory: A comparison of amnesic and demented patients,” *Journal of Clinical and Experimental Neuropsychology*, vol. 9, no. 5, pp. 479–497, 1987.

[45] M. F. Folstein, S. E. Folstein, and P. R. McHugh, “mini-mental state: a practical method for grading the cognitive state of patients for the clinician,” *Journal of psychiatric research*, vol. 12, no. 3, pp. 189–198, 1975.

[46] W. G. Rosen, R. C. Mohs, and K. L. Davis, “A new rating scale for alzheimer’s disease.” *The American journal of psychiatry*, 1984.