Design and Evaluation of an ICT Platform for Cognitive Stimulation of Alzheimer's Disease Patients

Andrea Caroppo[1(✉)], Alessandro Leone[1], Pietro Siciliano[1], Daniele Sancarlo[2], Grazia D'Onofrio[2], Antonio Greco[2], Gianfranco Borrelli[3], Paolo Casacci[3], and Massimo Pistoia[3]

[1] Institute for Microelectronics and Microsystems, National Research Council of Italy, Via Monteroni, c/o Campus Università del Salento, Palazzina A3, Lecce, Italy
{andrea.caroppo,alessandro.leone, pietro.siciliano}@le.imm.cnr.it

[2] Geriatric Unit and Laboratory of Gerontology and Geriatrics, Department of Medical Sciences, IRCCS "Casa Sollievo della Sofferenza", San Giovanni Rotondo, Italy
{d.sancarlo,g.donofrio,a.greco}@operapadrepio.it

[3] eResult s.r.l., Foggia, Italy
{gianfranco.borrelli,paolo.casacci, massimo.pistoia}@eresult.it

Abstract. Cognitive Stimulation aims to improve cognitive skills and quality of life for people with dementia by helping to reduce the functional disability resulting from damage to the brain. Recent studies suggest that this kind of treatment is effective, but it is not yet possible to demonstrate that leads to changes in behavior or in the patient's lifestyle. The present work investigates the impact and the effectiveness of an information and communications technology platform able to allow the cognitive stimulation practice within a domestic environment. The platform is made up of a set-top-box connected to a TV monitor, a Microsoft Kinect sensor and a (optional) smart garment for clinical signs detection. Preliminary results, achieved after the tests performed on patients with mild to moderate Alzheimer, demonstrates that the aforementioned platform is a very useful tool able to increase the neuropsychiatric and cognitive state of the patient.

Keywords: ICT platform · Smart sensors · Cognitive stimulation · Rehabilitation practice · Alzheimer's disease

1 Introduction

Worldwide, 46.8 million people have dementia, and every year there are over 9.9 million new diagnosed cases [1], with an increase of the economic impact and cost of the 35.4% from 2010. Alzheimer's disease (AD) is the most common form of dementia [2] and represents one of the major causes of disability, dependency, burden and stress

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of caregivers increasing institutionalization among older people worldwide [3]. Currently, there is no effective disease-modifying cure and treatment is directed mainly to manage the symptoms of dementia [4].

The limited efficacy of drug therapy and the plasticity of the human brain are the two most important reasons that explain the growing interest in non-pharmacological intervention for dementia patients. Among possible cognition-focused interventions for people with AD, the importance of Cognitive Stimulation (CS) is highlighted by several scientific works [5–7]. In addition, a recent study showed that an integrated treatment (it lasted about six months) that consists in subjecting patients to CS and to rivastigmine transdermal patch improves the emotional and cognitive behavioural aspects and, at the same time, reduces the mortality risk [8].

Recently there have been many advances in the healthcare area, mainly with the help of Information and Communication Technologies (ICT) solutions; in particular, the researchers focused their activities towards the design and implementation of enabling solutions which first must be effective from a cost point of view.

The development of a low-cost platform that integrates both CS modules and homecare services could be very effective in order to select a more appropriate medical therapy. Analyzing recent research studies, it is clear that the use of new technologies is widely accepted by the elderly, even if within the age group 65 or over the skill level in the use of ICT instruments is very low. In the field of healthcare, cognitive training and stimulation have been faced in the past years through a large number of ICT technologies [9–11]. For example, virtual reality offers training environments in which human cognitive and functional performance can be accurately assessed and rehabilitated [12, 13]. On the other hand, augmented reality provides safer and more intuitive interaction techniques allowing interaction with 3D objects in real world [14, 15]. In this scenario, social communication channels (natural speech, para-language, etc.) are not blocked, breaking down mental barriers applying such a technology to specific problems or disabilities. New solutions for cognitive assistance based on touch system have been implemented: in the field of CS; for example, commercial products like Nintendo's Brain Age and Big Brain Academy have been tuned as educational tools helping to slow the decline of AD [16, 17]. More recently, the large diffusion of interaction devices enabling body movements to control systems have been investigated, with specific focus on ICT technologies for natural interaction. Microsoft Kinect is the state-of-the-art [18] as 3D device for body movements acquisition and gesture recognition and the effects of this kind of technology for rehabilitation purposes is widely investigated [19, 20].

In this work, a novel ICT platform has been designed with the aim to support different kind of patients during the multi-domain stimulation practice without the presence of medical staff or caregiver. The rest of the paper is organized as follows. Section 2 introduces the ICT platform describing some specifics of the hardware devices used for the interaction with the system. Moreover, in the same section, some details about the software architecture and specifications relating the CS practice are reported. In Sect. 3 the effectiveness and impact of the ICT platform in AD patients is evaluated through numerical results obtained in the preliminary tests performed on actual patients. Finally, conclusive considerations are presented in Sect. 4.

2 Materials and Methods

The developed ICT platform provides a system for CS at home through the use of Natural User Interfaces (NUI), giving the opportunity to perform the practice without the presence of medical staff or caregiver. Analyzing the implemented solution from this point of view, it turns out to be completely different and innovative compared to existing systems [21]. This innovative aspect is amplified by the integration of a software module that permits to customize the therapeutic session (compound by sequences of exercises) according to the residual abilities and skills of the end-users. The platform integrates the following hardware components: (a) an embedded PC equipped with an Intel Core i5 processor, (b) a monitor TV with a dimension equal to 42 inches or greater, (c) a commercial and low-cost 3D sensor (Microsft Kinect©) able to track the human skeleton and to recognize the gestures through the SDK freely distributed by Microsoft, (d) a smart garment that integrates an accelerometer and different textile electrodes for the extraction of several clinical parameters, such as heart rate, breath rate and energy expenditure (Fig. 1).

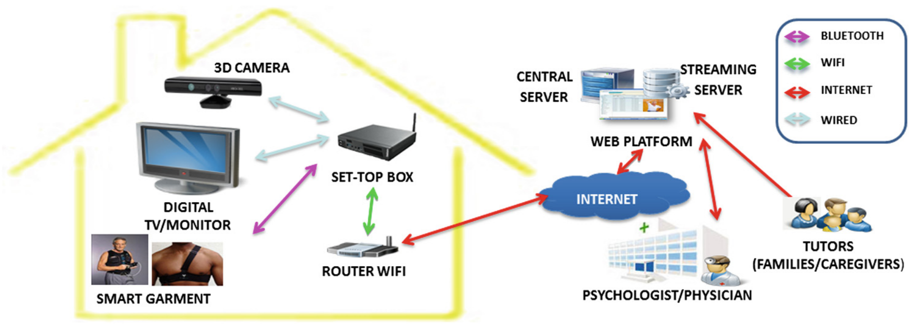


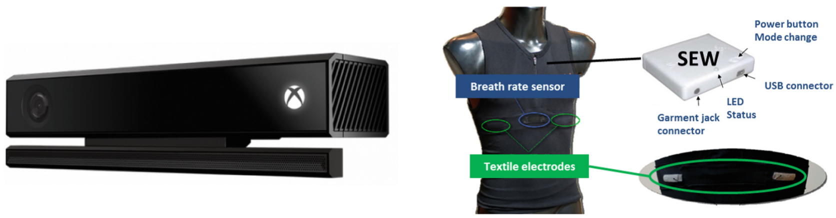
Fig. 1. ICT platform architecture overview

Moreover, a further innovative aspect developed in this ICT platform concerns the implementation of a software module for a real-time streaming of video data that are acquired during the execution of a therapeutic session. The module also records the video streaming, allowing the caregiver/physician the post-verification of correct CS practice from a remote location, such as the medical office. In this way, the psychologist or the physician has the opportunity to communicate with the observed patient during the exercise (highlighting for example errors in the execution of specific tasks) and to continuously monitor the progress or decline of their patients. Consequently, they have the ability to monitor multiple patients simultaneously. Whenever a CS session ends, a data synchronization is performed between a local database and a remote database (further details are given in Sect. 2.3) Finally, an ad-hoc multi-modal messaging procedure (SMS, Mobile App, e-mail, etc.) is performed. The data of the therapeutic session that are considered more important are sent to the physician/caregiver allowing an immediate check of the performance through an easy-to-use Graphical User Interface (GUI), available via Web on the Central Server.

2.1 Multi-sensor Devices as Enabling Technology

The core of the platform is represented by the sensor-based architecture that permits the natural interaction of the end-user with the system. Microsoft Kinect (Fig. 2a) is a motion sensing input device that allows users to interact intuitively and without any intermediary device with a Graphical User Interface (GUI) using body parts. From the working principle point of view, Kinect is a structured light scanner, meaning that it projects an infrared pattern that is then read by an infrared camera. After, the 3D information is reconstructed from the distortion of the pattern and this results in a depth channel which is made available through an Application Programmer's Interface (API) - Microsoft's 'Kinect for Windows SDK' [18]. The API was used to interface with its skeletal tracking software, providing an estimate for the position of 20 anatomical landmarks (2 of whom are used for hands tracking in the present platform) at a frequency of 30 Hz and spatial and depth resolution of 640 $\times$ 480 pixels.

Moreover, during the CS practice, a continuous monitoring of main clinical signs is obtained through a Wearable Wellness System (WWS) commercialized by Smartex [22]. The system integrates a sensorized garment equipped with textile electrodes and an electronic device (named SEW) dedicated to the acquisition, the processing and the storage of the data. The physiological parameters collected during the execution of the therapy (Heart Rate and Breath Rate) are analysed offline by the clinician in order to evaluate the level of psycho-emotive stress and the level of fatigue of the patients involved in CS practice (Fig. 2b).



(a) (b)

Fig. 2. (a) Kinect 3d sensor device for human part detection and gesture recognition, (b) smart garment and electronic device (SEW) for the acquisition, processing and storing of physiological parameters

2.2 Cognitive Stimulation Practice Details

The CS program is composed by sequences of exercises appropriately tuned by the physician or psychologist. Each exercise belongs to a category, bringing out specific cognitive activities according to guidelines of the state-of-the-art international evaluation scales for AD (e.g., Mini Mental State Examination - MMSE [23]). An innovative feature of the platform deals with the opportunity to customize each exercise on the basis of the severity of cognitive impairment and residual skills of the target. For this purpose, during the setting procedure, few input parameters need to be defined a-priori (e.g., execution time, maximum numbers of allowed errors, movement sensitivity).

From the taxonomic point of view, the following categories of exercises have been implemented: temporal orientation, personnel guidance, topographical memory, visual memory, hearing attention, visual attention, categorization and verbal fluency. Figure 3 shows the GUI of some CS exercises.

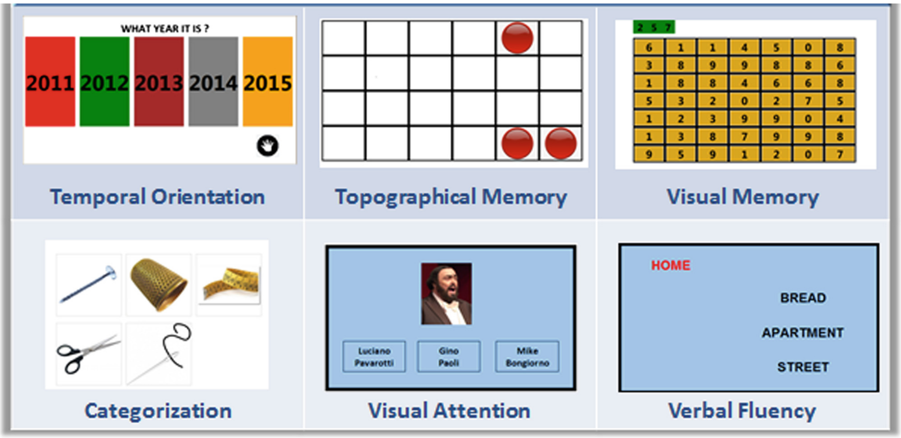


Fig. 3. Some example of exercise categories with related GUI

The design of the therapy can be remotely performed, thanks to a web application that allows physician to configure all the exercises based on the patient's residual abilities and related performance (see Sect. 2.3). In this way, the GUI related to a specific exercise could be different for each patient, for example the number of items displayed, the number of aids or the execution time may vary from the user's remaining abilities. In order to obtain an appropriate video rendering of every exercise, the ICT platform integrates an additional software module able to arrange the interfaces of each exercise independently from the display device (PC monitor, TV). The render of graphics objects integrated in the exercises has been designed according to the principles of usability, ergonomics and acceptability, as reported in ISO/IEC 2001a regulation [24] and through an extensive literature search, expert opinion and user experience.

2.3 Central and Home Server

The central platform is based on eResult's Omniacare, a multi-functional hardware and software system, specifically developed for the remote monitoring and assistance of frail users. The central platform's software architecture is modular: each element realizes some specific functions, as to be able to dynamically adapt to a variety of situations and environments. The system allows exploitation of more or less functionalities in a seamless way, by using specific elements, while the overall system keeps running.

Omniacare is based on a Central Server – Home Server concept. The Central Server is the main element of the system. User profiles, device configurations and all system data reside on the Central Server. It also provides the web interface that operators and therapists use to interact with the system, in order to customize exercises and therapy for patients. Configurations can be done on the Central Server by physicians only, to avoid unauthorized modifications by the users or caregivers. The Home Server and other devices periodically synchronize data and download configurations from and to the Central Server. It is endowed with the following robust inner characteristics: Hierarchical data structure; Web-based user interface; Advanced data navigation, display and search; Extensive data export functionalities; Granular user privilege management; Structured system event management; Information traceability. An example of the Graphical User Interface available on the Central Server is shown in the figure below (Fig. 4).

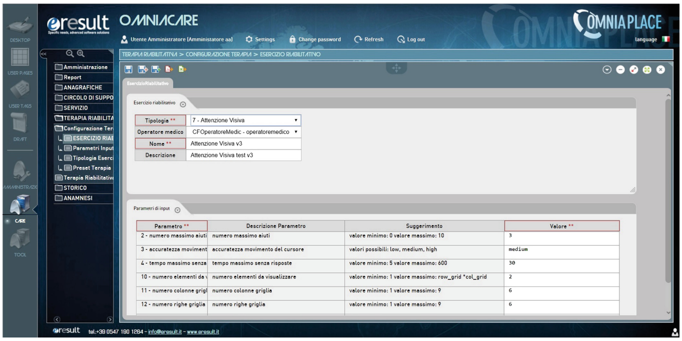


Fig. 4. Central server interface

The Home Server (HS) launches and controls the exercises, but also acts as a gateway that interfaces with detection sensors and external devices managing all of the diverse communication protocols. The HS collects data from the devices and provides configuration data exchange to proper manage them. The HS also consolidates and conditions data and sends them to the Central Server, according to the established rules and timing, while at the same time providing warning or alerts in case of a detected anomaly. The Home Server interface is shown below (Fig. 5).

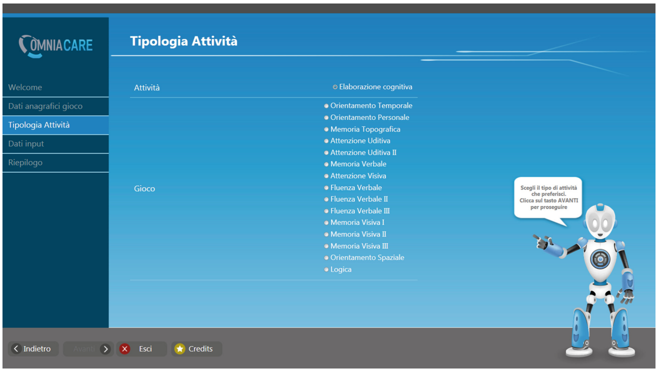


Fig. 5. Home server interface

3 Experimental Results

3.1 Impact of the CS Practice in AD Patients

The practical assessment of CS practice was performed in the period September 2013–February 2014; the study was conducted following the guidelines for Good Clinical Practice and the Declaration of Helsinki (DoH) that is the World Medical Association (WMA) best-known policy statement. The inclusion criteria adopted for the selection of patients were: (1) diagnosis of Dementia according to the National Institute on Aging-Alzheimer's Association (NIAAA) criteria [25]; (2) age ≥ 65 years; (3) ability to provide an informed consent or availability of a proxy for informed consent. Exclusion criteria were: presence of great comorbidity, tumours and different diseases that might be causally associated with psychological feature impairment (ascertained blood infections, vitamin b12 deficiency, anaemia, disorders of the thyroid, kidneys, or liver), history of alcohol or misuse, head trauma, drug use and presence of severe psychological feature impairment (MMSE < 10).

At the baseline and at the follow-up, performed once for each experimental stage, the subsequent parameters (explained in details within the text) were collected by a scientific interview, clinical analysis, and review of records from the patients' general practitioners: demographic information, clinical and medicine history and an entire dimensional and cognitive-affective assessment.

In the analysed patients, the cognitive status was evaluated by means of the Mini-Mental State Examination (MMSE), Babcock Story Recall Test (BSRT) [26], Verbal Fluency (VF) [27], Attentional Matrices (AM) [28] and Copying of Geometric Figures (CGF) [29].

Dementia was diagnosed by the Diagnostic and Statistical Manual of Mental Disorders – 5 Edition (DMS 5) criteria [30]. Diagnoses of possible/probable AD were made according to the NIAAA criteria and supported by neuroimaging evidence (CT scan and/or NMR).

Neuropsychiatric symptoms was evaluated with the Neuropsychiatric Inventory (NPI) [31] together with the subsequent twelve domains: hallucinations, delusions, depression mood, apathy, anxiety, euphoria, disinhibition, irritability/lability, aberrant motor activity, agitation/aggression, sleep disturbance and eating disorder. Emotive standing was evaluated using the Hamilton Rating Scale for Depression (HDRS-21) [32]. A CGA was carried out using assessment instruments widely employed in geriatric practice. Functional status was evaluated by activities of daily living (ADL) index [33], and by instrumental activities of daily living (IADL) scale [34]. Comorbidity was examined using the Cumulative Illness Rating Scale (CIRS) [35]. Nutritional status was explored with the Mini Nutritional Assessment (MNA) [36].

Cognitive status was screened by the Short Portable Mental Status Questionnaire (SPMSQ) [37]. The Exton-Smith Scale (ESS) was used to assess the risk of developing pressure sores [38]. The instrument to be used to assess the quality of life and satisfaction will be Quality of Life Enjoyment and Satisfaction questionnaire (Q-LES-Q) [39]. It's a self-report measure designed to simply acquire sensitive measures of the degree of enjoyment and satisfaction experienced by subjects in numerous areas of daily functioning.

Medication use was outlined in line with the Anatomical medicine Chemical Classification code system, and also the number of medicine utilized by patients was recorded. Social aspects such as family composition, home service, and institutionalization were also considered.

3.2 Pilot Results

The pilot study has included six patients enrolled in 3 completely different sites. Every patients have an initial program of six exercises for session with parameters established on the premise of the primary rehabilitation check. Analyzing the user responses, the amount of exercises (and related parameters) were raised or reduced respectively. All the patients enrolled showed the same good acceptability to the use of the ICT platform as measured through the employment of subjective feed-back. All patients have terminated the study and no drop-out were registered. The sensorized shirt was used to better set-up the system during the primary rehabilitation check meanwhile in the domestic environment the use of this instrument was not possible. After experimental period, the end users showed an improvement of 1.3% on the Rey-15, of 1.2% on the BSRT, of 10.4% on the MMSE score, of 2.5% on the VF, of 12.64% on the AM and 1.3% on the CGF. In addition, the end users showed an improvement of 13.2% on the NPI score, of 11.78% on the NPI-D (subscale of NPI that assesses the distress of the caregiver) score and 24.5% on the HDRS-21 score. The most marked improvement was achieved at Q-LES-Q score (47.89%), whereas the results obtained in correspondence of the CGA domains showed no differences. From the statistical point of view the results obtained may not be very reliable and this is more evident in correspondence of specific indexes used for cognitive evaluation of patients; however, it is important to note that the trends are promising and encourage to experience CS treatment through the proposed ICT platform on a greater number of patients.

4 Conclusion

The main purpose of the present work is to describe and to evaluate an ICT platform designed for autonomous CS practice within a domestic environment. The pilot results, even if referred to a limited number of patients, have shown that the use of the described platform improves the cognitive, affective, neuropsychiatric state, and the quality of life and the satisfaction of the patients.

The most important advantage emphasized by the end-users is related to the possibility of performing the CS treatment remaining in their own homes, and consequently keeping their safety and independence. Moreover, thanks to the platform architecture, the patients can avoid to move to a health care facility center that often can cause a lot of anxiety. Last but not least, the platform integrates monitoring and assistance modules from remote locations, facilitating the work of caregivers/physicians.

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