ICT Platform for Cognitive Stimulation: Technological Description and Evaluation of Effectiveness and Impact of the Practice in Alzheimer's Disease Patients

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Abstract— **Cognitive impairments, such as memory problems or other thinking problems, are a defining feature of the early stages of Alzheimer's Disease (AD). Cognitive Stimulation (CS) is a relatively new approach to improve well-being for people with mild to moderate AD. At present only preliminary evidence regarding efficacy is available but it is enough to suggest that this CS has the potential to bring about changes in behavior and maintain involvement in daily life. The main contribution of this work is to evaluate the effectiveness and impact of CS in AD patients using an information and communication technologies (ICT) platform, implemented through a customized Virtual Personal Trainer (VPT) that can allow the patients to perform the CS practice directly at home. The whole system is made up of an embedded PC connected to a TV monitor with internet connection, a low-cost 3d sensor and an optional e-shirt with textile electrodes for clinical signs detection. Moreover, the system provides an audio/visual link with the medical center, so the physician can interact with the patient during the rehabilitation practice, increasing the compliance and the efficacy and making sure that type and intensity of treatment are appropriate. Results obtained after the experimentation stages demonstrates that the use of the aforementioned ICT platform can improve the cognitive and neuropsychiatric state of the patient and its quality of life, confirming that CS could be represent an attractive option in the support of caregivers and patients affected of AD.**

Keywords- Cognitive Stimulation; Alzheimer's Disease; ICT Platform; Quality of Life.

I. INTRODUCTION

In the recent years, there has been significant progress in using Information and Communication Technologies (ICT) in the field of healthcare; in particular, a great effort has been addressed by researchers in order to develop enabling solutions that are cost-effective. Alzheimer's Disease (AD) is the most common form of dementia, a neurologic disease characterized by loss of mental ability. This kind of deficit interferes frequently with normal activities of daily living (ADLs) and usually occurs in old age. Generally, it is marked by a decline in cognitive functions such as remembering, reasoning and planning.

The importance of Cognitive Stimulation (CS) in the treatment of patients with dementia is underlined by recent scientific publications [1]-[3]. Therefore, a recent study showed that integrated treatment with rivastigmine transdermal patch and CS for six-months significantly improves the cognitive, emotional, behavioral aspects and mortality risk of AD patient [4]. The development of a low-cost platform/home-care service with CS functionalities could be very useful in order to increase the chances of an appropriate medical therapy. Some preliminary studies show that ICT tools are well accepted by elderly people, although education and ICT skills level is often low. Moreover, it is scientifically proven that ICT technologies improving quality of life and increasing the permanence at home.

In the field of healthcare, different kinds of technologies have being developed and used for cognitive training and stimulation in the past years [5]-[7]. For example, virtual reality offers training environments in which human cognitive and functional performance can be accurately assessed and rehabilitated [8][9]. On the other hand, augmented reality provides safer and more intuitive interaction techniques allowing interaction with 3D objects in real world [10][11]. 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, commercial products (Nintendo's Brain Age, Big Brain Academy, etc.) have been tuned as educational tools helping to slow the decline of AD [12][13]. 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 [14] as 3d device for body movements acquisition and gesture recognition and the effects of this kind of technology for rehabilitation purposes is widely investigated [15][16].

In this work, a Natural User Interface (NUI) 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 remainder of the paper is organized as follows. Section II reports the overview of the platform with specific focus on the hardware devices used for the interaction with the system. In Section III, some details about stimulation practice and environment setup are described. Section IV reports the evaluation of effectiveness and impact of the ICT platform in AD patients. In the Section V the result obtained are reported and finally the conclusions of this paper are presented in Section VI.

II. OVERVIEW OF THE PLATFORM

The developed ICT platform (called AL.TR.U.I.S.M. - Alzheimer patient's home rehabilitation by a Virtual Personal Trainer-based Unique Information System Monitoring) provides a digital tool for CS through VPT allowing the patients to perform the rehabilitation practice at home. From this perspective, the process is a highly innovative compared to existing systems [17] as the caregiver/physician defines a specific sequence of exercises (the therapeutic session) according to the residual abilities of the patient. From the hardware point of view the platform is made up of a set-top-box (a commercial embedded PC) connected to a TV monitor with Internet connection, a Microsoft Kinect sensor for human body tracking and gesture recognition and a WWS system with textile electrodes for clinical signs monitoring (Figure 1).
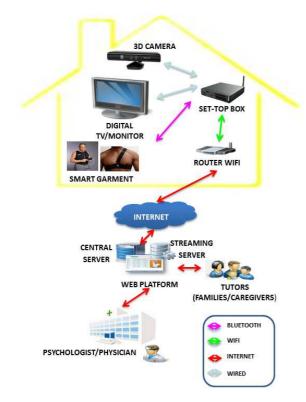

Figure 1. AL.TR.U.I.S.M. platform overview

Moreover, the platform integrates a software module able to stream visual and audio data acquired during the therapy. This module can record the video streaming for post-verification from a remote architecture by the caregiver or physician. From this perspective, the physician or the psychologist of the reference centre could communicate to the patients through a remote connection and then monitor the progress or trouble in the execution of the different required tasks.

At the end of the rehabilitation session, the central platform collects different kinds of data locally stored on the embedded PC. Finally, an ad-hoc multi-modal messaging procedure (e-mail, SMS, Mobile App for Android devices, etc.) is performed and relevant data are sent to the physician allowing instant verification of the performance through an easy-to-use Graphical User Interface (GUI). In the next sections some details regarding the hardware devices involved in the platform are reported.
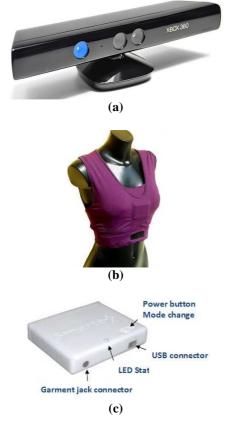
A. Microsoft Kinect Sensor

In order to approach the CS practice, the end-user needs a specific hardware device (Microsoft Kinect) which allows to interact intuitively with a GUI using their bodies (Figure 2.a). The Kinect is a motion sensor that can measure three-dimensional motion of a person. From the functioning principle point of view, the Kinect device integrates both a high resolution RGB camera and an infrared depth sensor.
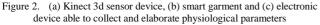
Microsoft's 'Kinect for Windows SDK'[18], was used to provide an Application Programmer's Interface (API) to the Kinect hardware. The API was used to interface with the Kinect sensor and its skeletal tracking software, providing an estimate for the position of 20 anatomical landmarks at a frequency of 30 Hz and spatial and depth resolution of 640×480 pixels.

The space resolution along the x and y axis is 3 mm at a depth of 2 meters, whereas the resolution of z-depth is 1 cm at the same depth. While increasing distance from the sensor, the accuracy decreases remaining within an acceptable range for people body part detection.

B. Wearable Wellness System

Another important feature of the platform is the continuous monitoring of physiological parameters during the execution of the therapy, for the evaluation of psycho-emotive stress of the patient involved in the CS practice. Physiological parameters are collected by a Wearable Wellness System (WWS) produced by Smartex [19]. The system includes a sensorized garment (Figure 2.b) and an electronic device (Figure 2.c). The sensorized garment is equipped with two textile electrodes directly connected to the device (named SEW). A jack connector links the sensorized garment with the electronic device. The e-shirt is available in both male and female version, with size ranging from S to XL. WWS is able to simultaneously acquire ECG, heart rate, breath rate and acceleration values along x-axis, y-axis and z-axis. Data acquired are sampled with different rates (breath-rate@25Hz, heart-rate@0.2Hz, 1-derived ECG channel@ 250Hz) and transmitted to the set-top-box via Bluetooth radio link.

(a)

(b)

(c)

Figure 2. (a) Kinect 3d sensor device, (b) smart garment and (c) electronic device able to collect and elaborate physiological parameters

III. STIMULATION PRACTICE DETAILS AND ENVIRONMENT SETUP

A. Multi-Domain CS Practice

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 [20]). 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.
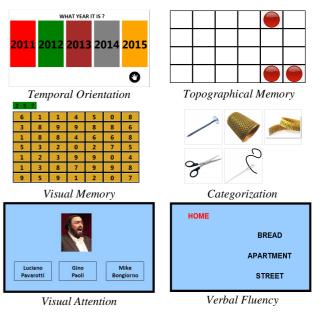

Figure 3. Examples of GUI for different categories of CS exercises.

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. As a result, the interface of a specific exercise can be different for each patient. For example, the exercise "Topographical Memory" requires the following parameters: number of rows in the grid, number of columns in the grid, number of red dots (correct answers), whereas the exercise "Categorization" requires only the number of images to display. In addition to the GUI modelling, it is possible to establish the maximum length (in time unit) of every exercise and to set (only for a certain categories of exercises) the number of aids. The specific input required for each category of exercise with the information about the presence or not of aids are reported in the next table:

TABLE I. SPECIFIC INPUT REQUIRED FOR EACH CATEGORY OF EXERCISE

Category	Specific Input	Help?
Temporal Orientation	Year, month, day, day of the week	Yes
Personnel Guidance	Body part target	Yes
Topographical Memory	N° of answers, N° grid rows, N° grid colums	Yes
Visual Memory	N° of images	Yes
Hearing Attention	Text/Story, N° of words to identifiy	No
Visual Attention	N° of answers, N° grid rows, N° grid colums	No
Categorization	N° of images	Yes
Verbal Fluency	Target word, synonym/contrary word	Yes

An appropriate display of every exercise and the independence from the specific output device (digital monitor, HD TV, etc.) is obtained thanks to the implementation of a software module for the best video rendering. The definition of graphics objects displayed on the GUI has been designed according to the principles of ergonomics, usability as referred in ISO/IEC 2001a [21] and acceptability through an extensive literature search, user experience and expert opinion.

B. Environment Setup

The setup of the environment can be done without any specific help, but it is important to observe a few simple requirements for proper CS practice execution.

For the best performance during the practice, Kinect must be placed allowing to acquire the whole body (see Figure 4). Some tips on how to place the sensor are listed in the following:

- sensor must be place near the edge of a flat, stable surface;
- sensor should be within 15 cm above or below a TV monitor, and between 0.6 meters and 1.8 meters from the floor;
- avoid positioning the sensor in direct sunlight or within 0.3 meters of audio speakers.

The end-user must be far from Kinect sensor at least 1.5 meters and never more than 3 meters (Figure 5), assuring the proper functioning of 3d skeletonization procedure provided by Microsoft Kinect SDK. Some categories of exercises can be executed from a seated position; however the user must always respect the specific operative range of the platform.. In order to interact with the VPT, the patient must move the hand minimizing occlusion with other body parts. Hand tracking algorithms have been implemented providing a customized level of movement sensitivity which is manually tuned by the physician (three different level of sensitivity have been implemented). For specific exercise (e.g., Personnel Guidance) gesture recognition algorithms have been developed in order to verify the correctness of the hand movement with respect to a previously recorded template.
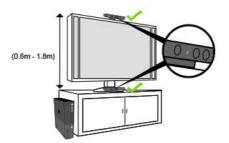

Figure 4.   (a) Kinect position for best performance during CS practice
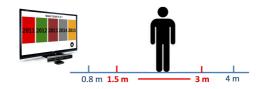

Figure 5.   Spatial position of end-user for proper interaction with the platform

IV. EFFECTIVENESS AND IMPACT OF THE PRACTICE IN AD PATIENTS

The study was conducted according to the Declaration of Helsinki, the guidelines for Good Clinical Practice and following the CONSORT statement. Was approved by our local Ethic Committee. The experimentation stages have begun at September 2013 up to February 2014. Inclusion criteria were: 1) age $\geq$ 65 years; 2) diagnosis of Dementia according to the National Institute on Aging-Alzheimer's Association (NIAAA) criteria [22]; 3) ability to provide an informed consent or availability of a proxy for informed consent. Exclusion criteria were: presence of serious comorbidity, tumours and other diseases that could be causally related to cognitive impairment (ascertained blood infections, vitamin B12 deficiency, anaemia, disorders of the thyroid, kidneys, or liver), history of alcohol or drug abuse, head trauma, and psychoactive substance use; presence of severe cognitive impairment (MMSE< 10). At the baseline and at the follow-up, performed after experimental stage, the following parameters, explained in details in the text, were collected by a systematic interview, clinical evaluation, and review of records from the patients' general practitioners: demographic data, clinical and medication history and a complete multidimensional and cognitive-affective assessment.

A. Cognitive evaluation and diagnosis of dementia

In all patients, cognitive status was screened by means of the Mini-Mental State Examination (MMSE) Babcock Story Recall Test (BSRT) [23], Attentional Matrices (AM) [24], Verbal Fluency (VF) [25], and Copying of Geometric Figures (CGF) [26].

Dementia was diagnosed by the Diagnostic and Statistical Manual of Mental Disorders – 5 Edition (DMS 5) criteria [27]. Diagnoses of possible/probable AD were made according to the NIAAA criteria and supported by neuroimaging evidence (CT scan and/or NMR).

B. Neuropsychiatric and affective assessment

Neuropsychiatric symptoms was evaluated with the Neuropsychiatric Inventory (NPI) [28] including the following 12 domains: delusions, hallucinations, agitation/aggression, depression mood, anxiety, euphoria, apathy, disinhibition, irritability/lability, aberrant motor activity, sleep disturbance and eating disorder. Affective status was evaluated using the Hamilton Rating Scale for Depression (HDRS-21) [29].

C. Comprehensive Geriatric Assessment (CGA)

A CGA was carried out using assessment instruments widely employed in geriatric practice. Functional status was evaluated by activities of daily living (ADL) index [30], and by instrumental activities of daily living (IADL) scale [31]. Cognitive status was screened by the Short Portable Mental Status Questionnaire (SPMSQ) [32]. Comorbidity was examined using the Cumulative Illness Rating Scale (CIRS) [33]. Nutritional status was explored with the Mini Nutritional Assessment (MNA) [34]. The Exton-Smith Scale (ESS) was used to evaluate the risk of developing pressure sores [35]. Medication use was defined according to the Anatomical Therapeutics Chemical Classification code system, and the number of drugs used by patients was recorded. Social aspects included household composition, home service, and institutionalization.

D. Quality of Life and Satisfaction assessment

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) [30]. It's a self-report measure designed to easily obtain sensitive measures of the degree of enjoyment and satisfaction experienced by subjects in various areas of daily functioning

V. RESULTS

A. Questionnaire results before experimental period

Between January and April 2013 a survey was conducted at the Alzheimer Evaluation Unit of the "Casa Sollievo della Sofferenza" Research Hospital in San Giovanni Rotondo (FG). The questionnaire included 17 items that explored different areas; the survey included 72 patients and their caregivers. The summary of the results are the following: 51.6% of patients need care in self-hygiene, 15.6% in moving at home, 12.5% in moving out of home and 10.9% in taking drugs. Among the patients with mild AD: 46.9% had a slight deficit in personal care, 37.5% had a mild motor disability, 6.3% sever loco motor disability, 4.7% present a serious lack in personal care, and 4.8% significant sensory deficits. The 48.4% of patients live with a spouse, 26.6% with a child or sibling, 23.4% alone and 1.6% with a private caregiver. Patients are assisted by family members (92.2%, with a mean age of 63.59 years ± 16.50) and private caregiver (7.8%, with a mean age of 48.20 ± 2.78 years). Family members take care for patients for an average of 6.22 ± 1.02 days a week and 6.94 ± 5.44 hours per day; private caregivers caring for patients for 6.00 ± 0.71 days a week and 12.0 ± 7.87 hours per day.

In the sample, 54.7% of patients like to watch TV and 26.6% watch preferably film. The 92.2% of patients are capable to turn on and off the TV, 85.9% is able to choose the programs in autonomy and use the remote control, the 67.2% is able to maintain a level of attention from the beginning to the end of a television program; the 79.7% of patients can use a PC only if helped and 50% cannot use the PC keyboard. Family members/caregivers have reported in their preferences that the AL.TR.U.I.S.M. system could be useful to facilitate communication with the medical center

of reference (34.4%) and improve the quality of care through constant monitoring of the exercises performed (32.8%). Moreover, the system could be very useful to improve the quality of life (73.4%) and quality of care and assistance (73.4%). Finally, 62.5% of patients could accept the use of interactive TV and devices to monitor vital signs and gesture recognition at a distance.

B. Pilot Results

The pilot study has included 6 patients enrolled in three different sites. Each patients have an initial program of six exercises for session with parameters established on the basis of the first rehabilitation test. Analysing the user responses, the number of exercises and parameters were increased or reduced respectively. All the patients enrolled showed a similar good acceptability to the use of the platform as measured through the use of subjective feed-back. All patients have concluded the study and no drop-out were registered. The sensorized shirt was used to better set-up the system during the first rehabilitation test meanwhile at home these system weren't used.

After experimental period, the end users showed an improvement of 10.4% on the MMSE score, of 1.2% on the BSRT, 1.3% on the Rey-15, 12.64% on the AM, 2.5% on the VF and 1.3% on the CGF. In addition, the end users showed an improvement of 24.5% on the HDRS-21 score, 13.2% on the NPI score and 11.78% on the NPI-D (subscale of NPI that assesses the distress of the caregiver) score. They showed a significant improvement of 47.89% on the Q-LES-Q score. The data included the CGA domains showed no differences. Unfortunately the results were not significant different from a statistical point of view for the extremely small sample size but the trend are promising.

VI. CONCLUSION

For elderly people, home is a place of memories where they spend most of their time. Their demands on to stay home will increase and change with growing age, especially when their health status starts to worsen. An important aspect for all people having the need to be supported in their daily-life-activities is to remain integrated in social life, despite of their age and/or existing disabilities.

We demonstrated that the use of the VPT can improve the functional, nutritional, cognitive, affective and neuropsychiatric state. Furthermore, the VPT can improve the customer's satisfaction and quality of life.

The home cognitive rehabilitation could be represent an attractive option in the support of caregivers and patients affected of AD. VPT is being implemented into more and more homes of the elderly in order to maintain their independence and safety. These VPT allow the elderly to stay in their homes where they feel comfortable, instead of moving to a health care facility. The transition to a health care facility can cause a lot of anxiety and to stay home using the VPT can either prevent or delay this anxiety. Moreover, VPT can provide the elderly with many different types of emergency assistance systems, security features, automated timers, and alerts. These systems allow for the

individual to feel secure in their homes knowing that help is only minutes away. VPT will make it possible for family members to monitor their loved ones from anywhere with an internet connection.

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