Interference Between Cognitive and Motor Recovery in Elderly Dementia Patients Through a Holistic Tele-Rehabilitation Platform

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Abstract. To improve the quality of life of elderly subjects affected by dementia, the rehabilitation environment has to translate from the hospital to the patient's home. A holistic tele-rehabilitation system can be successfully used to support and enhance a home-based rehabilitation process. The ABILITY platform foresees mobile and wireless technologies, integrated into a unique environment in which patients can become primary actors in their own care. In this work, we present a Pilot Study (N = 10) about the motor recovery, and in particular the relationship between the motor recovery and the cognitive recovery, in dementia patients. A group of control patients followed the usual care treatment and another group used the ABILITY platform at home. The results of the study suggested that the use of the tele-rehabilitation platform could improve both the motor skills, the cognitive skill and the interaction between them.

Keywords: Tele-rehabilitation · Tele-medicine · Mobile sensors · Dementia · Domotics · Active aging

1 Introduction

In an aging society like ours, the pathologies which affect elderly people represent a large burden for their families and for the national health system(s). Among the population with more than 65 years, dementia is one of the main causes of disability, causing a substantial drop of the self-sufficiency in the everyday life [1, 2]. The 5% and the 30% of the population respectively with more than 65 and 80 years is affected by neurodegenerative diseases and, every year, several millions of these neurological patients are diagnosed as new cases of dementia. One of the characteristics of dementia is a continuous and evolving decline in motor, behavioral and cognitive skills. The loss in motility and in communication and cognitive abilities can contribute not only to social isolation, but also to dangerous behaviors [3]. For these reasons, the treatment of dementia has become a priority for the public health system. Since, at present, pharmacological

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therapies do not exist, the treatment of dementia patients is devoted to relatives or in-home nurses (caregivers). Since the house of the patient is his/her principal environment, mobile and wireless technologies placed at the patient's home can provide therapeutic aids, direct communication with general practitioner and assistance to the caregivers. Maximizing the home assistance and tele-rehabilitation will cause a reduction of the treatments' cost of the hospitalization and will improve the patient's quality of life [4, 5].

Given the multifaceted aspects of dementia, the ideal tele-rehabilitation system has to deal with both motor and cognitive impairments, and has to improve capabilities for an independent life.

In this context, the goal of the ABILITY project was to design, develop and validate an integrated platform of services, aiming at supporting and enhancing the home-based rehabilitation process for patients with dementia. The namesake platform, representing the core of the project, consisted of a central unit and of mobile and wireless devices (e.g. tablets, RFID sensors, wireless scale and pressure sensors, activity trackers) for motor and cognitive rehabilitation of elderly people with dementia [6–8]. The project was developed through a collaboration of academic (Politecnico di Milano and Università degli Studi Milano - Bicocca), clinical (IRCCS Fondazione Don Carlo Gnocchi and Ospedale Valduce - Centro di Riabilitazione di Villa Beretta) and industrial partners (Telbios Srl, Astir Srl, Teorema Engineering Srl, Secure Network Srl, AB Tremila Srl and Sait Srl).

2 The ABILITY Platform Architecture

The ABILITY platform was designed to be a holistic tele-rehabilitation system for elderly dementia patients following a home-based rehabilitation treatment. The etiology of dementia can vary, ranging from Mild-Cognitive-Impairment (MCI), to post-stroke dementia (vascular) to degenerative dementia (due to Parkinson Disease or Alzheimer syndrome) [8]. The two main characteristic of the platform were the possibility for the clinicians to assign rehabilitation plans to be performed at home, and the holistic approach to rehabilitation, as the plan includes physical, cognitive and behavioral therapies/exercises. The platform was not used by the patients only, but also by the caregivers, by the neurologist in charge of the patient and by other clinical specialists (e.g. by the neuropsychologists and physiotherapists). Each of the users has proper functions: the patient can see the daily therapy, the neurologist can assign, modify or evaluate the therapeutic plans, the caregiver can interact with the medical personnel or can check how the rehabilitation is going.

The interaction of the different users and the logical architecture of the platform are depicted in Fig. 1. The lower part represents the patient's interaction with the platform. The patient (green circle) might be equipped with different devices that can be provided with the platform: a dedicated PC/Tablet, used by the patient to see the daily activity plan, to play serious games and to receive or write messages to the neurologist; an activity tracker (FITIBIT®) to measure the amount of physical activity of the patient and the quantity of his sleep; RFID sensors placed in different rooms of the house, in order to measure the time spent in the different rooms (e.g. how much time the patient spends in the bedroom during the day); wireless telemetry devices, such as a scale and a blood pressure monitor. The platform foresees also other devices, which are used only at the hospital (e.g. an EEG portable helmet to measure variations in the brain activity of the patients during specific cognitive or attentive tests). The "Middleware layer" manages the communications from the mobile devices to the PC and then forwards the information to the platform as structured data. The upper part of the figure represents the platform side, the intermediate part is transparent to the users and contains the databases, medical knowledge, business intelligence and decision support system tools, which facilitate the generation and the personalization of rehabilitation plans, also suggesting modifications when needed (e.g. the level of the exercises is too hard for the patient). The upper part represents the front-end interfaces, providing access to the platform to all the clinical staff (red circles) and to the caregiver (orange circle).

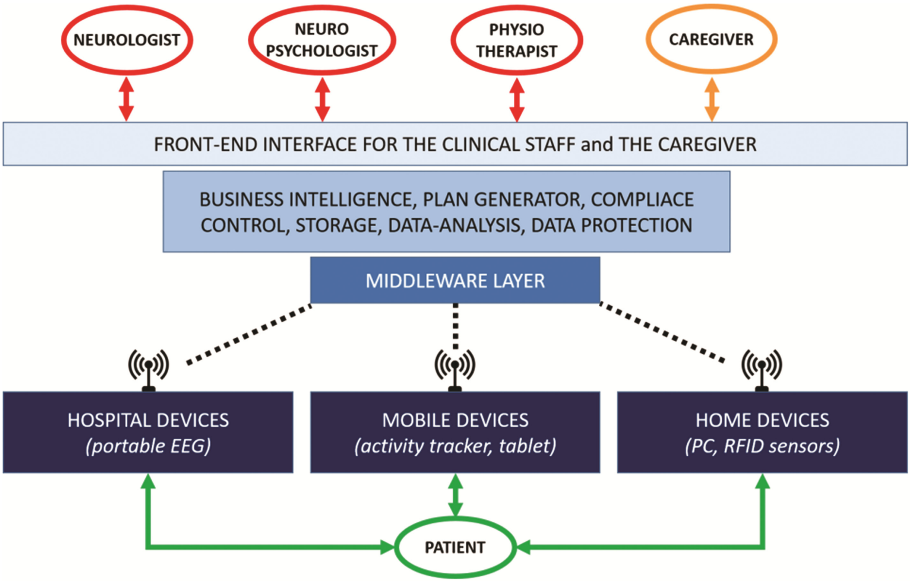

Fig. 1. The ABILITY platform architecture and the interactions of the different users with it. (Color figure online)

3 Pilot Study

3.1 Pilot Study Design

With the aim to investigate the motor aspect of the recovery, and particularly the relationship between the motor recovery and the cognitive recovery, we designed a pilot study. We investigated two small groups of patients: the control group (CTR) that was treated with the standard rehabilitation plan for dementia patients, with both motor and cognitive exercises, and the experimental group (ABIL) that was treated with the support of the ABILITY platform.

3.2 Participants

The participants recruited for the Pilot Study had to satisfy the following criteria. They had to be diagnosed with degenerative dementia: Alzheimer Disease (AD) at mild stage or Mild Cognitive Impairment (MCI) with an high risk to an evolution to AD [9], according to the diagnostic criteria of the DSM-5 [10]. They had to obtain less than 24 points in the Mini-Mental state examination test, they had to have completed at least 3 school years and to be aged between 60 and 85 years. Patients with severe deficits in visual acuity, acoustic perception, communication problems or dysmetria could not take part of the study, because these pathologies could interfere with the activities foresaw by the ABILITY program. The patients were randomly assigned to the ABIL or to the CTR groups. This study and the use of the ABILITY platform was approved by the Ethical Committee of the Valduce Hospital, Villa Beretta Rehabilitation Center.

3.3 Rehabilitation Protocol

The rehabilitation protocol was performed for 6 weeks, bot for CTR and ABIL groups.

CTR group was treated following the usual care protocol in use in the Villa Beretta rehabilitation center. In particular, patients were instructed to perform daily aerobic physical activity, to stimulate cognitive functions with conventional instruments (i.e., crosswords), and to compile a daily diary with physiological variables monitoring (i.e., pressure, weight, etc.).

ABIL group was instructed to use the ABILITY platform daily which allowed to perform cognitive functions rehabilitation with serious games and motor functions rehabilitation with step-by-step instructions.

3.4 Assessment Protocol

Both groups were assessed with the motor-cognitive protocol before the treatment (PRE) and at the end of the 6 weeks of treatments (POST). The proposed protocol consisted of a simple motor test, proposed in two different modalities: (i) classical motor task, and (ii) dual-task, with a cognitive interference in the motor task. The aim of the protocol was to evaluate both the motor performance *per se* and the interaction between the cognitive processes (required during the execution of the motor task), and the execution of the motor exercise itself. The protocol lasted around 20 min and it consisted of two sessions of the 6 min Walking Test (6MWT) [11], separated by a pause of 10 min, to give the possibility to the patient to rest, which was extended upon patient request. The 6MWT, in its classical version (6MWT-S – Simple), was executed with the standard protocol, using an indoor 50 m hallway. The starting and the ending points were marked with adhesive tape on the floor. The participants were informed that the aim of the test was to measure how much they can walk in six minutes. The subjects could decide at which pace take the exercise and also they were allowed to take pauses if they needed. The assisting physiotherapist had to measure the performed distance, the number of the potential pauses and the passed time.

The 6MWT, in the dual-task version (6MWT-DT) [12], was executed in the same way as the 6MWT-S, with the addition of a cognitive task. During the walking, the subjects had to recite the Italian alphabet only every other letter. After 3 min, the assistant changed the starting letter. In the first three minutes, the subjects started with the letter "A" (A-C-E-G-I-M-O-Q-S-U-Z), in the second half of the test the subjects started with the letter "B" (B-D-F-H-L-N-P-R-T-V). In this test, the physiotherapist had also to measure the number of errors made by the subjects.

3.5 Data Analysis

We used the Mann-Whitney U-test to verify if the ages of the subjects in the two groups were significantly different ($p < 0.05$) or not. Afterwards, we computed the average walking speed of the two groups before and after the rehabilitation treatments. We evaluated the walking speeds in both the 6MWT-S and the 6MWT-DT. For the 6MWT-DT we also computed the mean number of errors committed during the task, for both groups (CTR/ABIL) and for both conditions (S/DT). For every measure, we used the Mann-Whitney U-test to verify if there were significant differences ($p < 0.05$) between the groups or between the conditions. In order to verify the interference of the cognitive processes on the motor task, we have defined an ad-hoc index *I*, which quantify, as a percentage, the improvement (POST-PRE) in the 6MWT-DT versus the improvement in the 6MWT-S task, which was defined as follows (Eq. 1):

$$I = \frac{(Vel_{POST\_DT} - Vel_{POST\_S})}{Vel_{POST\_S}} - \frac{(Vel_{PRE\_DT} - Vel_{PRE\_S})}{Vel_{PRE\_S}} \cdot 100 \quad (1)$$

Where Vel_{POST_S} and Vel_{POST_DT} were the gait velocities in the POST session in the S and in the DT protocols, respectively; Vel_{PRE_S} and Vel_{PRE_DT} were the gait velocities in the PRE session in the S and in the DT protocols, respectively.

4 Results of the Pilot Study

4.1 Participants

6 patients for the control group (CTR), and 4 for the intervention group (ABIL) completed the proposed rehabilitation program. The recruited subjects were all diagnosed with degenerative dementia, with demographics reported in Table 1.

Table 1. Demographic data of the control (CTR) and experimental (ABIL) groups.

	CTR group (N = 6)	ABIL group (N = 4)
Diagnosis	Degenerative dementia	Degenerative dementia
Sex	M = 3, F = 3	M = 1, F = 3
Age (years)	75.0 ± 8.9 (61.1–84.6)	69.8 ± 1.7 (63.0–76.4)
School years	5.0 ± 0.0	6.5 ± 1.7
Mini-mental-state test	19.3 ± 5.8	22 ± 4.7

4.2 Motor and Cognitive Performance and Their Interaction

The subjects of the CTR and ABIL groups could be considered age-matched, since the p-value resulting from the Mann-Whitney test was equal to 0.48 *(>0.05).* All participants, but one of the CTR group, could be considered as community ambulators, since they had a gait speed higher than the threshold commonly used in literature of 0.8 m/s [13], the mean gait velocities along with their standard deviations of both groups in all the four conditions are reported in Fig. 2 and in Table 2.

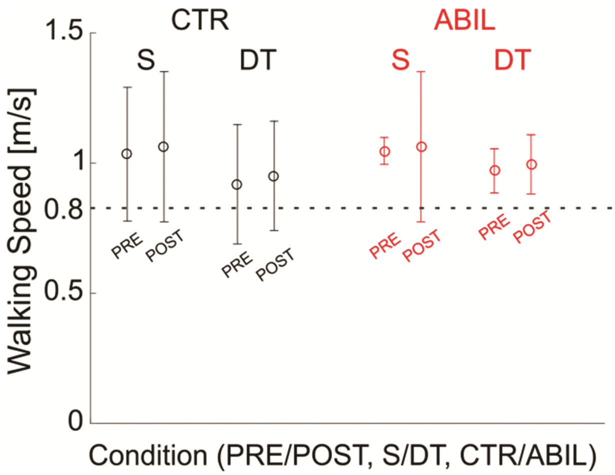

Fig. 2. The gait speeds of the two groups (CTR in black, ABIL in red), in the four conditions (S/DT and PRE/POST). (Color figure online)

Table 2. The gait speeds of the two groups (CTR in black, ABIL in red) in the four conditions (S/DT and PRE/POST) and the number of errors in the DT task are reported as Mean ± Standard Deviation. The *p-values* of the Mann-Whitney test between the CTR and the ABIL group are reported in the last column.

Protocol	Measure	CTR group	ABIL group	*p-value*
Simple	Vel_{PRE} *[m/s]*	1.034 ± 0.257	1.046 ± 0.052	1.000
	Vel_{POST} *[m/s]*	1.063 ± 0.288	1.025 ± 0.091	0.324
Dual task	Vel_{PRE_DT} *[m/s]*	0.918 ± 0.229	0.970 ± 0.085	0.714
	Vel_{POST_DT} *[m/s]*	0.951 ± 0.209	0.995 ± 0.113	0.914
	$Errors_{PRE}$	20.6 ± 8.9	6 ± 6.8	0.0381 (*)
	$Errors_{POST}$	17.8 ± 8.5	5.2 ± 4.6	0.0382 (*)

*$p < 0.05$

It is possible to notice that in both CTR and ABIL groups and in both S and DT experiments, there was a general increase of the gait speed induced by the rehabilitation training, which was however not significant, considering the minimally clinical significant change for the gait velocity in the 6MWT of 0.14 m/s [14, 15]. Also, the Mann-Whitney test comparisons performed between the CTR and the ABIL groups showed that in all the four conditions there were no significant differences in the gait speed. Otherwise, the number of errors committed by the ABIL group was significantly lower than the CTR group both in the PRE and in the POST assessments.

About the cognitive interference index *I*, the improvement of the subjects of the CTR group in the DT with respect to the S task was of the 2.05%, whereas the improvement of the ABIL group was of the 3.98%. However, due to the high variance and the low numerosity of the groups, the Mann-Whitney test did not show a significant variation between the two groups for the index *I*.

5 Discussion and Conclusions

The results obtained through the designed Pilot Study showed that both the usual care therapy of elderly dementia patients and the use of the ABILITY tele-rehabilitation platform generated an improvement -in a basic motor task- the locomotion. In particular, the gait speed increased from the PRE to the POST of about 0.03 m/s in both groups and in both the Simple (S) and the Dual Task (DT). Focusing on the investigation of the interference of the cognitive processes on the walking task, an interesting result emerged: the improvement in the DT with respect to the improvement in the S task was doubled in the ABIL group. This suggests the hypothesis that the use of a holistic tele-rehabilitation system like the ABILITY platform could help in improving both the motor skills, the cognitive skill and the interaction between them. Since the present is only a pilot study, the statistical significance of the presented results has to be improved by extending the number of the patient's cohorts, and attention might be devoted to differentiate responders and non-responders which has been demonstrated to be an effective approach with post-stroke patients [15, 16]. Moreover, the study might be extended to other motor-cognitive tasks during the rehabilitation of dementia in elderly subjects.

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