Observation of executive processes and associated dysfunction in aging and dementia for cognitive assistance systems

Audrey Serna, Vincent Rialle, and Hélène Pigot, *TIMC-IMAG , Laboratory, Grenoble, France Domus and Laboratory, Sherbrooke University, Sherbrooke, QC, Canada*

Abstract—**Aging and dementia of the Alzheimer's type lead to the progressive deterioration of cognitive and executive functions. In the context of smart homes and gerontechnology, an essential step to assist people suffering from these disorders is to identify their difficulties in daily living. A better utilization of assistive devices relies on a better understanding of cognitive handicaps. This paper presents an evaluation of executive processes impairment in daily living according to cognitive impairment. The observation of the performance of an activity of daily living by different groups of subjects (young, elderly, and MCI-AD people) and the specification of a precise scoring system show a deterioration of executive processes and a loss of autonomy during the task performance.**

I. Introduction

OLDER people and Alzheimer patients suffer from cognitive and executive disorders. As a consequence, they gradually loose their autonomy in daily life. The concept of smart homes seeks to overcome these disorders, in order to avoid an institutionalization or to delay it as much as possible. To improve their efficiency and their responsiveness, cognitive remediation and assistive systems should be based on a better understanding of cognitive dysfunctions and their impact on people's daily living. The aim of this paper is to describe an experiment that evaluates the impairment of executive processes during the performance of an activity of daily living (ADL).

Taking care of people weakened by pathologies related to aging, such as dementia of the Alzheimer's type, has become a major socio-economic problem. According to a statistical study, published by the European commission in 2006, 18 million people suffered from dementia in the year 2002 in the whole world. This study predicts that the prevalence of dementia should double every five years for people aged 65 and over [6]. These diseases are characterized by the impairment of both cognitive (memory, reasoning, language mechanisms, etc.) and executive (intentions generation, planning, monitoring, etc.) functions. The heaviest consequences are the incapacity to perform ADL and the nearly complete loss of autonomy [19].

Different tools and scales have been designed to evaluate and to measure cognitive and executive dysfunctions. For example, the Clinical Dementia Rating [15] provides a quantification of dementia evolution according to the patient's cognitive and functional performance in different areas. Generally, these measurements are based on interviews and neuropsychological assessments. These tests provide information on the patient's language, memory, perception, reasoning, and planning deficiencies [23]. However, the performance on these assessments is not a good predictor of the patient performance in everyday activities [3][4]. Whereas neuropsychological tests provide a measurement of the patients' cognitive abilities, occupational therapeutic tests reflect their performance in daily life. For example, the Kitchen Task Assessment [4] and *Le profil des AVQ* [9] measure the patient's autonomy in ADL performance. For these two tests, the global score is computed according to the level of cognitive support required to complete the task successfully. Though interesting, those studies do not provide enough details on the description of impaired mechanisms and on difficulties encountered by patients during the task performance.

To document cognitive impairment, it seems important to observe mechanisms involved in ADL performance and the difficulties due to their impairment. As stated previously, executive functions, responsible of intentional behavior, are weakened in aging and impaired in Alzheimer's disease [5][8]. Executive functions can be separated into four conceptual components: volition (goals and intentions generation), planning (strategies and actions plan elaboration), purposive action (plan execution) and effective performance (monitoring and correction) [12]. The latter, also called *executive control*, deals with behavior monitoring, adaptation to unexpected situations, self-correction and final evaluation abilities [14][22]. Executive control is essential for successful completion of ADL. Whereas this concept can be found in every executive functions theory, such as Luria's [13] or Norman and Shallice's [16][21] ones, it has not been the object of as detailed studies as planning mechanisms have[1][2][20].

In this study, we bring to light: (1) executive processes, and notably executive control, involved in ADL and (2) their impairment in the course of aging and Alzheimer's disease due cognitive impairment. We present the particular method (choice of the task, groups of subjects, scoring system, etc.) used to observe executive processes, the results analysis before discussing the possible use of cognitive models in assistive systems.

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A. Serna is with the TIMC-IMAG, CNRS UMR 5525 Laboratory, Institut National Potytechnique of Grenoble, France (phone: +33-4-76-63-74-33; fax: +33-4-76-51-86-67; e-mail: audrey.serna@ imag.fr).

V. Rialle is with TIMC-IMAG, CNRS UMR 5525 Laboratory, Joseph Fourier University, Grenoble, France (e-mail: vincent.rialle@imag.fr).

H. Pigot is with the Laboratoire DOMUS, Sherbrooke University, Canada (e-mail: helene.pigot@usherbrooke.ca).

II. METHODS

A. Experiment task

Our choice of the experiment task stemmed from several criteria. While every subject must know the task, it cannot be a routine activity so as to avoid automatic behaviors. The task must be complex enough to allow the observation of planning mechanisms (for example, there may have several different ways to complete the task). At last, the task must tolerate the introduction of disruptions. Indeed, we introduce disruptions during the performance of the task – without previously notifying the subject – to observe and to qualify his/her ability to control actions. By creating abnormal or unexpected situations and by adding new elements to the environment, we force the subject to adapt or correct his behaviour, to elaborate alternative strategies and to switch from one to another if they are not suitable.

The specific task selected for the experiment is the performance of an ADL (*fill in a form and post the letter*) inspired from the «write a letter» task in Forde and Humphreys experiments [10]. In our experiment, the subject must fill in a form to adhere to a cultural centre. The subject must write his personal data, including his category (student, retired, etc.). Then he must prepare the envelope: write the destination name and direction, put a stamp, and close the envelope. One of the disruptions introduced is to make the cultural centre address unreadable. Thus we introduce a new «obtain the address» sub-task, inspired from the «obtain an information» task in *Le profil des AVQ* [9]. The subject will have to find another way to obtain the address. The subject is free to pick the strategy he prefers among several choices: looking into the phone book, calling the information service or searching the Internet. The introduction of this sub-task allows the observation of executive mechanisms as a whole: from the generation of an intention, the elaboration and choice of a strategy, the planning of the actions to the execution and monitoring of the plan. In addition, during the performance of the sub-task, strategies switching can be observed. Indeed, some subjects may have some difficulties to find the address. They will have to use different strategies before finding the relevant information.

B. Subjects

To study executive mechanisms both in normal functioning and when altered, we observed three different groups of subjects performing the task: (1) young adults, for the study of executives mechanisms involved in the performance of ADL; (2) autonomous older people for the study of the degradation of executive mechanisms due to healthy aging; and (3) MCI (Mild Cognitive Impairment) and AD (Alzheimer's disease) patients for the study of executive mechanisms impairment due to illness.

The study included 30 subjects whose cognitive functions had been previously tested using the Mini Mental State Examination (MMSE) [7]. The MMSE provides a quantitative measure of cognitive impairment for adults. It is used to detect and to estimate the presence of cognitive impairment. The assessment evaluates the abilities of subjects on orientation, registration (immediate memory), short-term memory, language functioning, etc. Scores below 24 out of 30 indicate the presence of cognitive impairment.

The *young subjects* group included 12 students from 20 to 28 years old. They all lived independently. Every subject was familiar with the use of phone and computers. Most of them used Internet and the phone book to find some information.

The *elderly subjects* group included 11 elderly persons from 63 to 84 years old. The subjects were recruited through their rest-home or through an association for computer initiation. All the subjects were living autonomously, even subjects living in rest-homes (they had their own apartment inside the residence). Every subject was familiar with the phone use, and some of them with computers. Most of the subjects used the phone book to find specific information.

The *MCI-AD subjects* group included 7 patients from the geriatric service of the Broca hospital (Paris) from 71 to 84 years old. The group included 6 MCI patients and one AD patient. All the subjects were retired, and, despite their handicap, still lived at home. They were familiar with the use of phone, but none of them could use the Internet. To find information, they were used to searching in the phone book.

C. Scoring and assistance system

We used a specific scoring system to evaluate the task performance. This evaluation took into account several factors. First, the achievement of the task was evaluated through acceptation criteria. According to these criteria, the task was considered as achieved with success or with failure. Secondly, the test administrator interventions were integrated to the scoring system in order to indicate the degree of dependence in the task performance. Finally, the scoring system had to reflect the level of the support provided to subjects. Indeed, the test administrator's interventions depended on the subjects needs. The level of assistance is an indicator of the type of difficulties

Fig. 1. The global scoring scale

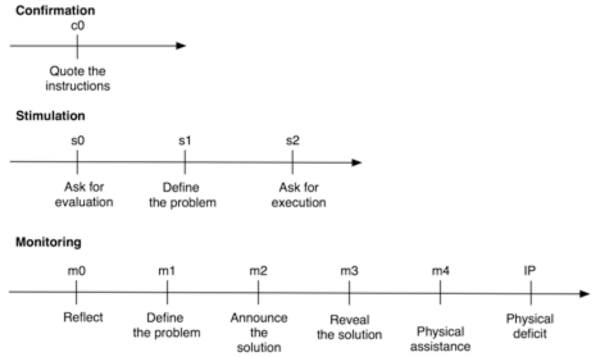

Fig. 2. The different assistance levels

encountered.

The scoring scale – inspired from the scale of *le profil des AVQ* [9] – includes six different stages (Fig. 1). The different assistance levels are detailed for each type of intervention (Fig. 2). The specification of these assistance levels is based on the definition of executive processes: being able to evaluate the results of an action, bringing some elements for the solution, elaborating a solution, etc.

The different stages of the scoring scale indicate the success or failure of the task and the nature of the assistance provided to the subject. The particular methodology used for this study requires us to take into account the nature of the interventions. Indeed, the introduction of disruptions influenced the behaviour of subjects. Some of them did not react to disruptions and needed cues to understand what they were expected to do in the context of the experiment. In those cases, the test administrator repeated the instructions (confirmation) or urged the subject to react (stimulation) in front of a disruption. This kind of intervention has to be differentiated from intervention when some real executive difficulties occur. It must be interpreted as a support linked to experimental conditions.

The first five stages of the scoring scale (Fig. 1) consider the task successfully completed: the subject completed every essential step.

For the first stage (score 0), the subject is independent and does not need any intervention from the test administrator.

For the second stage (score 0.5), the subject inquires the test administrator for a confirmation or authorisation to use some tools or objects in the experimental environment. The test administrator can quote the instructions (c0, Fig. 2).

For the third stage (score 1), the subject needs solicitation from the test administrator to complete some steps of the task. As we explained previously, this support is due to the introduction of disruptions in the experiment. It is the case when, for example, the subject verbalizes his intentions but does not act. To support the subject, the test administrator can ask him if he is satisfied of his realization (s0, Fig. 2), guide him toward the disruption (s1, Fig.2) or command him to execute his intentions (s2, Fig. 2)

The fourth and fifth stages (score 2 and 3) indicate that monitoring support is required to confront executive difficulties. For example, the subject fails to notice a mistake or he shows some difficulties to elaborate a strategy that fits specific circumstances. This kind of support has to be precisely specified to avoid an inaccurate observation of executive mechanisms and their impairment. The assistance must be gradual. First, the test administrator can rephrase the subject words (m0, Fig. 2). Then he can help the subject to define the problem (m1, Fig. 2), give him some solution clues (m2, Fig. 2), and then offer a solution (m3, Fig. 2). Finally, he can physically assist the subject to execute an action. The support provided to overcome physical difficulties is differentiated from support for executive difficulties (IP, figure 2). For example, the test administrator can read out loud a text that a subject is not able to read without magnifying glasses.

The last stage (score 4) concerns the failure of the task. The subject did not complete all the required steps despite the test administrator's assistance.

D. Errors categorization

The errors committed during the performance of the task are classified according to their relevance in terms of executive mechanisms. Category A errors reflect executive difficulties: planning, monitoring, or final evaluation disorders, etc. These difficulties can affect the performance of the task and require monitoring assistance from the test administrator. For example, the subject writes down his own address instead of that of the cultural centre, or he/she stops the task execution without posting the letter.

The other errors deal with disruptions introduction, inattention problems, or immediately corrected mistakes.

III. RESULTS

We present in this section the results of the task performance. We use the term *cognitive impairment*, respectively represented by young adults subjects (no impairment), healthy elderly subjects (impairment due to aging) and MCI-AD subjects (impairment due to illness). Mean scores obtained for each group of subjects are summarized in Table 1.

Table 1. Experiment results

	Young	**Elderly**	**MCI-MA**
Subjects number	12	11	7
Age	23,5 (2,97)	76,64 (6,9)	76,57 (4,54)
MMS	29,42 (1)	28,73 (1,1)	27,14 (2,41)
Score	0,63 (0,43)	1,77 (0,82)	2,29 (0,76)
Performance time	10:56 (00:57)	18:45 (08:19)	23:15 (08:33)
Cues number	1,75 (1,54)	4 (2,65)	8,89 (5,15)
Errors	1,25 (1,14)	3,27 (2,65)	4,29 (2,06)
Category A errors	0 (0)	0,55 (0,82)	2 (1,15)
Planning (sub-task)			
Strategies elaborated alone	2 (0,95)	1,55 (0,82)	1 (0,82)
Strategies elaborated with help	0 (0)	0,36 (0,50)	1 (1,15)

For the statistical analysis, we checked first that there was no difference in terms of gender. The results of the three groups of subjects were compared using ANOVAs (F) when normal distribution and variance homogeneity conditions were verified, and using Kruskal-Wallis (H) test – non-parametrical – in other cases.

The statistical analysis shows that the global score is clearly related to the cognitive impairment. There is significant difference between the three groups of subjects [$H=16{,}032$; $ddl=2$; $p=0{,}000$]. Fig. 3 illustrates the quasilinear evolution of the score according to the different groups of subjects. In other words, the task performance score increases as the cognitive impairment worsens.

Fig. 4 presents the distribution of scores obtained for each group of subjects. Young subjects scores vary from 0 (independent) to 1 (success with stimulation), with a mean

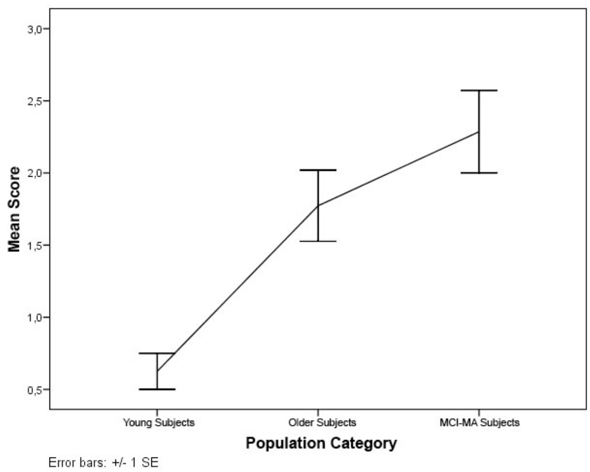

Fig. 3. Evolution of the task performance score according to cognitive impairment

score of 0,63 (s.d.: 0,43). Older subjects scores vary from 0.5 (success with confirmation) to 3 (success with monitoring and time exceeded); mean score: 1,77 (s.d.: 0,82). Finally, MCI-AD subjects scores vary from 1 (success with stimulation) to 3 (success with monitoring and time exceeded). They obtain a mean score of 2,29 (s.d.: 0,76). None of the subjects, from any group, fail to perform the task. As global scores reflect cognitive impairment, the number of test administrator interventions and their nature are significantly distinct for each group of subjects (for the total number of cues provided: H=11,352; ddl=2; p= 0,003). Fig. 5 illustrates the distribution of the different assistance levels provided to each group of subjects. Young subjects complete the task with a mean number of 1,75 interventions (s.d.: 1,54) from the test administrator. Most cues are confirmations or solicitations. Solicitation interventions are mostly demand of execution (solicitation s2), which reflect the lack of difficulties to find solution to encountered problems.

Elderly subjects complete the task with a mean number of 4 interventions (s.d.: 2,65) from the test administrator. These subjects require every level of assistance, from confirmation, to solicitation and monitoring. They need help to define the problem (s1 solicitation, m1 monitoring), to execute the solution they elaborated (s2 solicitation) and to identify the necessary elements for the resolution of the encountered problem (m2 monitoring). Finally, the test administrator has to be more present for MCI-AD subjects who complete the task with a mean number of 8,89 cues (s.d.: 5,15). They require much more support than the two other groups of subjects. Like elderly subjects, they require every assistance level (confirmation, solicitation and monitoring). They need help to define the problem (s1 solicitation, m1 monitoring), to identify the elements necessary for the resolution of the encountered problem (m2 monitoring) and above all they need the solution (m3 monitoring). The lack of execution demand (s2 solicitation) is due to the fact that subjects are unable to find adapted solutions. Despite the test administrator's solicitation, subjects have difficulties to work out a solution. The test administrator switches to monitoring support to help the subject to elaborate an appropriate way to solve the problem.

The total number of errors committed during the task performance is significantly different between the three groups of subjects [$F(2,27)=5,707$; $p=0,009$]. Category A errors, which denote executive errors, are significantly related to cognitive impairment [$H=15,657$; ddl=2; $p<0,001$]. The total number of errors increases with cognitive impairment and follows a linear evolution [$Flin(1,27)=10,988$; $p=0,003$ and $Fdev(1,27)=0,425$; $p=0,520$].

Young subjects make a mean number of 1,25 (s.d.: 1,14) errors during the task performance. However they do not commit Category A errors. For elderly subjects, the mean number of errors is 3,27 (s.d.: 2,65), of which 0,55 (s.d.: 0,82) are Category A errors. Finally, MCI-AD subjects commit a mean of 4,29 (s.d: 2,06) errors, whereof 2 (s.d.: 1,15) are category A. According to the graph presented in Fig. 6, the evolution of the cues number and the evolution of the total number of errors are correlated.

Cognitive impairment influence the duration of task performance. Indeed, the difference between the three groups of subjects is significant [$F(2,27)=7,735$; $p=0,002$]. Performance duration follows a linear evolution [$Flin(1,27)=15,082$; $p=0,001$ and $Fdev(1,27)=0,389$; $p=0,538$]. Fig. 7 illustrates this evolution. In other words, performance duration increases as cognitive impairment worsens.

Finally, cognitive impairment influences the subjects' planning abilities for the «find an information» sub-task. The mean number of strategies elaborated autonomously decreases whereas the mean number of strategies elaborated thanks to the examiner assistance increases

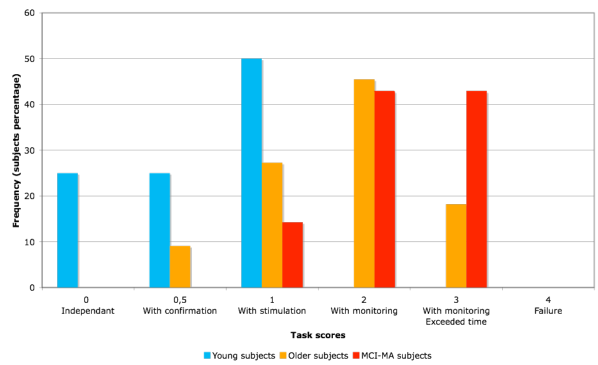

Fig. 4. Distribution of scores obtained for the task performance

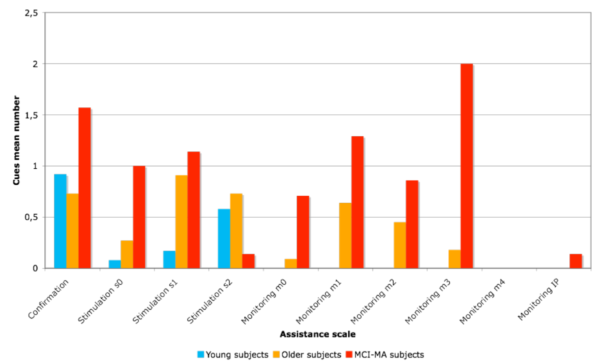

Fig. 5. Nature of interventions during the task performance

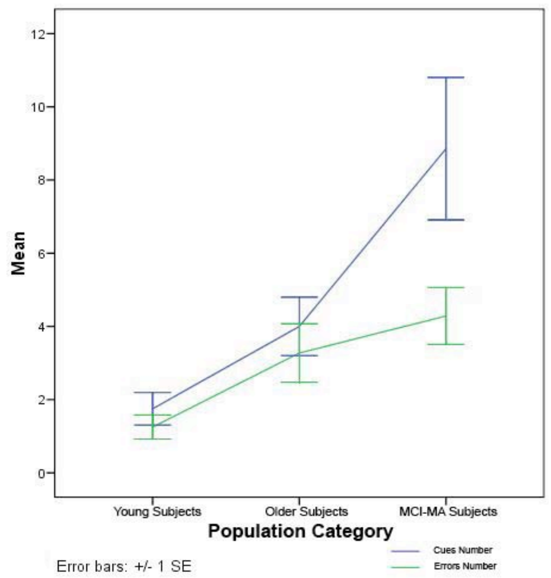

Fig. 6. Evolution of cues and errors numbers according to cognitive impairment

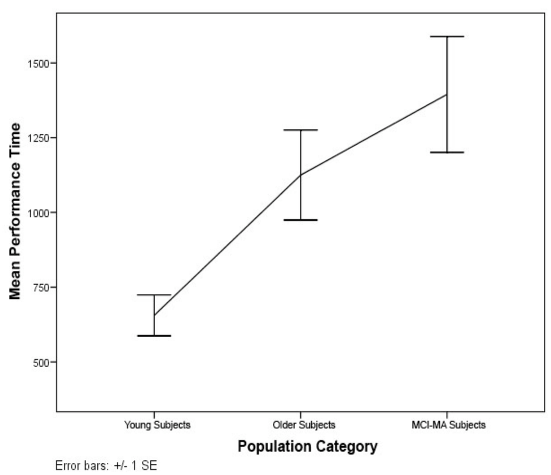

Fig. 7. Evolution of performance time according to cognitive impairment

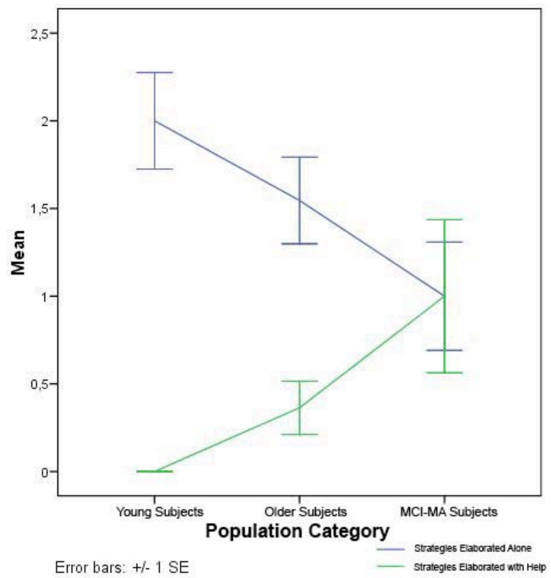

Fig. 8. Evolution of planning abilities according to cognitive impairment

significantly with cognitive impairment [H=8,417; ddl=2 ; p=0,015]. None of the young subjects needed assistance for the strategies generation phase. They elaborate a mean of 2 (s.d.: 0,95) strategies to find the address. Elderly subjects elaborate a mean of 1,55 (s.d.: 0,82) strategies on their own and 0,36 (s.d.: 0,5) strategies with the test administrator support. MCI-AD subjects elaborate a mean of 1 (s.d.: 0,82) strategy on their own and 1 (s.d.: 1,15) strategy with the examiner support.

IV. Discussion

The results we previously presented show a significant difference in the task performance between the three groups of subjects. Young subjects are autonomous or only need confirmation or solicitation from the test administrator. This kind of support is due to the introduction of disruptions in the experiment and is not significant of executive problems. Young subjects have adapted behavior when disruptions occur. The mean number of s2 solicitation (in comparison to s0 and s1) show that subjects are able to elaborate solutions to confront a specific problem. These observations are confirmed by the results obtained in planning: subjects elaborate, without assistance, different strategies to get the information. These subjects make few errors during the task performance. The committed errors never reflect executive problems (category A errors). Most of the time, subjects correct spontaneously the errors (except for inattention errors). On the contrary, some executive difficulties appear during task performance for elderly and MCI-AD subjects. Many of them require monitoring support to complete the task successfully. Even with assistance, some of them, and especially MCI-AD subjects, need a longer time to perform the task. These subjects poorly react to the introduction of disruptions and require support to adapt their behavior to unexpected situations. They need help to define the problem, to bring into light some key elements to finding a solution. Some MCI-AD subjects need to be given the solution. They require assistance to elaborate different strategies to get the information. Finally, these subjects commit more errors and fail in correcting them. Errors reflecting executive problems appear in the task performance. The mean number of category A errors is more important for MCI-AD patients. To summarize, the task and the scoring system presented in this study allow to underline the impairment of executive processes, which confirms cognitive impairment. First, people who do not suffer from cognitive impairment do not have executive difficulties (young subjects). On the contrary, people who suffer from cognitive impairment (elderly and MCI-AD subjects) display some executive difficulties. Secondly, we observe a deterioration of performance in terms of executive processes along with the cognitive impairment. Subjects lose autonomy as cognitive impairment worsens. We observe the increase of : performance duration, global score obtained, number of cues required to complete the task successfully and number of errors committed, especially those which are linked to executive disorders. In parallel, we observe a fall of the subjects' autonomy in planning.

This study provides relevant information on the subjects' abilities in terms of executive processes. Planning, adaptation to unexpected situations and self-correcting mechanisms are evaluated. Considering the assessments used in occupational therapy, the advantage of this study is the detailed specification of assistance levels, especially for monitoring support. This contribution can turn out to be useful for assistive devices in the context of smart homes.

Smart homes are designed to enhance the safety and the comfort of elders or people loosing their autonomy [11]. These objectives regroup various research fields, such as telemonitoring, domotic or cognitive assistance [17][18]. The latter is aimed to overcome patients' cognitive disorders in order to help them to recovering certain autonomy at home. Based on the ubiquitous computing paradigm, an apartment can be upgraded using technological devices (smart sensors, localization tags, interactive screens, interactive objects, etc.). Thanks to those devices (also called *gerontechnology*), intelligent systems can not only gather information on the subject's activities but also communicate with him or her. Ubiquitous computing takes advantage of numerical technologies in order to replace interfaces estimated too complex and not convenient enough for elderly or handicapped people, with "intelligent" environments able to interact with these people. In order to be as little invasive as possible, assistive devices must provide support only when required. In addition, this support has to be adequate to the specific situation and to the resident's cognitive handicap. To do so, assistive devices have to integrate knowledge about people's cognitive and executive disorders. The information provided by this study may be useful to document the loss of autonomy. Moreover the different levels of assistance presented in the scoring system may be used to regulate the intervention of the system in order to be efficient and not too invasive.

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