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How to Maximize the Effectiveness of Prompts in Assistive Technologies According to the Particular Cognitive Profile of People with Alzheimer's Disease?

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Abstract

Assistive technologies represent a potential solution to allow people with Alzheimer's disease (AD) to remain in their home for as long as possible. They involve the use of technological devices called prompts, which aim to provide adapted cognitive assistance when needed. However, a literature review of the field revealed a predominant use of verbal prompts with little knowledge of their real effectiveness. In order to help adapting assistive technologies to the particular cognitive profile of people with AD, this paper proposes comprehensive guidelines. First, we identify the main deficits of AD that influence the effectiveness of prompts. Second, we detail which prompting strategy to use accordingly. Third, we propose an experimental protocol based on a well-known test, and new prompting software, which allows for the validation of the proposed guidelines. Finally, we present the preliminary results of a first experiment conducted in our laboratory with participants ranging from mild to moderate AD. This paper is a revised and expanded version of a paper entitled Smart Homes for People with Alzheimer's Disease: Adapting Prompting Strategies to the Patient's Cognitive Profile presented at the 5th International Conference on Pervasive Technologies Related to Assistive Environments (PETRA 2012).

Keywords*: Smart Homes, Alzheimer's disease, Prompts, Efficiency, Guidelines*

1. Introduction

1.1. Alzheimer's Disease

The number of seniors worldwide has been increasing over the past years and will go on in the future, faster than ever. This phenomenon is due to medical findings, technological developments and social and environmental conditions. Since age is the main risk factor in the apparition of dementia, it is fair to say that the number of cases of this cognitive impairment will increase in the aging population [1]. In 2010, the number of people with dementia in the world was estimated at 35,6 millions, and this number will double by 2030. By 2050, it is estimated that 115,4 millions of people will live with it [2]. The main cause of dementia is Alzheimer's disease (AD) [3], which can be defined as a neurodegenerative illness characterized by a progressive and irreversible decline in cognition. The cognitive deficits most commonly associated with AD are memory impairments, aphasia, agnosia, apraxia and executive dysfunctions [4]. These deficits lead to a need for assistance in performing activities of daily living (ADL) [5]. ADL can be instrumental (e.g., cooking, driving, handling personal

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finances) or basic (*e.g.*, eating, dressing, bathing) and the capacity to complete instrumental ADL decreases in the early stages of AD. In the middle phase of AD progression, some deterioration in basic ADL occurs, as well as a bigger loss of instrumental ADL. As the disease gets worse, patients lose more and more skills and become more dependent of caregivers. This has an impact on patients, because the loss of autonomy can lead to frustration, apathy or depression, but it also has an impact on caregivers, for whom the physical, financial and social burdens increase [6]. These factors often make patients move in institutions, even if most of them wish to stay home for as long as possible [1]. Since the cost associated with AD is very high [7] and the resources are lacking (*e.g.*, medical staff), governments want to extend the time people with AD can remain in their houses.

1.2. Assistive Technologies

1.2.1. Good Hopes: In recent decades, technology has played an increasing role in the rehabilitation of persons with cognitive impairments [8] including those with dementia [9]. Indeed, researchers and clinicians have introduced computers and advanced technologies in clinical interventions for people with various cognitive and neuropsychological disorders. These technological interventions are also called “assistive technologies”, “cognitive prostheses” and “cognitive orthosis” [8]. They are defined as any system based on computers that helps the individual to perform any task related to his/her ADL [10]. Moreover, they are directed at the functional abilities (*i.e.*, those that were not affected by the disorder) of the user and they support his abilities that have been affected by illness, accident or aging, which increases his/her capacity to function effectively. Therefore, they provide a compensatory strategy when added to the environment of the person [11]. In this paper, the term “assistive technologies” (AT) will be used to represent these technological interventions (including cognitive prostheses and orthosis) for the purpose of concision.

The use of innovative assistive technology offers many exciting opportunities for better care and improving quality of life of people with AD and their families [12]. In a study by Lancioni and al. [13], the improvement in the performance achieved by participants using an assistive technology seemed to counter the growing failure in the realization of their activities, the frustration and withdrawal. Thus, it seemed to promote self-determination, vigilance and social image of the person. This achievement also seemed to provide the family and caregivers some respite, a more positive image of the person that they are caring for, the possibility of improving their emotional ties with that person, new positive expectations and the motivation to extend the intervention to other ADL [14, 15]. In another study by Kinney *et al.*, [16], the family members of the person who has been using an assistive technology said they noticed the following positive effects: 1) peace of mind; 2) more compassion and 3) more free time. This type oftechnology could also help minimizing the need of support from professional services and caregivers, reducing the stress of caregivers and the cost of care. Moreover, it could help people with dementia to live a better, safer and more accomplished life. Therefore, assistive technologies offer good hopes for the future [12].

1.2.2. Prompts in Assistive Technologies: Assistive technologies such as smart homes [17] constitute a potential solution [9, 18] to allow people with AD to remain in their house [19, 20]. Smart homes are built according to techniques of artificial intelligence (AI) [17] (*e.g.*, algorithms) to proceed further as a human in his/her decision making and planning [21]. In order to do so, they contain technological devices to capture the actions of the residents (sensors) and to provide them punctual assistance when needed (prompts). Prompts in smart homes are hints, suggestions and reminders to help the resident to complete a task. There are three main categories of prompts: auditory, visual and video. **Auditory prompts** can be verbal (*e.g.*, instructions, feedback, questions), sound (*e.g.*, alerts, reminders) or music (with or without lyrics). They require the use of equipment such as speakers, portable audio devices, headphones and handheld systems. **Visual prompts** may be photographic (*e.g.*, colors, shapes, images, pictures), textual (*e.g.*, keywords, sentences, textual descriptions) or light (variations of the intensity, color, blinking and direction) and require the use of projectors, screens, computers, handheld systems, light bulbs or laser pen. **Video prompts** are pictorial (*i.e.*, an auditory prompt and a visual prompt together) or modeling (*i.e.*, video of a person performing a task with an auditory prompt) and require the use of the same equipment as the auditory and visual prompts [22]. In this paper, video prompts will be classified in both auditory and visual prompts because they combine an auditory and a visual part. Sound and music (without lyrics) prompts are not enough explicit to be used as guidance compared to light prompts, which are not explicit but can clearly indicate the object to use. However, they can be useful to attract the attention of the person before sending the guidance.

1.2.3. Current Assistive Prompting: Assistive prompting with technological devices is a widely exploited strategy in research on smart environments and several papers are an exhaustive review of this field [see 8, 12]. A well-known example of an assistive prompting strategy is the COACH (Cognitive Orthosis for Assisting aCtivities in the Home by Mihailidis, Barbenel and Fernie, [23]) system, which uses pre-recorded automated verbal prompts in order to help people with moderate to severe dementia in washing their hands. This system was tested and results showed an increase in the autonomy of participants (*i.e.*, they have completed more steps of the task and they had less interactions with the caregiver). However, participants did not pay attention to more than half of the prompts that were sent. Following that, Labelle and Mihailidis [9] corrected the issue by creating a new version of this prototype to test verbal and audiovisual prompts with the same type of participants (*i.e.*, moderate to severe dementia patients) and for the same task (*i.e.*, hand washing). The results are similar to those of the first study (*i.e.*, participants completed more steps of the task with less interactions with the caregiver) but the audiovisual prompt seems to have been a little bit more effective than the visual one. This study is important because it raises the question of adapting prompts to the type of user.

Several assistive technologies use verbal prompts [20] and a deep research revealed a predominant use of this kind of prompts in assistive technologies for people with AD (*e.g.*, [23, 14]). The lack of knowledge about the real effectiveness of these prompts significantly affects their efficiency by providing cues that are not adapted to the user's profile [22]. For example, verbal prompts may be less effective for a person with Wernicke's aphasia (which is a disorder of language comprehension) because s/he cannot understand it. Customization of assistive technologies must consider several factors that influence their effectiveness, choice and acceptance by the user: 1) physical environment; 2) nature (*e.g.*, instructions against reinforcement, auditory against visual), speed, time and synchronization of prompts [9]; 3) attitude of this user against the technological intervention; 4) strengths and weaknesses, deficit and remaining abilities, priorities, needs, and preferences of the user [8] and 5) characteristics of the task (*e.g.*, familiarity, habits of the person regarding its completion) [20]. The failure to consider either of these factors can lead to an ineffective intervention or to the resignation of it, even if it has been proven to be effective in a controlled environment [8]. The principles of context-aware design can be applied to the design of assistive technologies so that they should be suitable for people with dementia. One of these principles states that personal information of the user (*i.e.*, his profile) (*e.g.*, type of dementia, severity level, physical and cognitive deficits) is an important part of the context that must be considered to customize assistive technologies. To provide a help that is appropriate to a person with AD, it is also important to consider that each patient presents a different profile within the usual symptomatology (*i.e.*, some spheres being more affected than others) that cannot benefit from an approach "one-size-fits-all" [20]. Since there is little knowledge about the clinical characteristics of the person with cognitive impairment against the effectiveness of cognitive assistive technologies [8], our team has addressed the issue. Specifically, we focused on the effectiveness of prompts according to the cognitive profiles of patients with AD.

1.2.4. Our Contribution: In order to contribute in solving this important issue, we propose, in this paper, comprehensive guidelines to help smart homes researchers maximizing the prompting efficiency by personalizing prompts according to the specific cognitive profiles of the patients with AD. Our multidisciplinary contribution takes several forms. First, we identify the main deficits of AD that influence the effectiveness of each specific prompt (see Table 1). Secondly, we present a set of comprehensive guidelines (see Figure 1), which were defined by combining the knowledge and experimental results gathered from many paradigms (*e.g.*, psychology, computer science, medicine, education). We then detail which form of prompts to use according to each particular cognitive trouble and explain why. We illustrate these guidelines by schematizing them into a decision tree, which is a flexible tool that can directly be implemented into an algorithm. Its use is therefore easier for computer scientists and engineers. Thirdly, we propose an experimental protocol, based on a well-known test, as well as a recently developed prompting software that we created in order to be able to validate the proposed guidelines. Finally, we present the preliminary results of a first experiment, conducted with participants with mild to moderate AD, where we tested three different forms of prompts.

2. Guidelines to Personalize Prompts According to the Specific Deficits of AD

Alzheimer's disease (AD) is characterized by a progressive and irreversible decline in cognition. The first cognitive symptom to appear is often memory loss, which gradually increases over years before other cognitive impairments occur [24]. As the disease progresses, long-term memory can stay quite intact, while short-term memory is more affected [11]. People with AD may, for example, have difficulties to learn new things and most of the time, in the early stages of the disease, patients tend to forget recent events, while the old ones are preserved. But memory is not the only instrumental function that is altered in AD. Language (aphasia), recognition (agnosia) and movements (apraxia) are also affected [4]. Aphasia is a deficit in production or comprehension of spoken or written language [25]. A person with AD suffering from aphasia could have difficulties to understand what is the meaning of some words s/he used to know, or have an incoherent speaking. Agnosia is a deficit in recognition that can't be due to a sensory deficit or a verbal or intellectual failure, which means that agnosic patients correctly perceive the visual or auditory stimuli but do not recognize them. Apraxic people have difficulties doing certain types of movements on command, particularly when those movements are out of context, because apraxia is a deficit in voluntary motor that isn't due to a paralysis, a motor weakness, a lack of motivation or a problem of understanding [26]. It makes the patient unable to remember the sequence of movements required to achieve his task. Most of the time, people with AD have all these cognitive disorders, at some different levels. However, instrumental functions are not the only ones to be altered in AD; executive functions are too. Executive functions generally include cognitive skills that are responsible for the planification, the organization and the synchronization of complex actions such as reasoning, problem-solving, self-monitoring, sequencing of task, prioritization and cognitive flexibility. All of them can be affected by AD. To be diagnosed as suffering from Alzheimer's disease, a person must have memory impairments plus one or more of the cognitive problems named above. Moreover, the symptoms must not be due to other diseases of central nervous system, to general conditions that can cause dementia, to infections caused by a substance or to a delirium [4]. Even if a person meets those criterions, a diagnostic should be established only if the cognitive impairments cause problems in social and occupational functioning of the person.

Normal aging comes along with a progressive loss of a lot of capacities. With time, sensory abilities inevitably decline and elderly may have problems with, for example, hearing and sight. Since the majority of people with AD are elders, because age is the main risk factor [1], sensory problems must be considered although they're not caused by AD, because they affect sensory modalities that are widely used while carrying out everyday tasks. These sensory deficits can significantly affect the efficiency of the prompts that are mainly presented in auditory modality (auditory and video prompts) and visual modality (visual and video prompts). In the literature, there is very few information about sensory modalities such as smell, touch or taste and their effectiveness on prompts, probably because those senses are less used in performing the activities of daily living (ADL). Although other types of prompts exist (such as olfactive, tactile, *etc*.), we will concentrate our paper on auditory and visual prompts (and deficits affecting them) because they are more commonly available in smart environments. Deficits that we will consider in this paper are memory impairments, aphasia, agnosia, apraxia, as well as deficits in executive functions and sensory disorders. We will elaborate more on these deficits in the coming paragraphs. Here is a table (see Table 1) based on the interpretation of data found in the literature and summarizing these deficits and the part of the prompt they affect.

Table 1. Deficits and the Part of Prompt they Affect

Deficits	**Part of prompt affected**	
	Auditory	**Visual**
Memory disorders	Depends on how the prompt is used	
Comprehensive aphasia	Spoken language	Writing
Agnosia (visual or auditory)	Verbal or non-verbal sounds	Writing or objects
Apraxia	Depends on how the prompt is used	
Executive functions	Depends on how the prompt is used	
Sensory problems (visual or hearing)	All types of sounds	All types of images

All these deficits affect the effectiveness of prompts in one way or another. The following figure (see Figure 1) represents a visual synthesis of the prompts that are effective for each of the specific deficits named above. It was obtained by combining knowledge and experimental data from literature with our own experimental results (see validation section). It can be used in part or in whole, depending of the scope of the assistive system we want to design. These guidelines will help smart homes researchers to personalize prompts, according to the specific deficits of the people with AD. This is an innovation in the field of prompts and Alzheimer's disease. Indeed, it opens up new horizons for this area of research. In the next paragraphs, we will detail in order each branch of the guidelines tree stated on Figure 1.

2.1. Memory Impairments

Memory impairments are probably the most well known symptom in Alzheimer's disease [1] and they occur in the very early stages of it [27]. At those early stages, a person could get lost, experience trouble in manipulating money and handling personal finances, repeat questions or act more slowly while performing everyday tasks. More generally, memory impairments affect general knowledge (semantic memory) and events experienced personally (episodic memory). Semantic memory refers to a component of the long-term memory and includes, among other things, general knowledge of concepts, facts and words' meaning. A person experiencing deficits in semantic memory could therefore forget the meaning of the word "spoon". If the person is trying to make a coffee and receive a verbal prompt telling her to mix with the spoon, s/he won't be able to do it even if s/he understands the instructions, because s/he won't know what a spoon is. In that sense, in a smart environment, verbal and music (with lyrics) prompts would be less useful for people with a deficit of semantic memory [28]. Of course, textual prompts lead to the same problem, because even if the word is read instead of being heard, it is still not understood by the person who forgot its meaning. However, these prompts could be effective if they included descriptions of the object forgotten, instead of the word itself. Light prompts could be effective because they allow pointing an object [28]. Photographic prompts may also be effective, as well as pictorial video prompts, since images facilitate access to semantic memory [29]. A modeling video prompt would be effective too, because it could show the person how to use the needed object. On the other hand, understanding video prompts may be an additional charge in memory [5, 30] leading us to say that there is a need for more research on them.

As soon as the long-term memory is affected by AD, deficits in episodic memory, another component of long-term memory, occur. In fact, episodic memory impairments are probably the earliest symptom in AD [31]. Episodic memory (verbal or non verbal) contains specific information about concrete experiences that we have lived, in particular places at particular times. It is also in this memory that we can find memories about the order in which things happened. Consequently, episodic memory is also known as autobiographic memory. Deficits in this memory would be related in a large part to the inability to consolidate or store new information. Thus, people with AD have difficulty to learn and remember new information [31]. They can also forget what they were doing, which leads to the inability to finish the task they have begun. Of course, people who experience deficits in episodic memory may benefit from prompts provided by a smart home. When the verbal part of the episodic memory is altered, to be more effective, auditory or visual prompts should not refer to language. Therefore, it would probably be better to use sound and music without lyrics, photographic, light or modeling video prompts as guidance, in order to get the person's attention. Pictorial video prompts would be less useful because the patient would ignore their auditory part and the visual part is already done by the photographic prompt. In contrast, if non verbal memory is affected, it would be better to use a prompt that refers to language (verbal, music with lyrics or textual). Otherwise, encoding disorders and impairments in working memory are very present in the symptomatology of AD. Indeed, people with AD have difficulties to maintain short-term information and this issue gets worse when they are asked to maintain it while doing a distractive activity [32]. In a smart environment, prompts will therefore be more efficient if they are short, clear and concise (*e.g.*, "pour the milk in the glass" instead of "now, it would be appropriate to pour the milk in the glass that is in front of you"), because the longer they are, the more a person with AD may forget the beginning before reaching the end. Prompts should also refer to short and precise steps, because if the step to do is too long or too global (*e.g.*, a prompt telling "do the laundry" is too global), the person may forget what s/he has to do while s/he's doing it. This type of guidance can be accomplished by all prompts stated on Figure 1.

2.2. Aphasia

Aphasia is commonly seen as a symptom of Alzheimer's disease (AD). We can say that a person has that symptom when s/he has difficulties to produce or understand spoken language or written language (agraphia and alexia), even if s/he hears and sees correctly through intact organs. Nearly all of patients with AD have language problems. A mild deficit in language is observed in the early stages of the disease and the presence of a severe deficit would indicate that the disease has reached an advanced stage. In the literature, aphasia is more commonly studied as a symptom related to a brain lesion and its expression depends on the place where the lesion is located. There are three main types of aphasia: expressive aphasia (Broca's), conduction aphasia (associative aphasia) and receptive aphasia (Wernicke's). Generally, patients with AD show a mix of expression and comprehension (receptive) impairments [33]. Expressive aphasia mainly concerns the expression of language, with a normal comprehension of spoken or written language. People may have a language production that is meaningful but slow, laborious and poorly articulated. Also, they can have difficulty to find the word they are searching for. This word finding difficulty is a common symptom in AD and occurs in the very early stages of the disease. Conduction aphasia is caused by a disconnection between Broca's and Wernicke's areas and is characterized by a good comprehension of spoken and written language, but a difficulty to repeat instantly the words heard or to self repeat verbal instructions. Given that these types of aphasia do not affect the effectiveness of prompts used in a smart environment, they won't be detailed in this paper. Receptive aphasia (Wernicke's) is characterized by a bad understanding of the spoken language (with/out verbal deafness) and/or by alexia (difficulties in comprehension of written language). The latter may affect the efficiency of a prompt using language, which the person would not understand correctly. Verbal and musical (with lyrics) prompts would therefore be less effective for a person with receptive aphasia of spoken language because the person can't understand the words used to help her/him remembering the steps of a task. Modeling video prompts may be effective, but mostly because of the visual part. However, the pictorial video prompt would be useless because the patient would ignore its auditory part and its visual part is already done by the photographic prompt. As the patient has difficulties to understand spoken language, it is very important that the prompts do not only refer to spoken language (see Figure 1). Likewise, if the person has problems to understand written language (alexia), a textual prompt would be less appropriate. However, pictorial video prompts can be used if the pictorial part of the prompt is not textual.

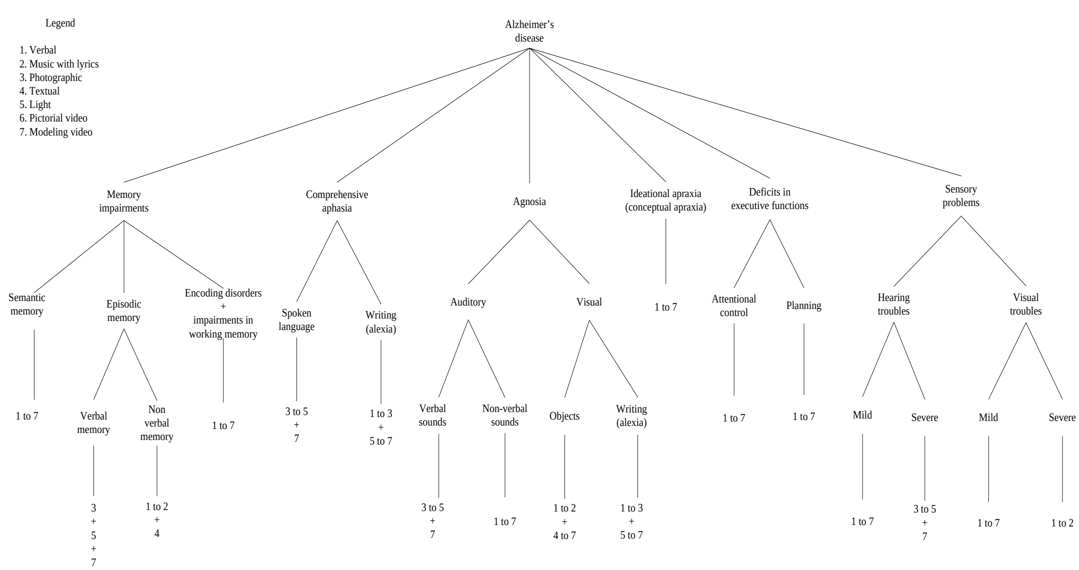

Figure 1. Prompts that are Effective for each of the Specific Deficit

2.3. Agnosia

Agnosia is a deficit of recognition that cannot be due to a sensory deficit or to a verbal or intellectual failure. An agnosic patient would perceive stimuli but would not recognize them. There are several types of agnosia, but the most documented are auditory and visual agnosias. Auditory agnosia is a "defective recognition of non-verbal sounds and noises" [34]. However, the typical patient is also unable to understand spoken language, to repeat spoken words and to write from dictation, not because s/he does not understand language, as in Wernicke's aphasia, but because s/he simply does not recognize the sounds s/he hears. Agnosia of verbal sounds is also known as *verbal deafness* in literature. Therefore, auditory agnosic people are often mistaken with deaf people, while aphasic people look like they are confused [34]. Auditory agnosia prevents people from distinguishing sounds from each other, and they tend to forget what is the meaning of the sound they hear. For example, a patient with AD suffering from auditory agnosia may have difficulties to distinguish an alarm sound from a phone ring tone, and could not say what the phone ring tone means. This kind of deficit can be very dangerous for the safety of the person with AD living alone, and can also be one more obstacle in the accomplishing of the ADL. In that sense, the use of prompts through the smart home may be very helpful if the symptoms of auditory agnosia are considered. Indeed, all prompts using sounds (verbal or non-verbal) should be avoided, because chances are the person does not recognize them. However, if the person has an agnosia of verbal sounds only, verbal and music with lyrics prompts would be less effective. Pictorial video prompts would be less useful too, because the patient would ignore their auditory part and their visual part is already done by the photographic prompt. As for the modeling video prompt, it would definitely be useful because it is dynamic: it shows the person "how to do". However, the patient would ignore its auditory part. If the person has an agnosia of sounds and noises but recognizes the verbal sounds, we can use the verbal and the music with lyrics prompts. Other prompts (photographic, textual, light, pictorial video or modeling video) can be effective (see Figure 1).

Visual agnosia is a specific agnosia of visual stimuli. People with visual agnosia see the visual stimuli, but do not figure out what they represent. Visual agnosias are specific to the particular aspect they affect; we can distinguish, for example, movement agnosia (in which case modeling video prompts would be less effective, because the person has difficulties to perceive visual motion), objects agnosia, color agnosia (in which case prompts based on colors would be less effective) and prosopagnosia (inability to recognize human faces). In general, the term "visual agnosia" without more precision refers to objects agnosia. This type of agnosia is, in the literature, often divided in two: aperceptive agnosia and associative agnosia. Patients with aperceptive agnosia have difficulties to see an object as a whole or in a meaningful way and cannot match, copy, discriminate or categorize drawings, pictures or objects. The typical patient with associative agnosia is unable to name an object or the image of an object that is shown to him/her, and makes semantic errors [35]. Nonetheless, if the verbal definition is presented to the patient with aperceptive or associative agnosia (*e.g.*, a cutting implement consisting of two blades joined by a swivel pin that allows the cutting edges to be opened and closed, for the object "scissors"), s/he will often be able to name it. Also, the patient is able to use the word "scissors" in his/her spontaneous speech, thus proving that s/he is aware of the existence of this object. The problem occurs when we specifically ask the person to name the object we show her/him, or the picture of it. Visual agnosia can also concern writing; indeed, a person with this trouble (known as *alexia*) would not be able to recognize the word "scissors" if written on a paper, in the same conditions as if it was a picture of the object. These two types of visual agnosias (writing and objects) often coexist. However, for practical purposes, we consider them in their pure form, individually. According to this information, we conclude that verbal prompts should be effective for both types of visual agnosias (objects (aperceptive and associative) and writing), since these prompts do not concern visually perceived stimuli. Music with lyrics prompts would be effective too. With a person having troubles in objects recognition (not writing), photographic prompts with objects (pictures or images) would be less useful. Indeed, s/he would not recognize the stimuli and would not know what to do with this information, unless the image shows how to use the object, which could give enough information to the person to remember what it is. This type of guidance would be easier with modeling video prompts. Photographic prompts could consist in colors or shapes but this type of guidance is not explanatory enough. Textual and light prompts would be effective. Pictorial video prompts could be effective if the images are not objects (they could be colors, shapes or words). It can also be effective if it shows objects, but images would have to be more explanatory and show, for example, how the object is supposed to be used. This can be accomplished with a sequence of pictures presented one beside the other. What is important for this kind of patients is that the prompts have to be more explanatory. A person with a visual agnosia that concerns writing could be less helped by textual prompts, because they would not recognize the words. Pictorial video prompts can be effective with these patients if the visual part is not a textual one. Finally, what is important is that the prompt does not only refer to writing (see Figure 1).

2.4. Apraxia

In the literature, it is possible to distinguish three main types of apraxia: ideomotor apraxia, limb kinetic apraxia and ideational apraxia, sometimes called conceptual apraxia. Ideomotor apraxia is observed when a person makes spatiotemporal mistakes in his/her movements and when his/her gestures are posed inappropriately (too fast or too slow, in the wrong direction, with a reduced amplitude). Limb kinetic apraxia manifests by a fine manipulation that is slow and clumsy, even if the knowledge of the appropriate action is preserved. Those two types of apraxia do not influence the efficiency of prompts, and therefore will not be discussed in this paper. Ideational apraxia is characterized by a lack of knowledge of sequences of actions [36], or an impairment in that knowledge. Most of the time, it is diagnosed when a person makes some errors of actions (*e.g.*, substitution of objects, omissions, mistakes in the sequence of actions). It is often seen in Alzheimer's disease (AD) [37]. Patients with conceptual apraxia will be unable to accomplish a sequence of actions requiring the use of various objects, in a specific order that is necessary to reach an intended goal [38]. For example, a patient could be unable to dress by herself/himself because of his/her difficulty to put the clothes on in the expected order, to button them correctly or to use zippers. Another patient could use a toothbrush to comb his/her hair, while another might put butter on a piece of bread before putting it in the toaster. In that sense, people with AD suffering from conceptual apraxia would benefit a lot from a step by step guidance, provided by a smart environment. Modeling video prompts seem to be the most effective for people who forget steps of a task [22]. To be effective, guidance must be given step by step. This kind of guidance could also be accomplished by light prompts by indicating, one after the other, the places where the objects to use are stored, in the order in which they have to be used. For example, a light illuminating the spoon, then the sugar jar, then a cup filled of coffee, could indicate to a person that s/he has to use the spoon first in order to take the sugar in the jar, before putting the sugar into the cup. Other prompts provide step-by-step guidance (verbal, music with lyrics, photographic and textual, pictorial video).

2.5. Deficits in Executive Functions

Executive functions refer to mental activity involved in planning, initiation and regulation of behaviour. They are related to superior cognitive abilities solicited in formulation of new plans and selection, planning and control of appropriate sequences of actions. Other cognitive skills, such as judgment, abstraction, problem solving and reasoning are also a part of executive functions. Deficits in executive functions often occur in normal aging, but the decline is more important and more frequent in Alzheimer's disease (AD). Indeed, they can cause many problems in the accomplishment of the activities of daily living (ADL). In the early stages of the disease, patients with AD may have difficulties to do tasks that refer to executive functions (*e.g.*, choose the right clothes, plan and cook a meal, move to another place) [24]. They may also have difficulties with complex activities requiring attention or mental flexibility, such as driving in urban areas. Attention problems are common among deficits in executive functions and control mechanisms of attention may be the first to be affected in AD [39, 24]. People with AD may therefore have troubles to treat simultaneously several sources of information, since their attention is less controlled and directed. In connection with this, executive dysfunctions may also cause a decrease in the ability to inhibit stimuli, which means that people with AD could have difficulties to focus on what is important, and to inhibit irrelevant information about the task they're doing. These attentional control problems may lead to a difficulty to do the activities of daily living, because people find it hard to stay focused on what they have to do and can be easily distracted from their task, which might never be completed. The more the executive dysfunctions are important, the more the need for assistance in ADL is required. For the attentional control problems, a verbal prompt can be effective to restore the purpose of the task [28] but people with AD do not respond optimally to such guidance [30]. It is possible to use a verbal prompt saying the name of the person to get his/her attention before using the prompt that will guide him/her [30], but a blinking light could also be used for this purpose, even if it is only moderately effective compared to the verbal prompt. It would be interesting to test sound and music without lyrics prompts to attract the person's attention. This short clue that a prompt is coming may help people to focus on what is going to be said. Modeling video prompt is the most effective for people with a lack of attention (*i.e.*, regardless of the other deficits that the person may have) [22]. However, a video prompt (pictorial or modeling) or a visual prompt (photographic, textual or light) could distract the person from the task s/he is doing [5]. For example, if the person is packing a gift and a pictorial prompt appears in front of her/him to remind her/him the step s/he has to do, his/her focus will go on the pictorial prompt and leave the gift s/he is packing. After this, s/he will have been distracted and may stop doing the task. There is a need for more research to conclude on which prompts would be the most effective in guiding the person without distracting her/him from an ongoing task. Executive dysfunctions lead to another problem which causes many difficulties with ADL: planning. Indeed, lack of planning can make a person unable to finish any activity and requires a step-by-step guidance that can be reached with various prompts (see Figure 1). Light prompts may indicate, one step after another, the location of the objects to use, in the specific order in which they have to be used.

2.6. Sensory Problems

Aging is a physiological process leading to changes in the structures and the functions of the body. All organs are affected by it, including those of the senses. Since there are five senses (hearing, sight, taste, smell and touch), aging occurs in all of them. Aging of the hearing is known as presbycusis, which is a general term meaning deterioration of the hearing, whether it is due to aging or other causes (*e.g.*, toxic causes). The number of people suffering from presbycusis increase with age [40] and the majority of people with presbycusis are elderly [41]. Presbycusis due to aging begins in the high frequency sounds and leads to difficulties for people to correctly follow a discussion in noisy places. Often, mild hearing loss can be corrected with hearing aids, which significantly increases the quality of life of the person. Aging of sight can be manifested through diseases such as macular degeneration, glaucoma or cataracts. These troubles affect a lot of elderly people and can lead to a disability or a difficulty to accomplish some activities of daily living (ADL). However, even if elderly people do not suffer from one or more of these diseases, there is great probability that they have a decline in sight (*e.g.*, presbyopia, decrease in visual acuity). People whose sight has been declining in recent years may have problems with driving, handling money, cook meals, use the phone or take their medication, which can be very problematic. Nevertheless, almost all of the sight problems named above can be treated or alleviated, for example, by surgery or glasses. Aging of the taste may lead to the complete disappearance of the taste (ageusia), a decrease in the perception of the taste (hypogeusia) or a distortion of the taste (dysgeusia). Causes of taste changes and distortions in normal aging are not very clear, although certain authors found a decrease in the number of taste buds, or a change in taste cell membranes [42]. The diminution of food intake could also explain these changes. Besides, medication plays a big role in modifying the taste, and elderly tend to take more medication than any other age ranges. Olfactory loss occurs in normal aging too. People can then less perceive odours and have difficulty to distinguish them from each other, which can be very dangerous (*e.g.*, the smell of smoke from a fire could remain unnoticed). Aging of the touch has not been much studied. However, elderly would have a perception threshold higher than younger people.

In smart environments, prompts addressing taste, smell and touch are less common, because they are a lot more intrusive, invasive (*e.g.*, inserted in clothes) and difficult to test and to implement. However, researches on prompts addressing taste, smell and touch would be very useful, because in AD people do not suffer from just one of the sensory deficits we discuss in this paper. They often have all of them, though at different levels, and for some people, prompts addressing taste, smell and touch could be the only effective ones. Of course they would not be very precise, but they could potentially help people with AD remembering things, or they could at least help getting the attention on another prompt.

Since we have decided on an approach of pervasive computing, in which we hide sensors in a smart environment, then we will focus on hearing and visual deficits. Of course, elderly people (and so people with AD) may have hearing and sight problems at the same time, but for practical purposes, we will consider them individually. A person who has mild auditory problems could be helped by auditory prompts, such as verbal and music (with lyrics) prompts. If we use verbal prompts or music with lyrics with those patients, it is recommended to use a male voice. Indeed, female voices are more acute, making them more difficult to hear [23]. For people with severe hearing problems, it is recommended to use visual prompts (photographic, textual, light and modeling video). However, the pictorial video prompt would be useless because the patient would ignore its auditory part and its visual part is already done by the photographic prompt. Modeling video could also be efficient, but it would be more because of the visual part and less because of the auditory part. People who have mild troubles of sight can correct a part of them. So, even if visual prompts (photographic, textual, light, pictorial video and modeling video) may be less effective for them, they can still be used. In the literature, there are guidance devices for the environmental management of older people with vision problems (*e.g.*, use of warm colors, have a good light, accentuating the contrasts, use of larger images) (*e.g.*, [43]). Those who would test visual prompts with people who have mild visual problems could use these suggestions. For people with severe visual problems, the best prompts would be auditory ones (verbal and music with lyrics).

2.7. How to use the Proposed Guidelines

Of course, all these deficits usually coexist. Thus, there is a set of inter-influence between these deficits on the effectiveness of prompts. Here is how to use the proposed guidelines: 1) Choose one of the deficits of the person; 2) Follow the appropriate branches of the decision tree; 3) Consider both the proposed prompts and those who were excluded; 4) Repeat the previous step for each deficit of that person; 5) The prompts that you should be using are those who come up for each deficit. To better illustrate this, we give the following example. For a patient with an agnosia of writing (alexia), the guidelines suggest the use of all prompts, except for textual prompts. However, this patient may also have trouble in understanding spoken language (aphasia), for which the guidelines suggest the use of all prompts except verbal, music with lyrics and pictorial video prompts. In that sense, if the patient has these two deficits, one must understand that the use of textual, verbal, music with lyrics and photographic prompts is not recommended for obvious reasons. This applies even if the patient has a third deficit (*e.g.*, a disorder of verbal episodic memory). In that case, the decision tree provides the use of photographic, light and video (pictorial and modeling) prompts. In the end, three prompts have not been put aside for either deficit: photographic, light and modeling video. So, these are the prompts that you should use with this patient. Further experiments will be needed to determine with more precision which of these prompts would be the most effective in this situation. The ultimate goal would be to have one or two prompts only (*i.e.*, those who have been the most effective) for each situation.

3. Validating the Proposed Guidelines: Experiment with Mild to Moderate Alzheimer Patients

Our laboratory aims to develop technologies to support people with AD, their caregivers and health professionals. The ultimate goal is to maintain people with AD at home using ambient intelligence. The laboratory has a complete cutting-edge home automation infrastructure. It includes an apartment (see Figure 2) that allows capturing the actions and localization of its users and to assist them in the performance of their ADL (if needed). This apartment is equipped with pressure mats and movement detectors that allow us to be informed of the actions and localization of the resident. We also have Radio Frequency Identification Data (RFID) tags on objects indicating their position, as well as electromagnetic contacts on the cabinet doors. Temperature and light sensors allow us to maintain a proper atmosphere. All these devices send information to a main computer where all can be managed. Also, we have a prompting system (with auditory, visual and video prompts) that can be controlled remotely and be sent for punctual assistance for the residents when needed. Each room of the apartment is equipped with prompts. Auditory prompts (verbal, sound and music) can be sent through Internet Protocol (IP) speakers. Visual (photographic, textual and light) and video (pictorial and modeling) prompts may be sent using either a television screen or an iPad located on the refrigerator door. We have set of lights that we can vary the intensity and blinking of. So, all the necessary equipment to conduct experiments is available. Moreover, our synergic multidisciplinary team (computer scientists, neuropsychologists and engineers) has good collaborations with organizations such as the local Alzheimer Society, regional hospitals, nursing homes for elders and health facilities, making it easier to recruit participants.

Figure 2. Overview of our Infrastructure

3.1. Experimental Protocol

Recently, our laboratory conducted an experiment with people with mild to moderate Alzheimer's disease to evaluate the effectiveness of three main types of prompts (*i.e.*, verbal, modeling video without sound and modeling video with sound) according to the neuropsychological profile of the participant (memory impairments, aphasia, agnosia, apraxia and deficits in executive functions). This experiment was conducted as part of a doctoral project. It has been approved by the ethical committee, which delivered the required certifications. This experiment consisted of two parts: a neuropsychological evaluation of the patient at home, followed by the experiment in our laboratory. The neuropsychological evaluation included tests detecting memory impairments, aphasia, agnosia, apraxia and deficits in executive functions. For the experiment, a new protocol was designed for the purpose of testing. It is based on the Naturalistic Action Test (NAT) [44]. This test evaluates the performance of individuals with neurological afflictions (stroke, traumatic brain injury, progressive dementia) in everyday actions. It has been slightly modified by our team to be used with prompts. The protocol works as follow: the participant is asked to make 1) a toast and a coffee and 2) to pack a gift (one task at a time). S/he sits on a chair and all the necessary equipment for the performance of the task is on the table in front of her/him. S/he is free to use whatever s/he wants to complete the task and may do so in the order s/he likes. A prompt can be sent using a software developed for this experiment (see next section) if the participant needs it (*e.g.*, s/he forgets a step) at any moment, by a research assistant. There is no time limit. Each test is videotaped and timed. The videos are framed in order to preserve the anonymity of the participant (the faces are not shown on the video) (see Figure 3). Also, we developed a score sheet to record the order in which the different stages of the task were performed [45].

Figure 3. A Participant doing a Toast and a Coffee

3.2. Developed Software

For testing purpose, a new prompting software has been developed (see Figure 4). This software has been programmed with Visual Studio 2010 using C# language, which allows a rapid development of the software and its interface. It was designed according to the chosen experimental protocol. Each activity of the NAT is encoded and the software proposes a step-by-step visual representation of the task (see left part of Figure 4). It allows an assistant to send a prompt from a distant computer when required (*e.g.*, if the participant uses the wrong utensil). With only a click on a button, a chosen form of prompt (*i.e.*, verbal, modeling video without sound or modeling video with sound) can be sent for a specific step of the task through a computer screen and speakers placed in front of the participant. The software also allows for the noting of results, of the number of erroneous steps, of the type of problem (*e.g.*, omission, inaction, substitution) and of the percentage of task completed. Moreover, it allows us to save each session separately with the type of prompt sent, the required completion time of the task and other notes that are relevant. Finally, it should be pointed out that the software uses a wired connection between computers in order to avoid security issues.

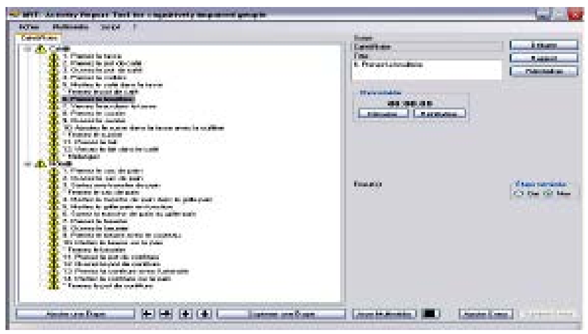

Figure 4. Our Developed Prompting Software

3.3. Results, Analysis and Discussion

Some participants have already completed the first phase of the experiment. Therefore, we can give first results. The participants of this experiment are stage 4 and 5 of the Global Deterioration Scale (GDS) [46]. They all had low scores (scores ≤ 23 indicating impairment of cognitive functioning) at the Mini Mental State Evaluation (MMSE) [47]. Also, they showed deficits in verbal episodic memory, lexical access (aphasia) and mental flexibility (executive functioning). Moreover, some participants had deficits in planning/organization of visual-spatial tasks, visual agnosia, ideomotor apraxia, low speed of information processing or ideational apraxia.

On average, participants completed the task of coffee and toast in 35.9 (± 4.7) steps and they completed the task of packaging a gift in 18.6 (±2.1) steps. The average is 1.9 (± 0.8) errors by participants for whom about 8 prompts were sent for the task of making a coffee and a toast. For the task of packaging a gift, an average of 1.6 (± 1.2) errors was observed and about 10 prompts were sent. Trends indicate that the verbal prompt and the modeling video with sound are effective (see Figure 5). The verbal prompt has an efficacy rate of 51% on average. As for the modeling video prompt, it has an average efficiency of 58%. These two types of prompts show a difference of efficiency of 7%. Also, results indicate that the modeling video without sound is less effective for the participants encountered (see Figure 5).

Several hypotheses could explain these trends. First of all, the effectiveness of verbal prompt could be due to the fact that it does not require attentional disengagement from the task. Indeed, the participant may continue the realization of the ongoing task while listening to the given instructions. Secondly, the efficiency of the modeling video with sound may be due to the combination of advantages of auditory and pictorial prompts. In addition, modeling videos with sound are dynamic and familiar. Finally, the low efficiency of the modeling video without sound may be caused by several factors. When a participant is engaged in a task of visual nature (*e.g.*, meal preparation, packaging of a gift), the presentation of a prompt using the same sensory modality requires an interruption of the current task and an attentional disengagement, while increasing cognitive load. Moreover, the modeling video without sound in the experience was preceded by an audible signal to alert the participant. When the signal was sent, participants ignored it because they were not able to locate the source and to understand the purpose of such an indicator. We have not advised them that assistance could be given through the screen in front of them. As a result, they did not look at the screen. Therefore, they could not benefit fully from the modeling video without sound, making it difficult to rule on its effectiveness by now. A similar phenomenon occurred with the modeling video prompt with sound due to the fact that participants did not look at the screen and, therefore, only benefited from the verbal part of the prompt. Other limits were noted in the protocol. Some participants did not understand that the verbal prompt was sent to them and when they figured it out, they had already missed an important part of the message. Indeed, some participants asked to hear the message again because they did not understand it. For all these reasons, it is difficult for us to provide you results showing a greater accuracy regarding the effectiveness of prompts depending on the deficits of people with AD. However, the protocol was revised in order to alleviate these limitations in the second experimental phase, which is set to begin soon. We decided to continue the experiment with more participants to verify if these trends are statistically significant. Results with a greater accuracy are yet to come, but we think that the promising results we obtained so far are already very useful for researchers working on smart home technologies [22]. These results allow us to give the following recommendations: 1) participants should be familiarized with the technology before starting the experiment (*i.e.*, advise her/him that s/he could hear an instruction or see an image or a video on the screen in front of her/him after having heard such sound or having seen the screen flashing) and 2) guidance prompts should be preceded by a prompt (*e.g.*, verbal, sound, music without lyrics or light) that catches the attention of the person.

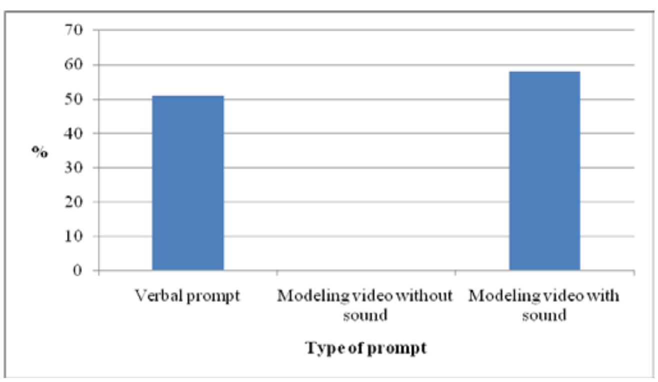

Figure 5. Efficiency of Prompts

4. Conclusion

Over the last few years, smart home technologies have become a very active research trend bringing hope in the effort to postpone the institutionalization of persons with Alzheimer disease. However, to be effective, a smart home has to compensate the deficits of its users by exploiting their remaining strengths [22]. The actual predominant use of verbal prompts (*e.g.*, [23, 14] seems to be a standard in the smart homes field and other assistive technologies. Lack of knowledge about the real effectiveness of these prompts significantly affects their efficiency by providing cues that are not adapted to the user's profile [22]. In order for prompts to be appropriate for a person with AD, it is important to consider that each patient is different and that it cannot be an approach to one-size-fits-all [20]. To contribute solving this important issue, we proposed, in this paper, comprehensive guidelines to help smart homes researchers to personalize prompts for patients with AD. This was accomplished: i) by identifying the main deficits of the illness that influence the effectiveness of specific prompts (see Table 1); ii) by developing comprehensive guidelines that indicate which form of prompts to use according to these specific deficits (see Figure 1), iii) by designing a new experimental protocol based on a well-known cognitive test allowing to validate the proposed guidelines, iv) and by presenting the preliminary results of a first experiment conducted in our smart home setting with participants with mild to moderate AD, using a new prompting software that we developed. The guidelines that we introduced allow orientation for research in the development of assistive technologies. It was modelized into a decision tree, which is a flexible tool allowing the guidelines to be directly implemented into an algorithm. Its use is easy for computer scientists and engineers. It should be noted that this research is only a step toward the development of adapted assistive devices for people with AD. The deficits of a person with AD are not the only factors to consider for the optimization of the efficiency of prompts. Other factors, such as remaining skills (as compensatory resources) and the nature and characteristics of the task, are also important to consider. For instance, we know that the familiarity (*i.e.*, familiar or unfamiliar), the complexity (*i.e.*, easy or complex) and the nature (*i.e.*, manual or cognitive) of the task, also have a significant impact on the prompting efficiency [22]. With the rapid development of assistive technologies, there is a real need for more experiments on the efficiency of prompts so that patients with AD may eventually benefit of the full potential of assistive devices and smart homes. Therefore, our team plans to conduct further experiments that will verify with more precision the efficiency of each type of prompts separately, according to the specific deficits of AD. Our multidisciplinary work will be beneficial for smart homes researchers wishing to maximize the prompting efficiency. At term, we hope that our work will contribute to bring a new quality of life for patients with AD and their caregivers.

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